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Energy transition as a central building block of a future industrial policy

Comparison and analysis of long-term energy transition scenarios

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Background and study rational

In the 2015 Paris agreement on climate change, which represents the first universal, legally binding global climate deal, 195 countries agreed on limiting the increase in the global average temperature to below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C. In order to reach these objectives rapid and substantial reductions of global greenhouse gas emission are required.

In order to achieve these levels of emission reductions, significant steps towards decarbonising the global economy and energy systems are required. With the current energy systems almost complete depending on fossil energy carriers, this means that substantial changes in all parts of the economy and particularly the energy systems are needed.

These long-term structural transformations entail both challenges and opportunities in terms of technical developments and economic efficiency but also in regards to required social and institutional changes. In order to make use of the wide-range of opportunities while meeting the potential challenges, it is necessary to strengthen the political discourse on the transformation of energy systems from a sustainable point of view.

With Japan and Germany being already in leading positions regarding the development of and investments in innovative energy technologies, the two countries share the responsibility to set examples in implementing the Paris agreement and contribute to the decarbonisation of the energy sector worldwide.

Different strategic options exist to make the required structural changes in the energy systems of Japan and Germany. But despite the diverse strategic options as well as the different preconditions in terms of geographic conditions, energy potentials or policy frameworks, Japan and Germany are confronting similar challenges.

Against this background, the presented research examines the wide range of strategic options for the energy transition as well as the associated strengths and weaknesses of both countries in a transparent way and from different perspectives by conducting a meta-analysis of available energy transition scenarios covering the range of strategic options for both Japan and Germany. The study, which was conducted by Wuppertal Institut (WI) together with DIW Econ and the Institute of Energy Economics, Japan (IEEJ), is part of the comprehensive study program of the German-Japanese Energy Transition Council (GJETC), which intends to foster a scientific debate on common and diverging perspectives for both opportunities and risks of a transition towards a sustainable energy system.

Research approach

The research was structured in three major steps, starting with the analysis of national energy transition targets and the selection and in-depth analysis of research-based energy transition scenarios. In the next step the results of these analysis were discussed in form of mutual commenting by the involved Japanese and German research institutes. Following these discussions, the country teams prepared a joint conclusion that is focused on policy recommendations and open research questions of key interest for the successful transformation of the energy system for both Japan and Germany.

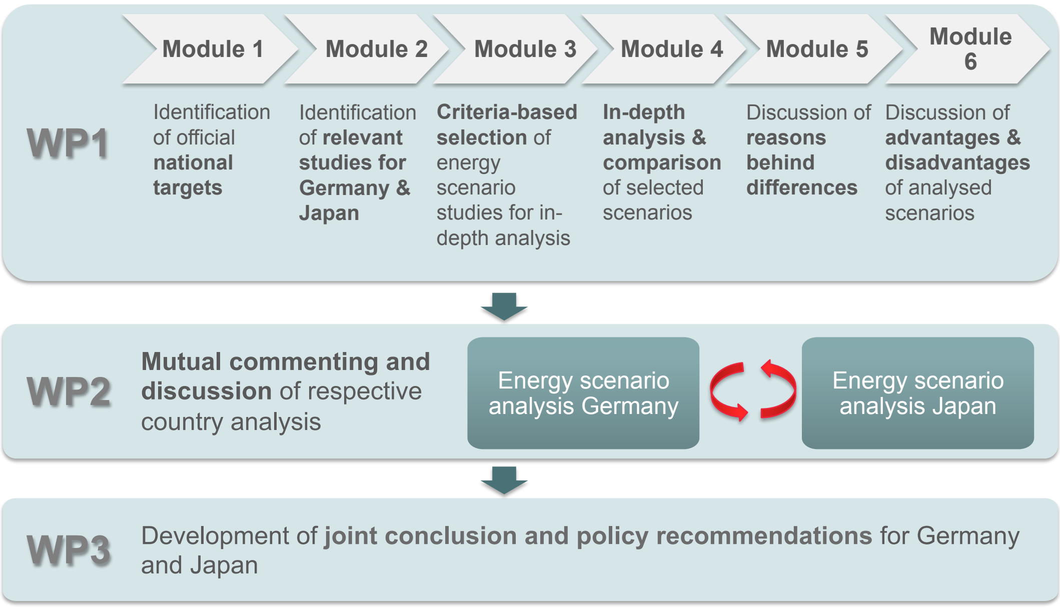


Fig. 0-1 Project structure and work packages

Besides the implications of the transition strategies for the energy system, a particular focus was put on the (macro) economic implications of the analysed transition strategies. Accordingly, one of the main selection criteria for the scenario studies to be analysed was that the studies included quantitative analysis of the macroeconomic implications of their energy scenarios. In addition to the inclusion of macroeconomic analysis, the following criteria were applied for the scenario selection: publishing date after 2011, provision of quantitative details for energy demand and supply side until at least 2030, coverage of the entire energy sector not only electricity and inclusion of both renewable energy and energy efficiency aspects. Based on these criteria, twelve scenarios from five studies were selected for Japan and five scenarios from four studies were selected for Germany for the in-depth analysis of the energy system and the macroeconomic implications of the pursued energy transition strategies.

National energy transition targets for Japan and Germany

In a first step the national energy transition targets for Japan and Germany were analysed and compared. The review shows that both the Japanese and German governments address similar energy transition objectives in the sense that both countries' governments emphasize the importance of

- Energy security
- Economic efficiency (or "competitiveness") and
- Environmental sustainability (or "GHG emission reductions").

However, there are noticeable differences between the objectives of both governments in respect to the following four issues:

- The future role of nuclear power
- Prioritisation of the GHG emission reduction objective
- Level of ambition of the GHG emission reduction objective
- Timeframe

In regards to the future role of nuclear power, Germany in addition to the objectives listed above is phasing out the use of nuclear power until 2022. The phase-out plan reflects the sceptical opinion of a majority of the German population towards the use of nuclear power and aims at reducing and eventually abandoning the risk of large-scale nuclear accidents as well as reducing other potential problems, such as those related to proliferation and the long-term, secure storage of radioactive waste. In Japan, on the other hand, the future role of nuclear power is not stipulated clearly in the country's energy policy objectives, but is regarded as one of the tools to achieve the three pillars of Japan's energy policy simultaneously.

Apart from the different positions on nuclear power, the Japanese and German targets differ in regards to their prioritisation. In Japan, where energy price shocks have severely affected the energy security in the past and, which due its geographic location as an island state, is more vulnerable to price volatilities and supply insecurities, the primary objectives are supply security and economic efficiency. In Germany, on the other hand, there is no prioritization between its four key energy policy goals (GHG emission reduction, nuclear power phase out, competitiveness and energy security), but the GHG emission reduction goal is often mentioned first in government publications. Furthermore, in comparison to Japan, Germany has the advantages of being situated centrally within Europe, facilitating import and export of energy (particularly electricity) and thereby reducing the security of supply risk.

A comparison between the GHG emission reduction targets of Japan and Germany for the year 2030 indicates that compared to the Japanese government's target, the German government's target is set higher in terms of the percentage of reduction aimed for. This can be observed for the emission reductions aimed for relative to any of the base years used by the two countries (2013 in the case of Japan, 1990 in the case of Germany) as well as for the metric of per capita GHG emissions. If both countries' 2030 GHG emission reduction targets are met and if recent UN population projections for both countries are taken as a basis, per capita GHG emissions, which are currently slightly higher in Germany than in Japan, would be lower in 2030 in Germany (at 7.1 t of CO_2-equivalent) than in Japan (at 8.7 t). However, when comparing these numbers, it should be noted that besides the reduction target itself, other indicators can be applied to asses the level of ambition, for example marginal CO_2 abatement cost. Different studies have shown, for example, that Japan has considerably higher marginal CO_2 abatement cost compared to other countries and regions, including the European Union (Akimoto et al. 2016; Aldy et al. 2016).

These differences in the energy transition objectives of Japan and Germany also influence the energy scenarios that are developed in both countries. This is especially true for government-commissioned studies, which can be expected to be guided by the official government targets.

Analysis and comparison of selected energy transition scenarios for Japan and Germany , with a focus on electricity supply

Indeed, the meta-analysis of the transition scenarios shows that all German energy scenario studies taken into account in this analysis show how the government's GHG reduction targets can be met, while at the same time the scenarios also aim to fulfil additional energy transition targets of the German government. In the Japanese case, on the other hand, priority is attributed to analysis of different aspect of energy policy. There is a focus on showing how energy self-sufficiency and energy cost competitiveness can be strengthened until 2030, although the 2030 GHG reduction target of the Japanese government is also pursued by all of the scenarios.

The meta-analysis puts a strong focus on analysing the envisioned changes in electricity supply, although other parts of the energy systems are also addressed.

There are several reasons for the focus on the power sector:

- Near- to mid-term changes in the electricity supply system are crucial in both countries to achieve the countries' respective energy policy targets.
- Energy system transformation discussions in both countries (as well as in many scenario studies) tend to focus on the electricity system.
- The energy system changes envisioned by the selected Japanese scenarios on the one hand and the selected German scenarios on the other hand differ strongly in regards to future electricity supply, leading to a particular interest in analysing these differences.

Key differences between the Japanese and German energy scenarios analysed in this study can be observed in regards to the emphasis put on different transition strategies. Based on the meta-analysis, a number of key strategies that are pursued in some or all of the analysed Japanese and German scenarios to achieve energy system changes could be identified (Table 0-1). The analysis shows that some general differences exist between the energy transition strategies typically selected in Japanese energy scenarios on the one hand, and those typically selected in German energy scenarios on the other hand. While scenarios from both countries aim to increase the use of domestic renewable energy sources and substitute fossil fuels through electricity, the strategies differ in regards to the future of nuclear power, level of renewable energy expansion, application of new technologies e.g. hydrogen and CCS, and the level of emphasis on GHG reductions.

Tab. 0-1 Overview of the level of reliance on key energy transition strategies in selected scenarios for Japan and Germany until the year 2030

	Germany			Japan		
	ZS	KS 80	KS 95	METI (2012) multiple models and scenarios	IEEJ (2015) multiple scenarios	RITE (2015) multiple scenarios
Energy demand reductions						
Final energy demand reductions through energy efficiency	Strong reductions	Strong reductions	Very strong reductions	Reductions	Reductions	Reductions
Final energy demand reductions through behavioural changes	Not considered	Not considered	Moderately considered	Moderately considered	Moderately considered	Moderately considered
Changing the use of energy sources						
Increased use of domestic renewable energy sources	Strong use	Strong use	Strong use	Moderate use	Moderate use	Moderate use
Phasing out the use of nuclear power	Complete phase-out	Complete phase-out	Complete phase-out	Yes (in some scenarios)	Yes (in some scenarios)	Yes (in some scenarios)
Continuing the use of nuclear power	No	No	No	Yes	Yes	Yes
Substitution of fossil fuels through electricity	Strong substitution	Very strong substitution	Very strong substitution	Moderate substitution	Moderate substitution	Moderate substitution
Use of renewable energy based H_2 or synthetic fuels as final energy carriers	No use (until 2030)	No use (until 2030)	No use (until 2030)	No use	No use	No use
Importing low-carbon or carbon-free energy sources/carriers						
Net imports of electricity	No net imports	No net imports	Moderate net imports	No trade	No trade	No trade
Net imports of bioenergy	No imports (until 2030)	No imports	No imports	No imports	No imports	No imports
Net imports of H_2 or synthetic fuels	No imports	No imports	No imports (until 2030)	No imports	No imports	No imports
Using CCS						
Use of CCS technology to reduce industrial GHG emissions	Not used	Not used	Starting to be used in 2030	Not used	Not used	Not used
Use of CCS technology to reduce power sector GHG emissions	Not used	Not used	Not used	Not used	Not used	Yes

Notes: For Japan's analysis, the METI (2012), the IEEJ (2015), and the RITE (2015) studies are composed of multiple results delivered from different models or scenarios. This table compiles the general or majority trend of these different models and scenarios.

The key reasons for these differences most likely stem from the different priorities in the realisation of the energy transition between Japan and Germany and the different assumptions about the costs of various electricity generation technologies as well as the importance associated to these cost differences. The differences in key energy transition strategies also mirror differences in priorities among the public, which in turn might be explained by cultural, historical and geographical differences. Furthermore, Germany's electricity grid is well connected to neighbouring countries, making the integration of electricity generation from (variable) renewable energy sources easier. Due to its higher population density, it may also be more difficult in Japan than in Germany to exploit the available renewable energy potential (especially in regard to onshore wind). These limitations might explain the more moderate penetration of renewable energy sources in the analysed scenarios for Japan compared to Germany.

Furthermore, nuclear power, together with coal, are regarded as the most cost competitive energy sources in the analysed scenarios for Japan. Most renewable energy sources are considered to be expensive in these studies, even considering the impressive trend of declining costs of many renewable energy technologies. In Germany, on the other hand, power generation costs of typical renewable energy technologies such as onshore wind and solar PV plants have already come down to levels which are competitive with most thermal power generation technologies, and costs are expected to become even cheaper in the future. This increasing cost competitiveness of renewable energy sources is – in combination with the German government's renewable energy deployment targets – a main reason why scenarios for Germany assume strongly growing shares of renewable electricity generation. These differences in the economic assumptions regarding renewable energy technologies apparently contribute to a great extent to the observed differences in the energy supply envisioned by Japanese scenarios on the one hand and by German scenarios on the other hand.

Another reason for the different strategies pursued by the Japanese and German scenarios could be that in Germany, decade-long experience with wind and solar power exists, including efforts of individuals and regions to become more energy independent. In Japan on the other hand, although the country was a frontrunner to develop solar PV and solar thermal water heater technology since 1980s, the vertically integrated and centralized energy industry structure makes it relatively unfamiliar to decentralized system.

Next to the structural reasons for the focus on different energy transition strategies the type of scenario models applied are likely also one of the reasons for the differences in the speed of the described technological transformation and GHG emission reductions between the Japanese and German energy scenarios. All analysed scenarios for Germany use a back-casting approach in combination with bottom-up models, in which certain targets are set and future energy system developments are then modelled until in line with these targets. Most of the analysed Japanese scenarios, on the other hand, are based on econometric models. Econometric models are used to simulate the likely future behaviour of market actors, based on past experience.

The results for the macroeconomic modelling show that scenarios for Japan and Germany both estimate that investments in energy efficiency and low-carbon electricity generation can generate positive impacts on GDP growth and employment, as it leads directly to an increased demand in sectors producing the required technologies. However, the divergent assumptions regarding the power generation costs create a disparity between Japan and Germany in the "net" economic effect. Japanese studies expect electricity supply costs of renewable energy-dominated systems to remain higher than those dominated by fossil fuels and nuclear energy and therefore find negative effects on GDP, income, and employment. In that case, the negative macroeconomic effects of the higher energy supply costs are expected to outweigh the positive impulses of additional investments. In part due to the more favourable renewable energy cost assumptions, German studies, on the other hand, tend to find net positive economic effects of a strong increase of renewables. Another explanation for the positive economic effects shown by the German decarbonisation scenarios may be the fact that they typically assume that a large share of the cost-effective energy efficiency potential will be realised. This leads the analysed German studies to conclude that achieving the climate targets is not only technically feasible, but that the required investments eventually reduce the overall energy system costs and lead to net economic benefits.

Furthermore, the dependence on fossil fuel imports is being reduced in both countries' mitigation scenarios. Lower fossil fuel imports are not only associated with positive economic implications, but they increase energy security at the same time.

Besides these common anticipations, difference between Japan and Germany can be seen in investments in fossil fuels and nuclear power. While Japan plans to invest in nuclear and high-efficiency thermal power plants, the German scenarios anticipate that energy from fossil fuels and nuclear power will be substituted by renewable energy sources. Another difference between the analysed Japanese and German scenarios can be found in the assumed change of electricity prices. These differences can partly be explained by the different priority settings and the public discussions in both countries. While German scenarios expect net economic benefits in the longer term, an increase of electricity prices during the transitional period is accepted to some extent to achieve the objective of reducing GHG emissions. In Japan, since the increase of electricity costs and prices in recent years became an overwhelming issue during public discussions on the future energy system, a reduction of electricity costs and prices became a kind of a guiding principle for the scenario development.

Although the described findings allow to better understand the differences and similarities in regards to the key transition strategies of the analysed scenarios, our analysis also faced several difficulties. In general, it may be noted that the comparison was often difficult as the assumptions and modelling approaches differed widely both within each country's analysis and between the Japanese and German analysis. Despite this observation, the analysis and comparison allowed to derive a number of recommendations for policy action and future research which are described in the following section.

Policy and research recommendations for Japan and Germany

A general insight from the analysis of selected energy scenarios for both Japan and Germany is that in both countries considerable deviations from recent energy system developments are needed in order to reach the countries' respective 2030 energy transition targets. This finding becomes even more relevant when the challenges of the longer time frame until 2050 are regarded. Thus, additional policy measures are clearly and urgently required. These include additional measures that would also need to be induced by appropriate policies in the areas of final energy demand reductions in all sectors through energy efficiency and/or more energy-sufficient lifestyles. For the transport sector, this means that fuel mix changes and CO_2 emission reductions are required. These would need to be supported by urban planning efforts that focus on reducing transport needs and fostering public and non-motorised transport options. Furthermore, an increased implementation of energy-saving measures in the existing buildings stock are found to be particularly necessary to reduce final energy consumption.

Moreover, wind and solar PV penetration will need to continue to increase steadily in the years and decades to come. At the same time the system capabilities to absorb a higher share of intermittent renewables need to be expanded. Generally, the analysed scenarios expect a sufficiently high price on CO_2 emissions to considerably facilitate GHG emission reductions in all sectors. A meaningful and sufficiently certain increase in the CO_2 price over time can support the required broad investments in low carbon technologies, although countries may also opt to use other mechanisms (such as regulatory measures) to promote investments in low carbon technologies. On the other hand, careful consideration and design need to be made here in order to protect consumers, in particular low income households. Furthermore, as no uniform international carbon price system exists and energy costs are different across countries reflecting their national circumstances, governments should ensure that their policies and measures do not harm their respective country's industrial competitiveness relative to major trading partners.

Next to these general policy recommendations, further cooperation between Japan and Germany in the energy field are highly recommended. The long-term structural changes required for a sustainable transition of the energy systems can almost certainly not be achieved by one country alone, but can only be realized in international cooperation. Especially in highly industrialized countries such as Japan and Germany, joined efforts are needed to better meet the challenges and make use of the wide-range of opportunities the energy transition entails. Collaboration opportunities include, but are not limited to, combining efforts to achieve cost reductions in PV, onshore and offshore wind technologies as well as sharing experience in regard to successful deployment of new technologies, system integration of renewables and energy efficiency policies. Likewise, cooperation in the field of electric, hybrid and hydrogen cars offer potential synergy effects, as both countries are home to strong and globally leading car industries. Moreover, the exchange of ideas on potential solutions for the long-term decarbonisation of energy and emission-intensive materials processing industries – possibly with a strong participation of industrial stakeholders – offers multiple opportunities for strategic collaborations. This is especially true as mitigation in this area will be complex and capital-intensive, so a mutual approach of industrialised countries to this challenge appears to be of great importance.

Besides the potential for strategic cooperation, the energy transition also promises opportunities for business activities in Japan and Germany in the next years and decades. Assuming that both countries take additional steps in the coming years to accelerate the energy transition, business opportunities will likely arise in the following areas: highly energy-efficient end-use technologies, technologies that facilitate demand side management/demand response and the optimisation of distributed electricity generation. Offshore wind power plants could also be a potential business opportunity. The same applies for the transport sector, where highly energy-efficient cars and electric cars as well as efficient public transport could be sectors for increased business activities. Furthermore, companies in the energy-intensive materials processing industries that plan ahead and devise roadmaps on how they may achieve deep emission reductions in the decades to come, can also potentially achieve competitive advantages over other companies in the medium to long-term future.

In addition to policy recommendations and potential business areas of interest, the study results underline the potential for further research in the Japanese-German energy context. Although the joint research study provided valuable opportunities for the study teams to learn more about the common aspects and differences between the transition strategies in both countries in regards to the energy system and macroeconomic implications of the energy transition and also in regards to the energy scenario research in both countries, it became clear that more and extended research is needed in order to answer numerous open questions in regards to the effects of energy transitions on macroeconomic and cost developments and future industrial policies. Accordingly, further research is recommended in the field of scenario development, specifically in regards to methodology and comparability issues as well as macroeconomic implications of short-, medium-, and long-term energy system transformation strategies.

In order to better understand what technological or social innovations offer the highest potential for synergies and mutual learning between the countries, it would be desirable to develop scenarios applying a common methodology based on comparable energy system and macroeconomic assumptions for both Japan and Germany.

1 Introduction

1.1 Background

In December 2015 the so-called “Paris agreement” on climate change, which represents the first universal, legally binding global climate accord, was agreed on by 195 countries (UNFCCC 2015). The main goals of the agreement are to limit the increase in the global average temperature to below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C. In order to reach these objectives the governments of the 195 states agreed that rapid and substantial reductions of global greenhouse gas emission are inevitable.

In order to achieve ambitious levels of emission reductions significant steps towards decarbonising the global economy and energy systems are required. With the current energy systems almost complete depending on fossil energy carriers, this means that substantial changes in all parts of the economy and particularly the energy systems are needed.

These long-term structural transformations entail both challenges and opportunities in terms of technical developments and economic efficiency but also in regards to required social and institutional changes. Some of the major challenges of the energy transition include the investment requirements in renewable energy technologies and high energy efficiency measures; development of new distribution infrastructures, which are suitable to handle the increasing share of intermittent renewables and the growing number of interfaces between the electricity, gas and heat sectors or the transformation of the transport sector where the majority of passenger and freight traffic continuous to dependent on fossil fuel as energy source. The choice of options to meet these challenges will next to the technical and economic aspects require the consideration of multiple factors. Especially, aspects like public acceptance and the sensitization of the public in regards to more sustainable lifestyles, are expected to be central for the implementation of effective energy transition strategies.

Despite these potential challenges the transitions towards sustainable energy systems and a decarbonized economy also offer significant opportunities. Next to the positive effects in regard to environmental sustainability the energy transition can also have positive impacts on aspects like energy security by increasing the domestic energy supply and reducing import dependency at the same time. Furthermore, sustainable energy transition strategies are expected to provide numerous economic opportunities like creating high-quality growth and employment. In order to make use of the wide-range of opportunities while meeting the potential challenges, thereby avoiding lock-in effects and associated capital and job losses, it is necessary to strengthen the political discourse on the transformation of energy systems from a (not only environmentally but also economically) sustainable point of view.

1.2 Rational and objectives of the study

With Japan and Germany being already in leading positions regarding the development of and investments in innovative energy technologies, the two countries share the responsibility to set examples in implementing the Paris agreement and contribute to the decarbonisation of the energy sector worldwide.

Different strategic options exist to make the required long-term structural changes in the energy systems of Japan and Germany. But despite the diverse strategic options as well as the different preconditions in terms of geographic conditions, energy potentials or policy frameworks, Germany and Japan are confronting similar challenges.

Against this background, the German-Japanese Energy Transition Council (GJETC) which intends to foster a scientific debate on common and diverging perspectives for both opportunities and risks of a transition towards a sustainable energy system, initiated a comprehensive study program. Within the framework of this study program, five strategic topics were identified that are of common interest for both the Japanese and the German side.

The research presented in this report, conducted by the Wuppertal Institute together with DIW Econ and the Institute of Energy Economics, Japan (IEEJ), addresses one of these topics, the strategic topic 1: “Energy transition as a central building block of a future industrial policy – Analysis of energy transition scenarios”. The main objectives of this study are to examine the wide range of strategic options for the energy transition as well as the associated strengths and weaknesses of both countries in a transparent way and from different perspectives.

To this end, a comprehensive meta-analysis of available energy transition scenarios covering the range of long-term strategic options for both Japan and Germany was conducted. Analysing different scenarios, which are instruments to provide scientific policy advice on complex matters such as the energy transition in times of political insecurity, offers a chance to learn more about potentially beneficial strategies and avoiding path dependencies and technological lock-ins. With the large number of differing energy scenarios available, for both Germany and Japan, this meta-analysis addresses the challenge in the policy-making process to interpret these numerous studies and to derive recommendations.

First, the national energy transition targets and the range of existing research-based, long-term scenarios including those that are in line with or go beyond the official national targets were identified. In a next step, a comprehensive meta-analysis of a number of selected Japanese and German energy transition scenarios was conducted. The selected scenarios cover a wide range of long-term strategic options for both Germany and Japan. Besides the implication of the transition strategies for the energy system, a particular focus was put on the (macro) economic implications of the analysed transition strategies.

2 Research approach

2.1 Overview project structure

With respect to the terms of references, the study was structured in three main work packages which are illustrated in Figure 2-1 and briefly described in the following:

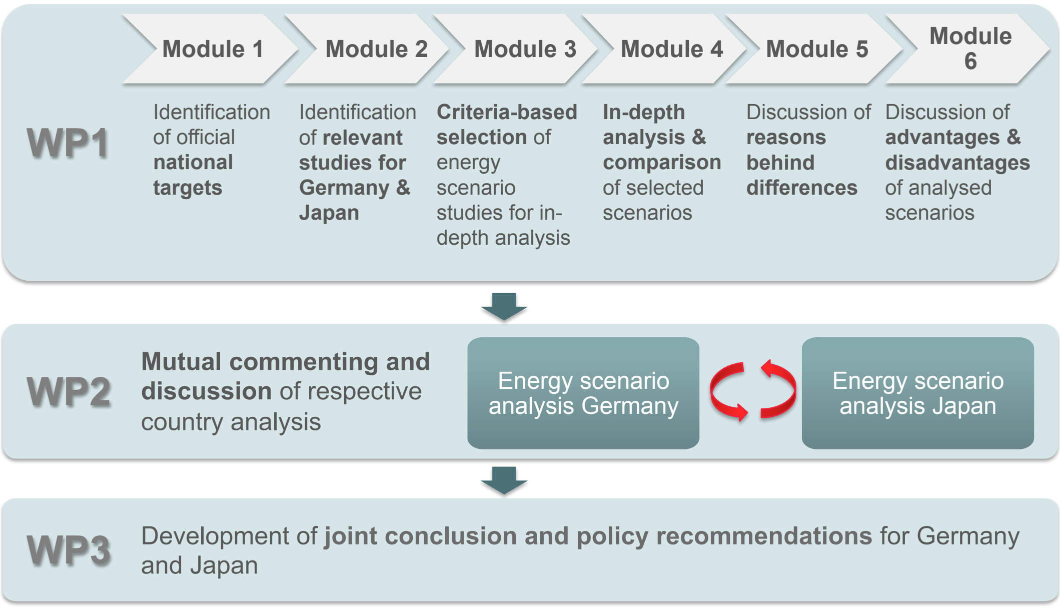


Fig. 2-1 Project structure and work packages

- **Work package 1**
  Meta-analyses of energy scenarios based on the latest research regarding a wide range of strategic options and research questions for each country. The German as well as the Japanese analysis followed a joint structure. On the German side, Wuppertal Institute focused on the analysis of the energy system implications of the energy transition, while DIW Econ contributed with respect to the economic implications.
- **Work package 2**
  The results of this analysis was discussed in form of mutual commenting by the involved Japanese and German research institutes. In this step, possible reasons for diverging results like different approaches, assumptions or input data were identified and discussed.
- **Work package 3**
  Following these discussions, the country teams prepared a joint conclusion that also derived policy recommendations for Germany and Japan as well as open research questions of key interest for the successful transformation of the energy systems in both countries.

2.2 Detailed description of work packages

This section gives a detailed description of the analysis steps. Methodologically, work package 1 is the most important and will be described in more detail than work package 2 and work package 3.

2.2.1 Work package 1

Work package is structured into six analysis steps (Figure 2-1):

- **Module 1 – Identification of official national targets**

  In this module the national energy transition targets set by the German and Japanese governments are identified for the years 2030 and 2050. The information on these targets is compiled from various official government publications and legislations. Based on the latest available data it is briefly discussed if both countries appear to be on track to reach the targets.

- **Module 2 – Identification of relevant studies for Germany and Japan**

  In this step, a comprehensive literature analysis is conducted to identify all relevant and up-to-date energy scenario studies for Germany and Japan that describe the medium to long term effects of the energy system transition and the associated economic implications in detail. To ensure the relevance and timeliness of the studies "up-to-date" is defined as studies that were released in 2011 or later.

- **Module 3 – Criteria-based selection of energy scenario studies for in-depth analysis**

  Based on the literature review conducted in the previous step, a number of scenarios for Japan and Germany are selected for an in-depth analysis of the energy system and economic implications of the energy transition strategies. The selection of the scenarios for Japan and Germany is based on the following criteria:

  - Time horizon of scenarios:
    - At least 2030, preferably 2050
  - Scope of studies:
    - Entire energy system covered
    - At least some analysis of the macroeconomic implications of the energy system transformation (encompassing all relevant transition strategies, not for example only the effects of the deployment of renewable energy technologies)
  - Level of detail
    - Quantitative detail at least in regard to primary energy supply, electricity generation and final energy demand
  - Variety in final selection of scenarios and studies (only necessary if more scenarios are identified than can be analysed in detail)

- Set of scenarios should reflect variety in how energy transition goals are achieved (and whether they are overachieved or not)
- Set of studies should reflect variety in the type of macroeconomic modelling performed

- **Module 4 – In-depth analysis of selected scenarios and comparison between them**

  For the analysis of the energy system implications as well as the macroeconomic implications, information about key energy system and macroeconomic characteristics is collected and compared between the selected studies (within each country) for the base year, for 2030, and as far as available in the studies, for 2050. The data collection includes information on applied modelling approaches, key framework assumptions (e.g. GDP, population, number of households) energy system assumptions (e.g. renewable potentials, technology and cost assumptions), key energy system characteristics (e.g. final and primary energy supply, electricity generation, CO2 emissions) and expected macroeconomic implications (e.g. employment, investment rates). The range of 2030 and 2050 energy system characteristics from the analysed scenarios will be evaluated against the long-term energy and climate county targets, which are identified in Module 1. The comparisons forms the basis for the following module, in which the differences between the scenarios will be analysed and discussed.

- **Module 5 – Discussion of reasons behind the differences in the analysed scenarios**

  Based on the results of the previous modules, in this step the key similarities and differences between the analysed scenarios are identified. While similarities may point towards “robust” developments or strategies, it is important to better understand the reasons for differences between the scenarios. Identified differences are therefore discussed in more detail and as far as possible, the (potential) reasons for these differences are highlighted.

- **Module 6 – Identification of advantages and disadvantages of the analysed scenarios**

  Based on the analysis of the previous two modules, this final module of work package 1 identifies the key advantages and disadvantages of the analysed scenarios. By taking into account available literature, a set of indicators is constructed to evaluate the advantages and disadvantages of different energy scenarios in respect to energy security implications, economic effects, environmental sustainability, social acceptance and robustness in the face of uncertainties about future technological progress and social change. A special focus will be on the identification and discussion of differences in the robustness of various scenario developments.

2.2.2 Work package 2

The results of the meta-analysis will be discussed in form of mutual commenting by the involved Japanese and German research institutes. In this step possible reasons for diverging results like different approaches, assumptions or input data will be outlined. Figure 2-2 summarizes the mutual commenting process:

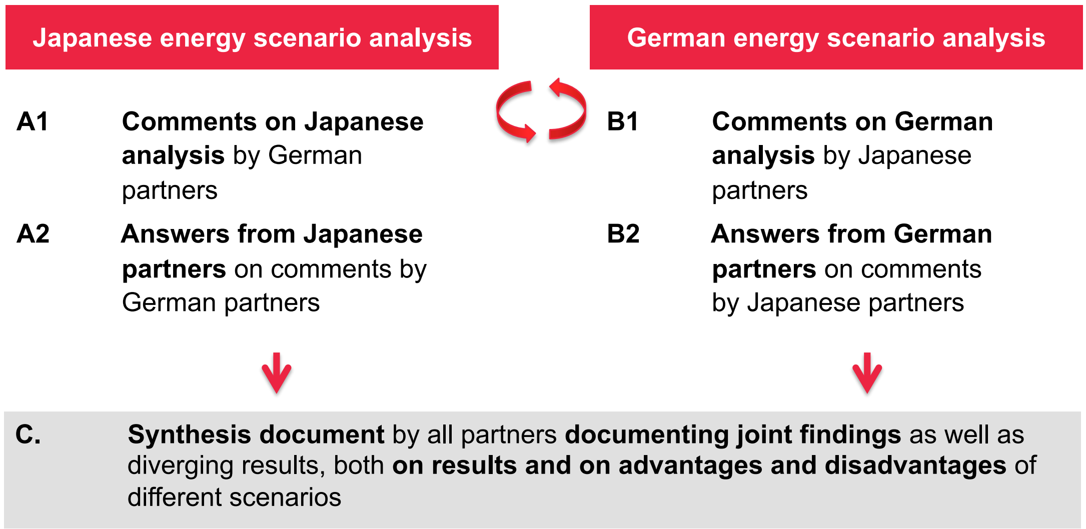


Fig. 2-2 Structure mutual commenting

2.2.3 Work package 3

In this work package, the country teams prepare a joint conclusion that focuses on policy recommendations for Germany and Japan and a brief overview of potential business opportunities in both countries in the coming years and decades. The joint conclusion will also summarize the findings on impacts on energy security, cost development, employment, innovation dynamics and competitiveness on global lead markets as well as findings on how to better integration of energy transitions and climate protection. Furthermore, open research questions for the successful transformation of the energy system in both countries are identified.

3 Energy transition targets for Japan and Germany

This chapter provides an overview and a brief discussion of the respective current energy transition targets of the Japanese and German governments.

3.1 Energy transition targets for Japan

In June 2010, Ministry of Economy, Trade and Industry (METI) established the 3rd Strategic Energy Plan which consists of seeking more than 50% share of nuclear energy in 2030 power generation mix. However after the Great East Japan Earthquake when experienced stop operation of all existing nuclear power plant, the government decided to review the Strategic Energy Plan from scratch. Then in October 2011, discussion has started to present choice of future energy mix in the Fundamental Issue Committee. The committee submitted the report in June 2012 which consists of four options of power generation mix in 2030.

Since March 2013, METI organized the discussion in another committee to formulate the 4th Strategic Energy Plan. Discussion was made on every aspect of energy supply chain which was resulted to deliver a draft of the Plan in December 2013. The Cabinet approved the Strategic Energy Plan in April 2014. Based on this, the METI established the Long-term Energy Supply and Demand Subcommittee under the Strategic Policy Committee of the Advisory Committee for Natural Resources and Energy. After numerous and wide ranging discussions in the subcommittee, the Long-term Energy Supply and Demand Outlook has been adopted in July 2015.

The current Strategic Energy Plan (April 2014) [1] identify the core element of energy policy in a form of 3E+S.

"The point of the energy policy is to first and foremost ensure stable supply ("Energy Security"), and realize low cost energy supply by enhancing its efficiency ("Economic Efficiency") on the premise of "Safety." It is also important to make maximum efforts to pursue environment suitability ("Environment")." (METI, Provisional translation of the Strategic Energy Plan, April 2014)

The Long-term Energy Supply and Demand Outlook describes the desired future energy supply-demand structure to be realized along with the principle of energy policy "3E+S" of the Strategic Energy Plan. It was developed as a viable outlook to reflect macroeconomic indicators, industrial trend, and build up of supported policy and technological development. The analytical time range is extended to fiscal year[2] (FY) 2030.

[1] The Strategic Energy Plan is drafted by the Minister of Economy, Trade and Industry and decided by the Cabinet. To draft the plan, the Minister listens to the opinions of the heads of the related administrative agencies and the Advisory Committee for Natural Resources and Energy regarding the policies, etc. to be comprehensively executed on energy supply-demand based on the Basic Act on Energy Policy (promulgated and enforced in 2002).

[2] Fiscal year start from April in certain year and end at March in the next year.

Box 1: Transition of Japan's Energy policy

The first oil crisis in 1973 deeply affected Japanese economy because Japan's primary energy supply depended around 90% to import and more than 70% to oil at that time. After experienced large economic trouble and recognized vulnerable state of energy supply, Japan introduced policy measures to strengthen energy security which form Japan's modern energy structure. Namely; i) diversify type of energy to reduce oil dependency and to increase use of non-oil energy, ii) security of stable oil supply, iii) promotion of energy conservation, iv) Research and Development of new energies. After experiencing the second oil shock, Japan further propelled the above tasks to secure stable energy supply and improve energy conservation.

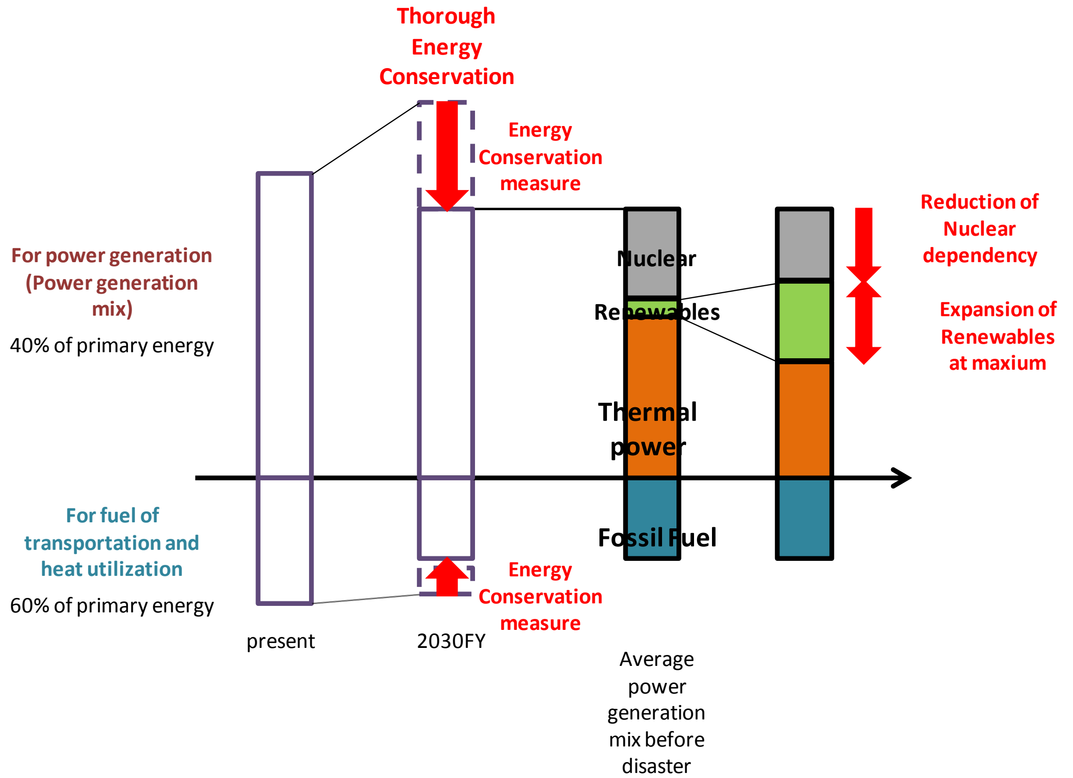
While Japan proceeded energy conservation and introduced non-oil energy, oil price dropped internationally after 1980s trough 1990s. It made a new challenge for Japan to balance energy security and economic efficiency of energy supply. During the period, the government pursued increase economic efficiency of energy supply by liberalizing energy market to promote competition. Liberalization of market started from oil market after 1987 and gas and power market after 1995.

After the early 1990s, in particular after, so called, the Earth Summit in Rio de Janeiro in 1992, global warming became an inevitable pillar of energy policy and Japan was not an exception. In 1997 during the COP 3, Kyoto Protocol was adopted internationally, in which Japan decided to reduce GHG emission by 6% from 1990 level during the first commitment period from 2008 to 2012. Japan participated in the Cancun Agreement up to 2020 but did not join the second commitment period of the Kyoto Protocol on the ground that it would not provide a fair and effective international framework with the participation of all major emitters. After that, Paris Agreement entered in force in November 2016. Japan submitted NDC, in which decided to reduce GHG emission by 26% relative to 2013.

It is important that energy policy is implemented reflecting changes of global energy market, national economic structure and peoples' lifestyle. Energy policy also has close relationship with environmental policy and science & technology policy.

3.1.1 Basic Principle for Drawing the Long-term Energy Supply and Demand Outlook

Basic principle of Japan's long-term energy transition is to improve energy efficiency and expand the use of renewable energy while reducing the contribution of nuclear energy to the extent possible. Important point here is to achieve this principle without distorting 3Es. For instance, when aiming to reduce CO_2 emission, use of renewable energy and nuclear power shall be increased while use of coal shall be decreased. However, when aiming to reduce energy cost, use of lower-cost base-load power generation such as nuclear, coal, hydro, and geothermal shall be expanded. As example clearly indicates, ideal structure of energy mix is different for each element of 3Es. This is the difficulty to structure long-term target of energy mix.



Source: METI, Reference material for the Long-term energy supply-demand outlook, July 2015

Fig. 3-1 Overall concept image of Japan's energy transition

As a result of deep discussions, the committee set out four fundamental policy targets to form the outlook up until 2030.

Tab. 3-1 Policy targets Japan

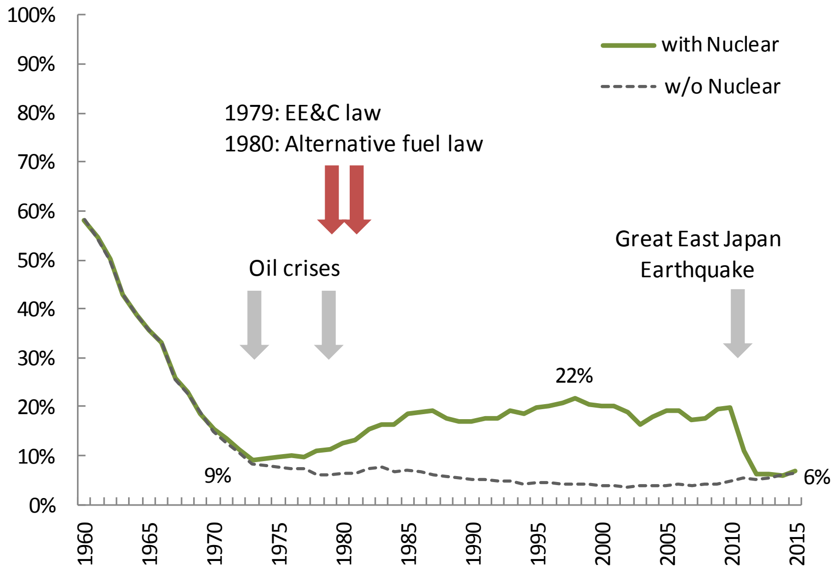
Safety	Ensure safety of nuclear power generation as a premise.
Energy security	Improve energy self-sufficiency to approximately 25% which is higher than the level before Fukushima-Daiichi nuclear accident (approximately 20%).
Economic efficiency	Reduce electricity cost to less than current level.
Environment	Launch GHG reduction target which is comparable to that of European countries and the U.S. hence to lead the world.

Safety

Confidence in nuclear power has been decreasing because of the Fukushima-Daiichi nuclear accident. Besides nuclear, oil & gas and other energy infrastructures were also required to become more robust against natural disasters after experiencing the supply shock caused by the earthquake in 2011. Therefore, in terms of nuclear energy, Japan has developed and applied the world's highest level of regulatory requirements and safety standards. In other sectors including oil and gas, the government will take the lead in the development and implementation of tougher safety measures.

Energy security

Improving the rate of energy self-sufficiency has been a major goal of Japan's long-term energy policy. However, despite all the efforts since the oil crisis in the 1970s to improve self-sufficiency, Japan's energy self-sufficiency rate has dropped from approximately 20% to a mere 6% because of the shutdown of the nuclear power plants.



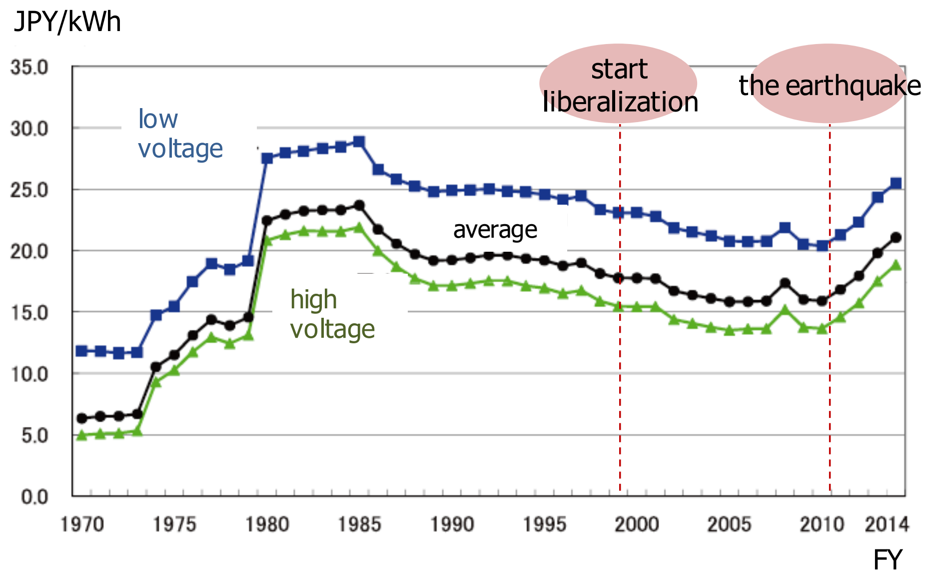
Source: IEA, Energy balance 2016

Fig. 3-2 History of energy self-sufficiency in Japan

Thus, Japan will continue its traditional efforts to reduce the risks associated with the import of energy by reducing energy demand, increasing indigenous production, and diversifying energy type and import partner country. In this light, Japan set a target of improving its self-sufficiency rate to approximately 25%, which is higher than before the Great East Japan Earthquake, by increasing the use of renewable energy and the use of nuclear.

Economic efficiency

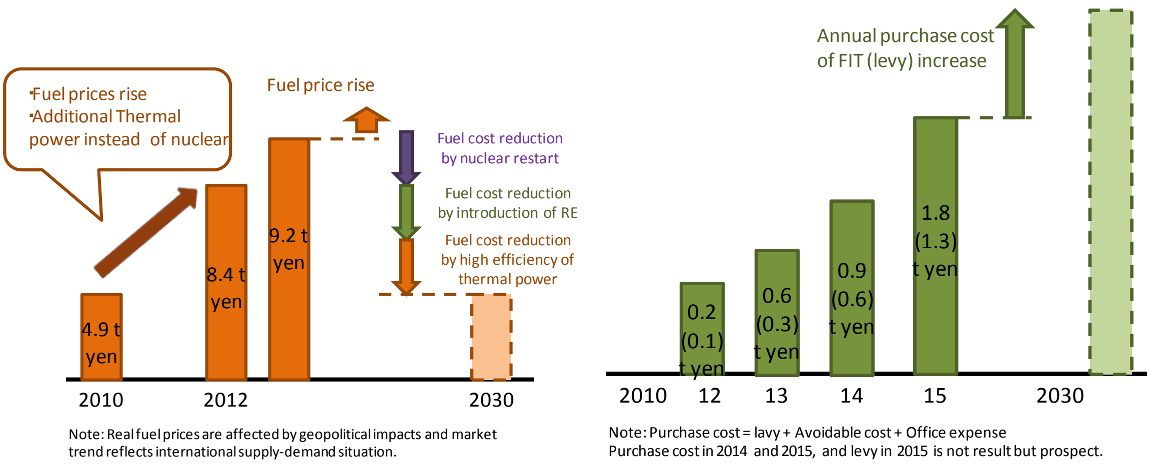
After the Great East Japan Earthquake, electricity prices have largely increased in both the household and the industrial sectors.



Source: METI, Energy White Paper 2016

Fig. 3-3 History of retail electricity price

The government has already been tackling the decrease of energy prices as much as possible and has also been promoting reform of the energy system. However, the share of nuclear (lower cost energy) in total electricity generation reduced after the Great East Japan Earthquake, LNG (higher cost energy) consumption rose to fill the electricity supply gap, and the use of renewable energy (higher cost energy) increased. This structural change naturally resulted in an increase of electric power costs.

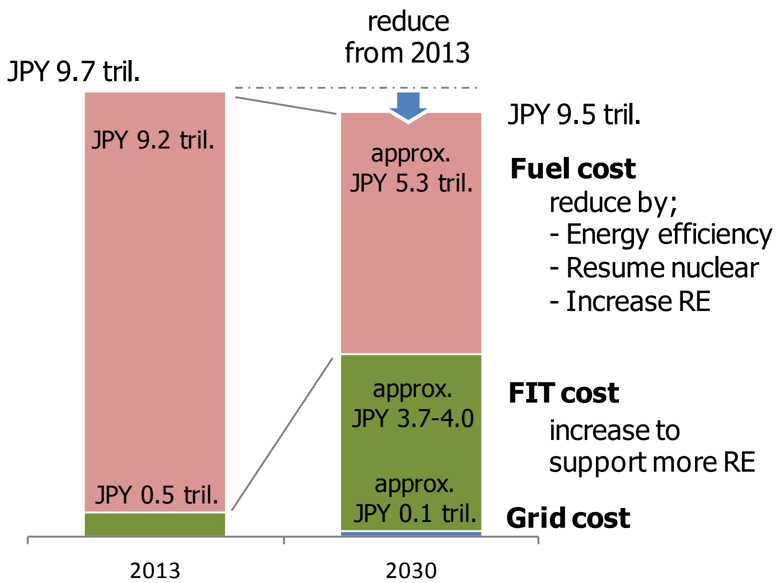


Source: METI, Reference material for the Long-term energy supply-demand outlook, July 2015

Fig. 3-4 Increase of fuel cost for power generation (left) and increase of FIT cost (right)

This results in creating a tougher business environment for the industrial sector including small and medium-size enterprises. Reducing electricity prices was also an urgent issue in order to maintain employment and people's standard of living. Needless to say, it is better for electricity prices to remain stable in the mid- to long-term.

Under circumstances where the economic cycle is starting to move positive, it's important to ensure international industrial competitiveness and to place the Japanese economy on a full-fledged growth track. It is also necessary to build an energy supply-demand structure to support this economic growth. Thus, the goal is to lower electric power costs below their 2013 level.

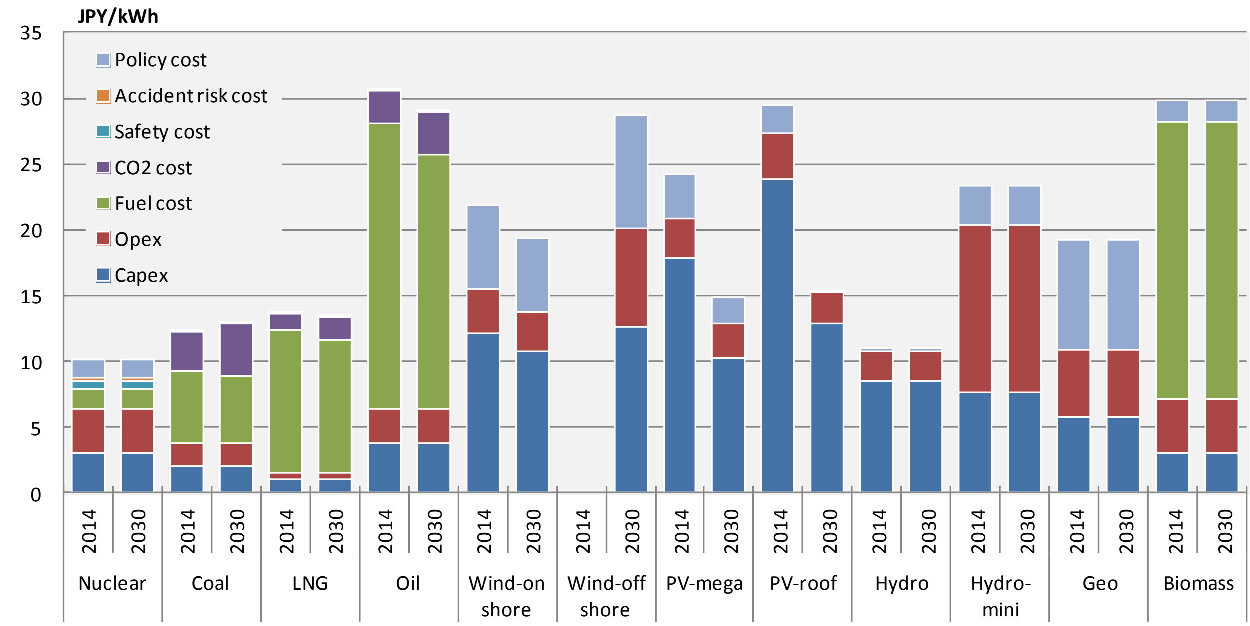


Source: METI, Reference material for the Long-term energy supply-demand outlook, July 2015

Fig. 3-5 Electricity cost reduction strategy

During the series of discussions to formulate the long-term supply-demand outlook, the technical working group was formed to assess power generation cost. The aim was to provide useful power generation cost information to enrich discussion to formulate the outlook. The assessment result indicates that even in 2030 when cost of renewable power generation become lower, nuclear and fossil-fuel power generation has economic advantage.

As indicated in the figure, nuclear power generation cost includes the one related to additional safety measures, accident risk and back-end. Even counting such cost, nuclear power is economically competitive to other sources. Furthermore, one should note that this cost assessment is for new construction of model plants. Generation cost of existing nuclear power plants which has been restarted would be much cheaper.



** Safety cost: Additional cost for improving safety of nuclear power, hence not applied to other type of energies.*

Source: METI, Report from the working group to assess power generation cost, April 2015

Fig. 3-6 Cost of power generation in Japan

Environment

The increased use of fossil fuels for power generation instead of nuclear power generation has been resulting in an increasing environmental load. Global warming is now becoming the world's common agenda and Japanese government is willing to take leading role to act against it. The government seek to present ambitious GHG emission reduction target toward 2030 which is comparable to that of Europe and United States of America.

Nationally Determined Contribution (NDC)

Japan has ratified the Paris Agreement and it become effective since December 2016. Japan's nationally determined contribution for GHG emission reduction after 2020 is reduction of 26.0% by FY2030 compared to FY2013 (25.4% relative to FY2005), or about 1.042 billion t-CO_2-eq as 2030 emissions), which is underpinned by the Long-term Energy Supply Demand Outlook for FY2030.

Tab. 3-2 Comparison of GHG emission reduction target

	Base year 1990	Base year 2005	Base year 2013
Japan	-18% by 2030	-25.4% by 2030	**-26% by 2030**
USA	-14～16% by 2025	**-26～-28% by 2025**	-18～-21% by 2025
European Union	**-40% by 2030**	-35% by 2030	-24% by 2030

** Bold text represents official targets of each nation/region.*

Source: METI, Reference material for the Long-term energy supply-demand outlook, July 2015

Just after the signing to Paris agreement (April 2016), in May 2016, Japan's government was adopted the „Plan for Global Warming Action". It describes strategy for long-term GHG emission reduction goal under certain conditions.

„Japan will aim at 80% GHG emission reduction by 2050;

- *Under the fair and effective international framework where all the major emitters will participate,*
- *When major emitters will take lead to encourage international society to make their effort to reduce emission at their capability,*
- *While balance global warming mitigation action and economic growth."*

In addition, the Plan also presented some key principles in pursuing the above long-term goal recognizing such a large scale reduction would be difficult to achieve by continuing conventional initiatives. Therefore, the Plan made it clear that Japan would exert utmost effort to solve global warming problems through;

- Promoting research, development, and dissemination of innovative technologies.
- Encouraging domestic investment and enhance international competitiveness,
- Seeking opinions and wisdom broadly from the public.

Choice of renewable energy

Renewable energy is a crucial component of achieving two pillars among 3Es, namely energy security and environment. Meanwhile, careful assessment is required when choosing type of renewable energy depending on each characteristic. The government divided renewable energy into two categories by its nature.

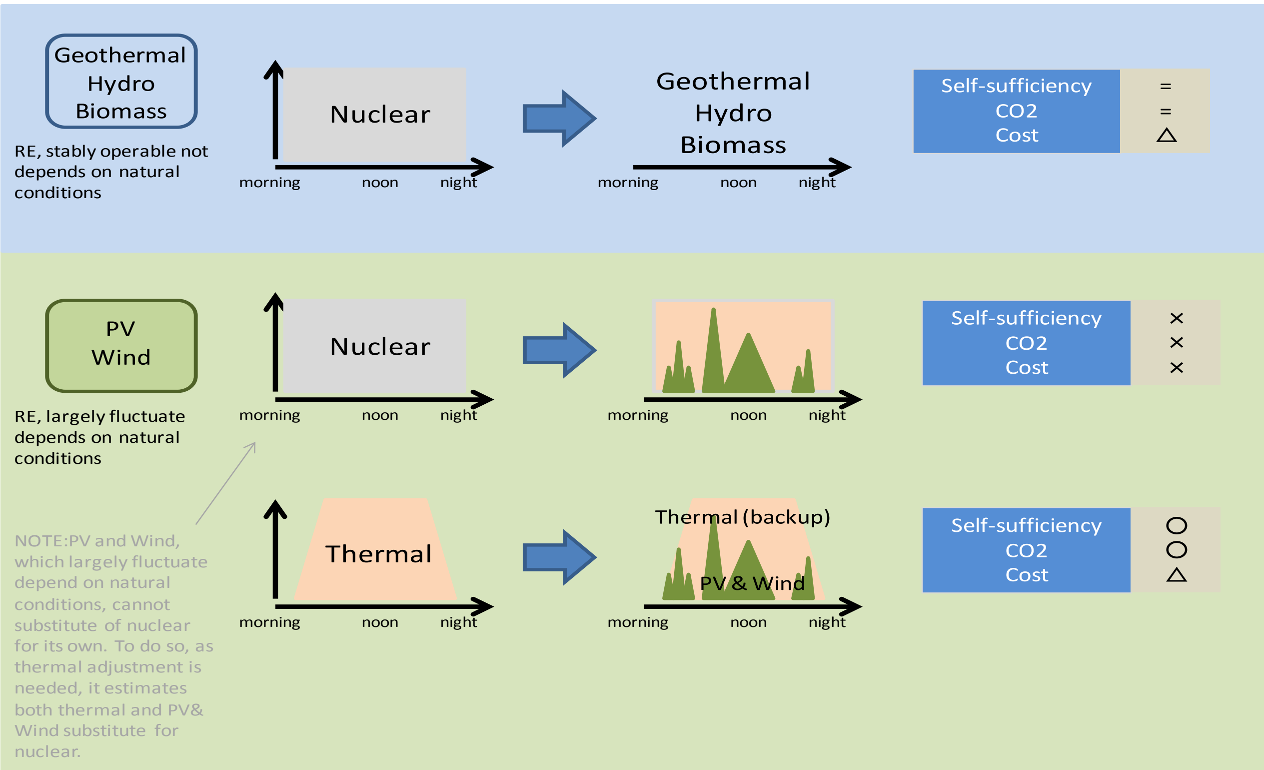
- **Geothermal, hydro, and biomass**

  Capable of stable/continuous operation and electricity output, hence able to replace nuclear power. While, it has challenges of geographical distribution and fuel supply which may potentially dampen its use.

- **Wind and solar photovoltaic**

  It will replace fossil-fired power generation rather than nuclear power, because it requires to run fossil-fired power generation as an adjustable power due to variable output. Its use will be minimized within a limit of certain accumulated electricity cost until 2030.

With this basic understanding, the government put a priority to promote geothermal, hydro, and biomass to the maximum extent of its availability. Then variable renewable energy will be introduced until total electricity cost will reach to upper limit of JPY 9.5 trillion (Figure 3-6).



Source: METI, Reference material for the Long-term energy supply-demand outlook, July 2015

Fig. 3-7 Characteristic and adaptability for 3Es of different types of renewable energy

3.1.2 Outlook of Energy Supply and Demand Structure in FY 2030

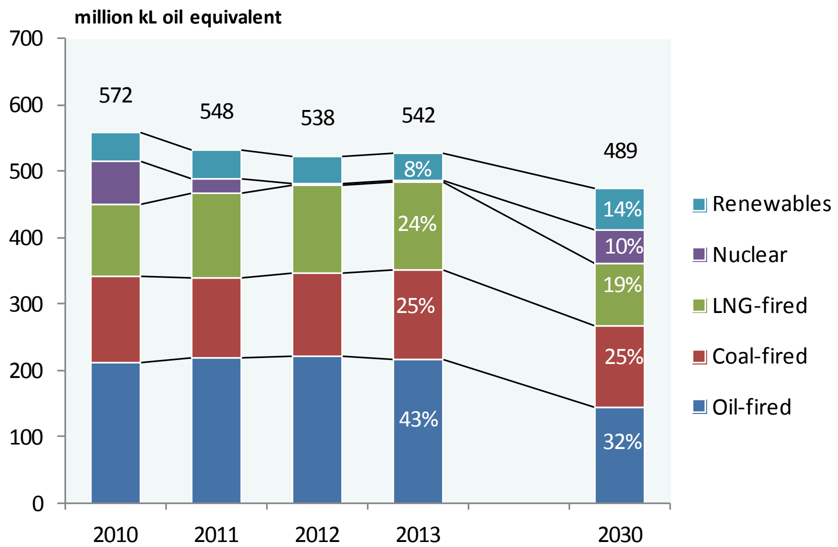
Japanese government set the outlook of energy supply-demand structure in FY2030 as follows along with the basic principle mentioned above.

Energy demand and primary energy supply structure

While expecting an increase in energy demand because of economic growth, significant improvements in energy efficiency are also expected by promoting thorough energy efficiency and conservation measures.

Specifically, based on numerous assumptions including the economic growth rate[3], the latest population projections[4], and industry activity levels, energy demand without additional energy efficiency and conservation measures were estimated. Technologically feasible and realistic energy efficiency and conservation measures in the industrial sector, commercial sector, residential sector, and transportation sector are all accumulated to reduce about 50.3 billion liters (crude oil equivalent) of final energy consumption. This results in the final energy demand of 326 billion liters in FY2030[5].

As a result, the primary energy supply structure in FY 2030 will be as shown below. This change will improve the energy self-efficiency in Japan to about 24.3% and will decrease CO_2 emissions from fossil fuel combustion by 21.9%[6] compare to the emissions in FY2013.



Source: METI, METI, Reference material for the Long-term energy supply-demand outlook, July 2015

Fig. 3-8 Primary energy supply Japan

[3] "Economic and Fiscal Projections for Medium to Long Term Analysis" Feb 2015, Cabinet Office. The Economic Revitalization Case assumes the average annual economic growth between FY2013 and FY2022 to be 1.7% in real terms. This 1.7% is applied to FY2024 onward.

[4] The National Institute of Population and Social Security Research (Medium-Mortality Assumption)

[5] Energy efficiency (Final energy demand per GDP) will be improved by 35% from FY2013 to FY2030.

[6] Greenhouse gas emission reductions in Japan totalize the above-mentioned CO_2 emission reductions from energy sources, other greenhouse gas emission reductions, measures for absorption sources, etc. Specifically, the emissions are 26.0% lower than in FY2013.

Power generation mix

The basic principle of the power supply-demand structure is to lower dependency on nuclear power generation as far as possible. This will be achieved through energy efficiency and conservation on the demand side, the introduction of renewable energy, as well as improving the efficiency of thermal power generation.

Although estimating an increase in electric power demand due to economic growth and a higher share of electricity use in final consumption, the implementation of strong energy efficiency (power-saving) measures will offset this increase in power demand in FY2030 to almost the same level as in FY2013.

In addition, renewable energy is regarded as an important low carbon domestic energy and its use will be maximized by taking into consideration the natural conditions and the characteristics of each source. In particular, geothermal, hydro, and biomass are expected to replace some portion of nuclear power generation because it is capable of supplying electricity stably. While solar PV and wind power, it's implementation will be maximized to the limitation of certain level of accumulated electricity cost which shall be lower than current total cost of power generation. .

Regarding thermal power generation, the environmentally balanced and more efficient use of coal and LNG thermal power generation are expected as cheaper and cleaner power generation sources respectively. Oil thermal power generation capacity will be held to use as a backup in an emergency, but its operation will be minimized.

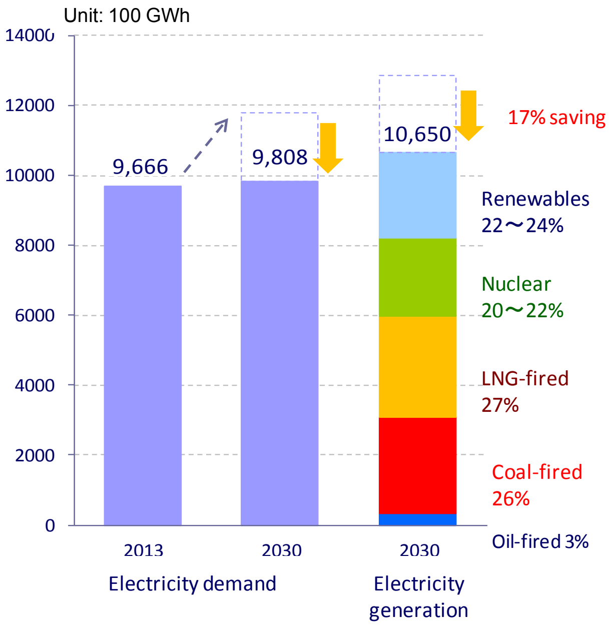
Regarding nuclear energy, although efforts to reduce its use will be pursued, Japan is expected to continue its use in FY2030 because of its benefits in improving self-sufficiency, reducing energy costs, and lowering the environmental load. Meeting enhanced safety standards is an absolutely necessary condition for the operation of nuclear power plants.

As a result, the electric power supply-demand structure in FY2030 will be as shown below.

This structure will decrease dependence on the nuclear power plants to approx. 20 to 22% from about 30% before the Great East Japan Earthquake. The share of base-load power generating sources including hydropower, coal-fired thermal power, nuclear power will be about 56%.

The government has also conducted sensitivity analysis of power generation mix. More precisely, it calculate change of CO2 emission amount and power generation cost when increase 1% point share of certain energy, in turn decrease 1% point share of another energy, in power generation mix.

The result indicate that the largest trade off in terms of CO2 emission reduction arises between coal and nuclear/renewable energy. In terms of economics, the largest trade off arises between nuclear and renewable energy.



Source: METI, METI, Reference material for the Long-term energy supply-demand outlook, July 2015

Fig. 3-9 Power generation mix Japan

Tab. 3-3 Sensitivity analysis to change power generation mix

Increase of share \ Decrease of share	Coal -1%	Gas -1%	Nuclear -1%	RE -1%
Coal +1%		+ 4.4 million ton-CO_2 - JPY 64 billion	+ 8.4 million ton-CO_2 + JPY 34 billion	+ 8.4 million ton-CO_2 - JPY 184 billion
Gas +1%	- 4.4 million ton-CO_2 + JPY 64 billion		+ 4.0 million ton-CO_2 + JPY 98 billion	+ 4.0 million ton-CO_2 - JPY 120 billion
Nuclear +1%	+ 8.4 million ton-CO_2 - JPY 34 billion	+ 4.0 million ton-CO_2 - JPY 98 billion		±0 million ton-CO_2 - JPY 218 billion
RE +1%	- 8.4 million ton-CO_2 + JPY 184 billion	- 4.0 million ton-CO_2 + JPY 120 billion	±0 million ton-CO_2 + JPY 218 billion	

Source: METI, Reference material for the Long-term energy supply-demand outlook, July 2015

Technological innovation and international contribution

Japan's energy transition policy is unique in its geographical broadness, which is not limited to inside of national border but extended to global society.

The NESTI 2050 (the National Energy and Environment Strategy for Technological Innovation toward 2050 (April 2016)) pointed out that the world need innovative technology to achieve the below 2 degree Celsius target, and that Japan will make effort to develop innovative technology in the field of conservation, storage, and generation of energy, and then contribute to the world by deploying it.

The Long-term climate change policy platform (April 2017) identified the three arrows (strategies) of globally inclusive decarbonisation strategy.

- International contribution through dissemination of Japan's efficient and environmentally friendly technologies.
- Global value chain based (not only at production stage but put more focus on utilization stage of product life cycle) GHG emission reductions by industry.
- Development of innovative technology.

3.2 Energy transition targets for Germany

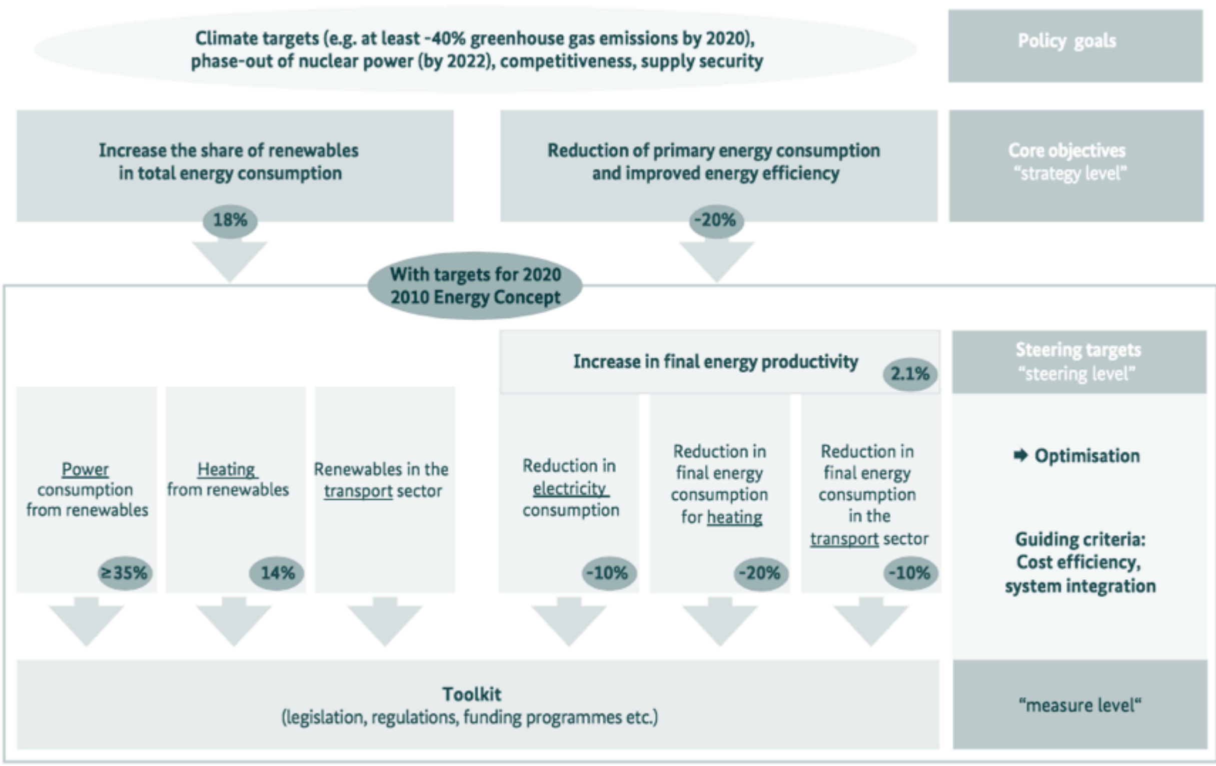
The German government has developed a “target architecture” (BMWi 2016) that intends to structure and prioritise the various goals set in the Energy Concept of 2010 and the so called “energy package” of 2011. This target architecture distinguishes between multiple goal levels, as can be seen in Figure 3-10, which illustrates the architecture based on the targets for the year 2020 as set in the 2010 Energy Concept.

The overarching “policy goals” comprise:

- The climate targets (see greenhouse gas emission targets in Table 3-1)
- The phase-out of nuclear electricity generation by 2022
- Targets for competitiveness and security of supply

The “core objectives” describe the two main strategies that are expected to drive the energy transition forward:

- An increase in the share of renewables in total energy consumption
- And a reduction in the use of energy



Source: BMWi 2016

Fig. 3-10 Structure of the objectives of the German energy transition process

Tab. 3-4 Overview of key energy transition targets for Germany

	Historic values		Targets			
	2000	2016	2020	2030	2040	2050
Greenhouse gas emissions						
Total (compared with 1990)	-17 %	-28 %	-40 %	-55 %	-70 %	-80 to -95 %
Energy sector (compared with 1990)	-16 %	-22 %	n. s.	-61 % - -62 %	n. s.	
Buildings (compared with 1990)	- 18 %	-37 %	n. s.	-66 % - -67 %	n. s.	
Transport (compared with 1990)	+11 %	+1 %	n. s.	-40 % - -42 %	n. s.	
Industry (compared with 1990)	-27 %	-34 %	n. s.	-49 % - -51 %	n. s.	
Energy efficiency / Energy savings (cross-sectoral)						
Primary energy consumption (compared with 2008)	0%	-7 %	-20 %	n. s.		-50 %
Gross electricity consumption (compared with 2008)	-8 %	-4 %	-10 %	n. s.		-25 %
Renewable energy sources						
Share of gross electricity consumption	7 %	32 %	40 to 45 % (2025)	55 to 60 % (2035)		at least 80 %
Share of heat consumption	4 %	13 %	14 %	n. s.		
Share in transport sector	1 %	5 %	10 %	n. s.		
Share of gross final energy demand	4 %	15 % (2015)	18 %	30 %	45 %	60 %
Average annual final energy productivity improvements	1.3 % (2008-2015)		2.1 % (2008-2050)			
Transport						
Final energy demand (compared with 2005)	+6 %	+1 %	-10 %	n. s.		-40 %
Number of electric vehicles (battery electric vehicles & plug-in hybrids)	n. a.	54,997	1 m	6 m	n. s.	
Buildings						
Annual rate of energy-related refurbishments	approx. 1 % (2005 to 2008)		2 %			
Primary energy consumption	n. a.	-16 % (2015)	n. s.			-80 %
Heat consumption (compared with 2008)	n. a.	-11 % (2015)	-20 %	n. s.		
Nuclear power generation (compared with 2010)	+21 %	-40 %	-100 % (from the end of 2022 on)			

Sources of targets and data: BMWi/BMU 2010, Bundeskabinett 2011, BMWi 2016, BMWi 2017a, BMUB 2016, UBA 2017a, UBA 2017b, UBA 2017c, UBA 2017c, KBA 2017

Security of supply	Covering Germany's energy needs at all times.
Nuclear energy phase-out	Switching off the last nuclear power plants at the end of 2022.
Affordability Competitiveness	Maintaining affordability of energy and ensuring Germany's competitiveness.
Grid expansion	Expanding and modernising grids to meet demand.
Sector coupling Digitisation	Unlocking the potential of efficient sector coupling and digitisation for a successful energy transition.
Europe International	Establishing a reliable European and international framework for more climate change mitigation, renewables and energy efficiency.
Research Innovation	Fostering forward-looking innovations for the restructuring of the energy supply.
Investment Growth Employment	Retaining and creating jobs in Germany and laying the foundations for sustainable prosperity and quality of life.

Source: BMWi 2016

Fig. 3-11 Targets and policies affecting energy transitions

These two core objectives are defined in concrete terms by "steering targets" for the three action areas of electricity, heating and transport. The steering targets and the corresponding measures at the "measure level" are supposed to be aligned in a way so as to ensure that the overarching policy goals can be achieved in a reliable and cost-effective manner.

Key quantitative targets of the „Energiewende" are shown in Table 3-4, while additional qualitative targets are listed in Figure 3-11. Table 3-4 includes the sectoral GHG emission reduction targets for 2030 set by the government for the first time in its "Climate Action Plan 2050" of late 2016 (BMUB 2016).

For those energy system characteristics, for which 2020 (interim) targets were set, assessments can be made on whether Germany is on track or not to meet them. The German government's latest "Monitoring Report" of December 2016 includes such an assessment based on progress made in the past years up to the year 2015. Based on this assessment, the following Table 3-5 summarizes for which characteristics Germany is on track to reach its 2020 targets and for which ones stronger progress than in the past will be needed until 2020.

In the table, characteristics are classified as "on track" if the "Monitoring Report" has found that past trends are fully in line with the respective 2020 targets. Characteristics for which recent trends are not in line with the respective 2020 targets are classified as "stronger progress needed". Within this group, the extent to which recent trends diverge from the 2020 targets are different from one characteristic to another. Some of the targets in this group may be considered "out of reach", but since various kinds of drastic short-term policy interventions are principally possible, we refrain here from referring to any target as "out of reach". However, recent trends in final energy demand in the transport sector, renewables in the transport sector and gross electricity consumption are particularly at odds with the respective 2020 targets.[7]

[7] A detailed discussion of the progress made so far for each target is beyond the scope of this report, but interested readers are referred to the "Monitoring Report" (BMWi 2016) for further information and the data behind the report's assessments.

It is noticeable that most of the targets that will likely be met concern the expanded use of renewable energy sources. In this area, considerable progress was made in the past two decades, especially in regard to the expansion of renewables in the electricity sector. On the other hand, most characteristics that will be difficult to be met deal with reducing energy demand. For many years, faster progress in realising available energy efficiency potentials have been called for by many German researchers (e.g. Hennicke 2013).

One of the targets likely to be missed is the key policy goal of reducing GHG emissions by 40 % compared with 1990. As already a few years ago it has become increasingly clear that this target is in danger of being missed, the government in late 2014 released a Climate Action Programme 2020, which contains measures to be implemented by 2020 for Germany to still reach its 2020 GHG emission reduction target. However, recent emission trends as well as recent analysis suggest that the GHG emissions reduction target will be missed by a large margin, if no far-reaching measures with short-term emission implications (such as a shutdown of a considerable number of coal power plants) are implemented. Without such measures, German GHG emissions are now expected to be only about 31 % or 32 % lower in 2020 than they were in 1990 (Agora Energiewende 2017, Bauchmüller 2017).

Tab. 3-5 Evaluation of Germany's current progress in reaching 2020 energy transition targets (based on latest assessment by the German government (BMWi 2016))

Characteristics for which Germany is on track to meet 2020 targets[8]
Share of renewables in gross electricity consumption
Share of renewables in heat consumption
Share of renewables in gross final energy demand
Reduction in heating energy demand in the buildings sector
Characteristics for which stronger progress than in the past is needed to meet 2020 targets
Reduction in greenhouse gas emissions
Reduction in primary energy consumption
Increasing final energy productivity
Reducing gross electricity consumption
Share of renewables in the transport sector
Reduction in final energy demand in the transport sector

Source: Own assessment based on the analysis in BMWi (2016)

[8] Additional policy measures may still be needed to reach the respective targets.

Several studies make it clear that quickly reducing and eventually phasing out coal power plants is a key prerequisite for Germany to reach its short- to long-term GHG reduction targets (e.g. BMUB 2015, Agora Energiewende 2016, NABU 2017). However, the German government has so far been opposed to develop a concrete phase-out plan for electricity generation from coal. In its Climate Action Plan 2050 (BMUB 2016), the government has conceded that a “stepwise reduction” of coal electricity generation is required to reach its GHG reduction targets and that discussions are needed on how to make sure that the related economic and social transformation process in coal-rich regions of Germany can be managed successfully.

The nuclear phase-out as a key part of the German “Energiewende” tends to draw particular interest from many Japanese researchers and stakeholders. Therefore, Box 2 intends to provide some background on the decision made by the German government in 2011 to phase out the use of nuclear power by the year 2022. The Box also aims to highlight the research findings that contributed to the prevailing view in Germany that the impacts of a nuclear phase out on electricity prices and the overall economy are rather small.

Box 2: The decision to phase out nuclear power in Germany by 2022

Less than a week after the beginning of the nuclear catastrophe in Fukushima, Japan, on 11 March 2011, the German government ordered eight of Germany’s 17 existing nuclear power plants (NPPs) to stop operating for an initial 3-month evaluation period. These were the seven oldest NPPs still in operation in Germany at that time plus another NPP in northern Germany, which had previously suffered from various technical problems. In the summer of 2011 a law came into force that finally terminated the operating licenses of those eight plants, with an instruction for the remaining nine NPPs to be closed down successively by the end of 2022. Earlier that summer, the “Ethics Commission for a Safe Energy Supply”, consisting of experts and civil society representatives and created by the German Chancellor Angela Merkel in the wake of the nuclear catastrophe in Fukushima, recommended a complete withdrawal from nuclear energy within a decade. The commission concluded that a “withdrawal from nuclear energy is necessary and is recommended to rule out future risks that arise from nuclear in Germany. It is possible because there are less risky alternatives.” (Ethics Commission for a Safe Energy Supply 2011)

In making the phase-out decision, the government basically returned to the nuclear phase-out plan that had originally been implemented by a previous government in 2002 but had been modified by the then newly elected government in October 2010, granting an average of twelve additional operating years to all 17 NPPs (Lechtenböhmer/Samadi 2013). The decision in 2010 to prolong the use of the existing nuclear power plants was highly contentious in Germany, as a majority of Germans has long been critical of the use of nuclear power (EC 2010). The catastrophe in Fukushima further fuelled the anti-nuclear sentiments in the German population and contributed to strong election results of the decidedly anti-nuclear German Green party in several regional elections, most notably in the state of Baden-Wuerttemberg, where the party was strong enough to lead a coalition that ousted the conservative government.

A study commissioned by the German government in the wake of the nuclear accident at Fukushima (BMWi 2011) analysed the isolated implications of a stepwise nuclear phase out until 2020/2025 on electricity prices, employment, GDP and CO_2 emissions. The study employs a European power market model to estimate future electricity price developments and it uses a macro-econometric simulation and forecasting model (called PANTA RHEI) to analyse the potential macroeconomic effects.

Compared to a prolonged use of nuclear power until the mid or late 2030s, a nuclear phase out between 2020 and 2025 was found by the study to increase electricity prices for households in 2030 by 2% and for most of the industry by 3.5%. Only the electricity intensive industry, which makes up a small share of total German industry in terms of value added and employment, was expected to be affected much more strongly, with a 17% higher electricity price in 2030. Several other power market modelling studies (Samadi et al. 2011, Knopf et al. 2014, Traber/Kemfert 2012, Grossi et al. 2014) support the finding of very moderate isolated price effects for household customers and most of the German industry as a result of an earlier nuclear phase out.

BMWi (2011) further found that GDP in 2030 was expected to be 0.25% lower and employment some 0.1% lower in the earlier phase-out scenario. Energy-related GHG emissions in Germany in 2030 were expected to be almost 10% higher in the early phase out scenario. However, it should be emphasised that the study assumed that electricity generation from renewables would be the same in both scenarios in 2030 (and electricity demand almost identical) and that therefore, nuclear power in the phase-out scenario is substituted only by electricity generation from fossil fuel power plants.

Other research concluded that even a faster than decided nuclear phase out “will not undermine security of supply and network stability in Germany and Central Europe.” (Kunz et al. 2011)

4 Overview and selection of energy transition scenarios for Japan and Germany

An important step in preparing the analysis of the energy transition strategies for Japan and Germany is the selection of the scenarios to be examined. For this purpose, a literature analysis was carried out for both countries identifying studies that were completed in 2011 or later. The year 2011 was chosen to ensure the relevance and timeliness of the studies, in particular against the background of the nuclear accident that took place in Fukushima in 2011. The nuclear disaster at the Fukushima Daiichi nuclear power plant has not only had an impact on the design of energy transition strategies for Japan but also led to an accelerated nuclear phase out in Germany, in contrast to the phase out planned in the energy concept from 2010 of the German government. Scenarios that were created in 2011 or later usually reflect these developments.

4.1 Overview of energy transition scenario studies for Japan and Germany

In course of the comprehensive literature analysis a number of relevant energy scenario studies for Japan and Germany, which describe the medium to long-term effects of the energy system transition and the associated economic implications, were identified. Table 4-1 provides an overview of these energy scenario studies for Japan and Table 4-2 lists the energy scenario studies identified as relevant for the German context.

Tab. 4-1 Important energy scenario studies for the Japan energy system released since 2011

Study	Commissioned / Prepared by	Year
Asia / World Energy Outlook	IEEJ	multiple years
Long-term scenarios for decarbonizing Japan	WWF	2017
Energy Transition Strategy	METI	2016
Long-term Energy Supply and Demand Outlook based on the 4th Strategic Energy Plan (2014)	METI	2015
Toward Choosing Energy Mix	IEEJ	2015
Analysis of energy mix and outlook of GHG emission	RITE	2015
Analysis of Japan's Long-Term Energy Outlook Considering Massive Deployment of Variable Renewable Energy under Nuclear Energy Scenario	Komiyama / Fuji	2015
Japan's likely 2030 energy mix: more gas and solar	Bloomberg New Energy Finance	2015
Comparative assessment of GHG mitigation scenarios for Japan in 2030	IGES	2015
Comparative assessment of Japan's long-term carbon budget under different effort-sharing principles	Kuramochi et al.	2015
Comparative assessment of GHG mitigation scenarios for Japan in 2030	Kuramochi et al.	2015
Pathways to deep decarbonization in Japan	Kainuma et al.	2015
Japan's energy conundrum: Post-Fukushima scenarios from a life cycle perspective	Pereira et al.	2014
Draft of choice of energy mix	METI	2012
A roadmap toward a low-carbon society in Japan using backcasting methodology: Feasible pathway for achieving an 80% reduction in CO_2 emission by 2050	Ashina et al.	2012

Tab. 4-2 Important energy scenario studies for the German energy system released since 2011

Study	Commissioned / Prepared by	Year
Erneuerbare vs. fossile Stromsysteme: ein Kostenvergleich	Agora Energiewende / Öko-Institut	2017
Die Energiewende nach COP 21 - Aktuelle Szenarien der deutschen Energieversorgung	Bundesverband Erneuerbare Energien	2016
Wirtschaftliche Bewertung des Aktionsprogramm Klimaschutz 2020	BMUB	2016
Was kostet die Energiewende? Wege zur Transformation des deutschen Energiesystems bis 2050	Fraunhofer ISE	2015
Beschäftigung durch erneuerbare Energien in Deutschland: Ausbau und Betrieb, heute und morgen	BMWi	2015
Klimaschutzszenario 2050 - 2. Modellierungsrunde	BMUB	2015
Was kostet die Energiewende? - Wege zur Transformation des deutschen Energiesystems bis 2050	Fraunhofer ISE	2015
Klimaschutz: Der Plan - Energiekonzept für Deutschland	Greenpeace	2015
Grundlagen und Konzepte einer Energiewende 2050	BUND	2015
Die Beschäftigungseffekte der Energiewende	Bundesverband Windenergie	2015
Die neue Stromwelt - 100% Erneuerbar	Bündnis 90/Die Grünen Bundestagsfraktion	2015
Current and Future Cost of Photovoltaics	Agora Energiewende	2015
Kombikraftwerk 2	BMUB	2014
Entwicklung der Energiemärkte– Energiereferenzprognose	BMWi	2014
Gesamtwirtschaftliche Effekte der Energiewende	BMWi	2014
Treibhausgasneutrales Deutschland 2050	UBA	2014
Geschäftsmodell Energiewende - Eine Antwort auf das „Die-Kosten-der-Energiewende“-Argument	Fraunhofer IWES	2014
Gesamtwirtschaftliche Wirkungen von Klimaschutzmaßnahmen und -instrumenten – Ökonomische Analysen der Politikszenarien für den Klimaschutz VI	UBA	2013
Ermittlung der Wachstumswirkungen der KfW-Programme zum Energieeffizienten Bauen & Sanieren	KfW Bankengruppe	2013
Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global	BMU	2012
Volkswirtschaftliche Effekte der Energiewende: Erneuerbare Energien und Energieeffizienz	BMU	2012

4.2 Selection of scenario studies for in-depth analysis

From the group of identified energy scenario studies, twelve scenarios from five studies were selected for Japan and five scenarios from four studies were selected for Germany for the in-depth analysis of the energy system and the macroeconomic implications of the pursued energy transition strategies. The selection of the scenarios for Japan and Germany was based on the following criteria (which are also described in section 2.2.1):

- Publishing date
- Quantitative details for energy demand and supply side for at least 2030
- Cover the entire energy sector not only electricity
- Include both renewable energy and energy efficiency aspects
- Include macroeconomic analysis

Applying these criteria, the following scenarios were selected from the list of identified scenario studies. The key exclusion criterion was that the selected studies needed to include a quantitative analysis of the macroeconomic implications of their energy scenarios. As the analysis of macroeconomic effects is of key interest for the study at hand (in line with the Terms of Reference), no scenario studies were selected that did not include such analysis.[9] For Germany, this criterion was mainly responsible for reducing the number of scenario studies to be considered to the four studies listed below.

Japan

Study:	**Long-term Energy Supply and Demand Outlook**
Prepared by:	METI
Publishing year:	2015
Time horizon:	2030

Study:	**Asia/ World Energy Outlook 2016**
Prepared by:	IEEJ
Publishing year:	2016
Analysed Scenario:	Reference scenario
	Advanced Technology scenario
Time horizon:	2030

Study:	**Toward Choosing Energy Mix**
Prepared by:	IEEJ
Publishing year:	2015
Analysed Scenario:	Scenario1: RE35%, Thermal65%, Nuclear0%, Total electricity generation 1.1PWh
	Scenario2: RE30%, Thermal55%, Nuclear15%, Total electricity generation 1.2PWh

[9] It should be emphasized that macroeconomic implications refer to changes to indicators such as GDP, sectoral value added and employment. Some of the scenario studies (e.g. Fraunhofer ISE 2015) identified for Germany in Table 4-2, for example, include estimates on future energy system costs, but do not include analysis of macroeconomic effects.

	Scenario3: RE25%, Thermal50%, Nuclear25%, Total electricity generation 1.2PWh
	Scenario4: RE20%, Thermal50%, Nuclear30%, Total electricity generation 1.2PWh
Time horizon:	2030

Study:	**Analysis of energy mix and outlook of GHG emission projection in Japan**
Prepared by:	Research Institute of Innovative Technology for the Earth (RITE)
Publishing year:	2015
Analysed Scenario:	Several scenarios for power generation mix Base road power (nuclear+ coal+ hydro+ geothermal): 40%, 50%, 60%
	RE: 15%, 20%, 25%, 30%,
	2 scenarios for CO_2 price: IEA WEO New Policies Scenario and 450 Scenario equivalent.
Time horizon:	2030

Study:	**Draft of choice of energy mix**
Commissioned by:	METI
Publishing year:	2012
Analysed Scenario:	4 scenarios for power generation mix
	Scenario1: nuclear 0%, RE 35%.
	Scenario2: nuclear 15%, RE 30%.
	Scenario3: nuclear 20-25%, RE 25-30%.
	Scenario4: nuclear 35%, RE 25%.
Time horizon:	2030

Germany

Study:	**Klimaschutzszenario 2050 - 2. Modellierungsrunde**
Commissioned by:	BMUB
Publishing year:	2015
Analysed Scenario:	Klimaschutzszenario 80 (KS 80)
	Klimaschutzszenario 95 (KS 95)[10]

[10] Unlike the other three studies for Germany, from which scenarios are selected for the analysis at hand, this study contains two separate scenarios that are both in line with the German government's GHG reduction targets. The two scenarios cover both ends of the government's 2050 GHG reduction target rage (80% to 95% reduction compared to 1990). Although the study only calculates the macroeconomic consequences

Time horizon: 2050

Study: **Entwicklung der Energiemärkte – Energiereferenzprognose**
Commissioned by: BMWI
Publishing year: 2014
Analysed Scenario: Zielsenario (ZS)
Time horizon: 2050

Study: **Gesamtwirtschaftliche Wirkungen von Klimaschutzmaßnahmen und -instrumenten – Ökonomische Analyse der Politikszenarien für den Klimaschutz VI**[11]
Commissioned by: UBA
Publishing year: 2013
Analysed Scenario: Energiewende-Szenario (EWS)
Time horizon: 2050

Study: **Volkswirtschaftliche Effekte der Energiewende: Erneuerbare Energien und Energieeffizienz**[12]
Commissioned by: BMUB
Publishing year: 2012
Analysed Scenario: Leitszenario 2009 (LS09)

- Szenario PV2, verhaltener Export, Preispfad B (for the assessment of renewable energy deployment)
- Scenario „Effizienz ambitioniert“ (for the assessment of energy efficiency measures)

Time horizon: 2050

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for the less ambitious KS 80 scenario (arguing that the radical changes in the KS 95 scenario pose challenges to the modelling of the macroeconomic impacts), it was decided here to also include the KS 95 scenario in the scenario analysis of the following chapters. This decision was made because the other selected scenarios are relatively similar in regard to their long-term GHG emission reduction ambition, and including the KS 95 scenario can therefore highlight how future energy system developments may have to diverge from an 80% reduction pathway, if more ambitious reductions are aimed for.

[11] Energy scenario based on UBA (2013b): Politikszenarien für den Klimaschutz VI - Treibhausgas-Emissionsszenarien bis zum Jahr 2030.

[12] Energy scenario based on BMU (2009): Leitszenario 2009 - Langfristszenarien und Strategien für den Ausbau erneuerbarer Energien in Deutschland unter Berücksichtigung der europäischen und globalen Entwicklung.

5 Comparison of key assumptions and outcomes of the selected energy scenarios

This chapter intends to provide a detailed comparison of key assumptions and outcomes of the selected energy scenarios for each country. The analysis in this chapter will be largely descriptive in nature and will focus on the content of the selected scenario studies. The following Chapter 6 will then analyze in more detail a number of key energy transition strategies that are pursued in most or all of the scenarios.

As in the following three chapters (6, 7 and 8), the analysis in this chapter will be performed separately for Japan and Germany. In the “Joint Conclusion” (Chapter 9), the Japanese and German scenarios and their respective expected implications will then be compared with each other and conclusions from this comparison will be drawn.

5.1 Japan

5.1.1 Comparison of key assumptions

Tab. 5-1 List of scenarios and key assumption

		Published year	Base year	Time horizon	Model	Scenario
METI [*METI(2012)*]		2012	2010	2030	4 CGE models (Osaka Univ., NIES, Keio Univ., RITE) +Ecnometric model	Power generation mix in 2030; 4 secnarios. Reference: nuclear 26% ,RE 11% ,EE&C no Option1: nuclear 0% ,RE 35% ,EE&C yes Option2: nuclear 15% ,RE 30% ,EE&C yes Option3: nuclear 20-25% ,RE 25-30% ,EE&C yes Option4: nuclear 35% ,RE 25% ,EE&C yes
IEEJ	Toward choosing energy mix [*IEEJ(2015)*]	2015	2013	2030	Econometric model	Power generation mix in 2030; 4 scenarios Scenario1: RE 35%, Thermal 65%, Nuclear 0% Scenario2: RE 30%, Thermal 55%, Nuclear 15% Scenario3: RE 25%, Thermal 50%, Nuclear 25% Scenario4: RE 20%, Thermal 50%, Nuclear 30%
	Outlook 2016 [*IEEJ(2016)*]	2016	2014	2040	Econometric model	Technology and policy; 2 scenarios Reference Scenario Advanced Technology Scenario
RITE [*RITE(2015)*]		2015	2013	2030	CGE model (+ LP model)	Power generation mix in 2030; Assume share of base road power (nuclear, coal, hydro, geothermal) : 40%, 50%, 60% Assume share of RE: 15%, 20%, 25%, 30% Carbon price, 2 scenarios IEA WEO 2014, New Policies Scenario equivalent IEA WEO 2014, 450 Scenario equivalent

CGE model= computable general equilibrium model
EE&C=energy efficiency and conservation

Source: METI, Basic data for draft of choice of energy mix, June 2012; IEEJ, Toward choosing energy mix, January 2015; RITE, Analysis of energy mix and outlook of GHG emission projection, March 201, IEEJ Asia/World Energy Outlook 2016

This section will compile key assumptions of three organization (seven models) listed above. Except IEEJ(2016), six models are mainly aiming at assessing economic impact of different power generation mix in 2030. Meanwhile in IEEJ(2016), it analyze energy supply-demand structure until 2040 by adopting different scenarios focusing on technological development. Although IEEJ(2016) and RITE(2015) analyses global energy outlook, this study only evaluate information about Japan.

5.1.2 Comparison of methodologies (especially models applied)

METI(2012) applied four computable general equilibrium (CGE) models, Osaka university, National Institute of Environment Study: NIES, Keio university, and Research Institute of Innovative Technology for the Earth: RITE, to quantitatively assess economic impact of different power generation mix considering the accident of Fukushima Daiichi nuclear power plant.

When considering complexity of CGE model, it is desirable to standardize endogenously calculated result of the reference case as much as possible including GDP, energy consumption, and CO2 emission, in addition to apply the same exogenous scenarios such like population and currency exchange rate, to carefully measuring economic impact of different power generation mix. Therefore, common economic and energy (and electricity) demand outlook has presented by secretariat of committee and every organization calibrated the reference case created by their model. Further, typical results under the same assumption such like change of electricity demand due to electricity price increase has compared to evaluate performance of subjected models.

RITE(2015) employed two kinds of models: a global energy system model DEN21+ which minimizes the energy system costs and a global CGE type model DEARS. They set power generation mix and carbon cost as assumption, and DEN21+ model will calculate cost minimum energy system to deliver such like primary energy supply and energy system cost. Economic growth rate is also an exogenous input in DEN21+, and electricity demand is estimated by assuming its income elasticity. And then, it evaluate effect on economic structure and energy supply-demand by using CGE model and linear programming (LP) model. While DEARS model calculate macroeconomic impact of such energy system change.

Meanwhile in IEEJ(2015), it employ econometric model for analysis. An econometric model projects functions explaining past economic activities and energy demand with macro variables of other social and economic activities (e.g., economic growth, crude oil prices, the number of households, vehicle ownership, etc.) and extrapolates future explanatory variables into these functions for making future projections. Parameters (sensitivity coefficients) used for functions are statistically estimated based on past data (least-square method). While a general equilibrium model compared frequently with the econometric model is based on an assumption that “each economic unit behaves rationally based on price information,” people in the actual world do not necessarily behave rationally. In contrast, the econometric model is based on an assumption that “each economic unit will behave in the future based on past experiences.” Unless people substantially change their behavioural principles, past trends can be used to project future economic and energy supply and demand structures with great accuracy. IEEJ’s model is caracterized by inter linkage beween macro economy and energy demand. They developed an integrated econometric type model to estimate both future macro economy and future energy structure in a consistent manner.

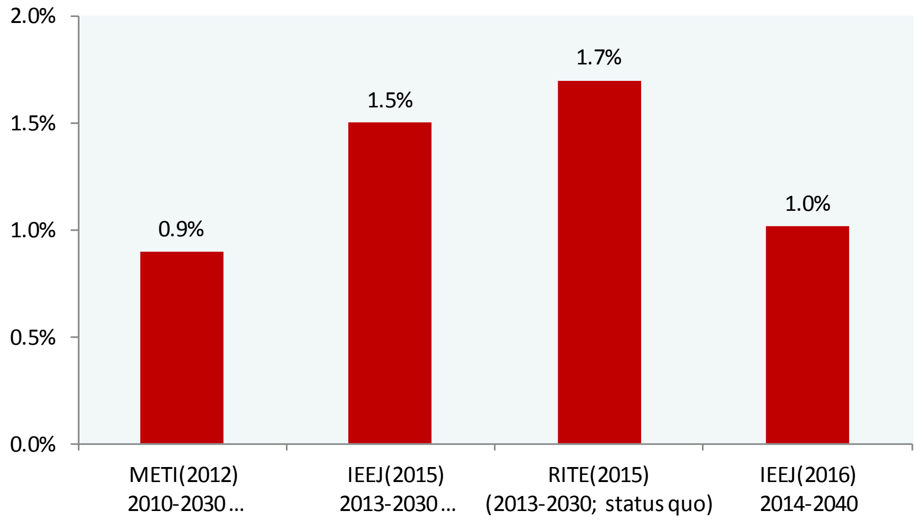
IEEJ(2016) analyses energy structure until 2040 by assuming economic, social, energy policy, and technological advancement conditions. Its analysis focuses on impact of technological advancement on energy structure, while not assess economic impact.

5.1.3 Comparison of macro-frame

In IEEJ(2015) and RITE(2015), economic growth rate is exogenous variable. They assume 1.5% and 1.7% of annual average growth rate (AAGR) until 2030, respectively, by making reference to government's "Strategy for Rebirth of Japan (2011)". While, assumption of AAGR 1.7% of economic growth rate in RITE(2015) is consistent with that of METI's Long-term energy supply demand outlook (2015).

Economic growth rate in IEEJ(2016) is also and exogenous variable, and refer to International Monetary Fund's (IMF) "World Economic Outlook (2016)" for medium term, and assume 1.0% of AAGR after that until 2040 by considering decreasing population and so on.

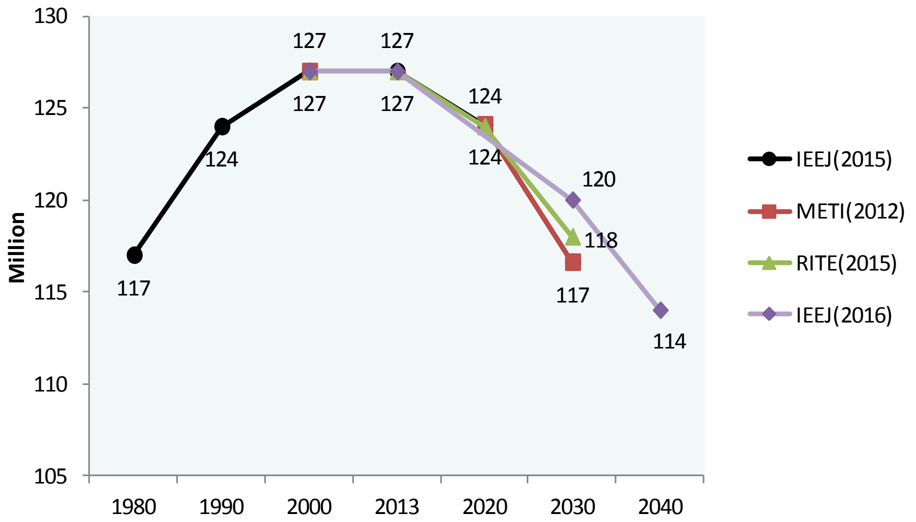
On the other hand in METI(2012), four CGE models endogenously calculate economic growth. They adjusted total factor productivity (TFP) and other parameters to calibrate their model to create common reference case for making comparison easier. The reference case assumes growth rate of 0.9% by making reference to the reference case in "Economic and Fiscal Projections for Medium to Long Term Analysis (2012)". In addition, METI(2012) set two cases for sensitivity analysis that are high growth case (1.5%) and low growth case (0.3%). High growth case assumes successful implementation of government's economy stipulating policy, while the low growth case has proposed by a committee member.



Source: METI, Basic data for draft of choice of energy mix, June 2012; IEEJ, Toward choosing energy mix, January 2015; RITE, Analysis of energy mix and outlook of GHG emission projection, March 2015, IEEJ Asia/World Energy Outlook 2016

Fig. 5-1 Assumed annual average growth rate of GDP

In terms of population, Japan has seen a declining trend since 2011 and faces the prospect of the further decline in the future. In 2015, the elderly population[13] account for more than double the young population, indicating a further fall in the birth rate and a further aging population in the future. Most of analyses employs periodical publication of National Institute of Population and Social Security Research, hence there is no significant difference in population assumption of METI(2012), IEEJ(2015), and RITE(2015). However in IEEJ(2016), it utilize numbers from United Nation's "World Population Prospects (2015)", thus assumed future population is slightly larger than the others, although declining trend is same. Meanwhile, every analysis doesn't change their population assumption between scenarios.



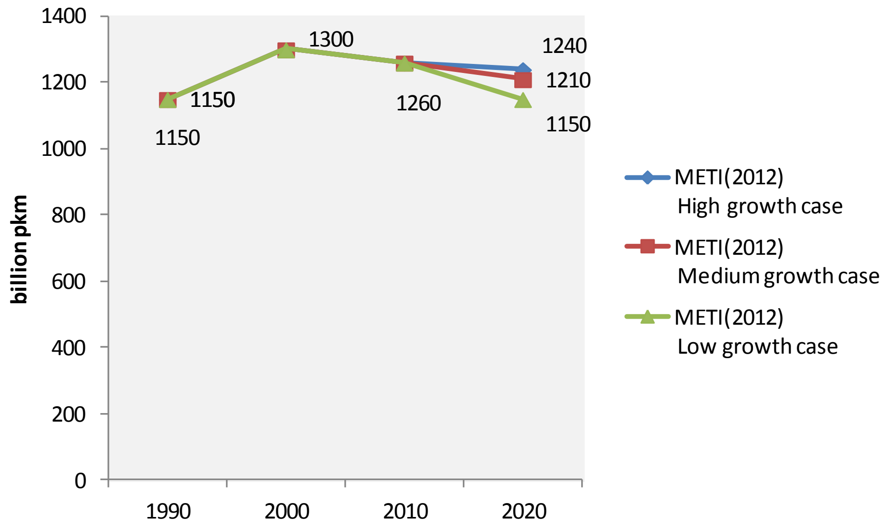
Source: METI, Basic data for draft of choice of energy mix, June 2012; IEEJ, Toward choosing energy mix, January 2015; RITE, Analysis of energy mix and outlook of GHG emission projection, March 201, IEEJ Asia/World Energy Outlook 2016

Fig. 5-2 Assumption of population

Some other assumptions for the transport sector and commercial sector are presented in the METI(2012) scenario. The following few figures indicate assumptions by METI(2012) for transport demand for passenger vehicles (person-km), transport demand for freight vehicles (tonne-km), and floor area of commercial buildings.

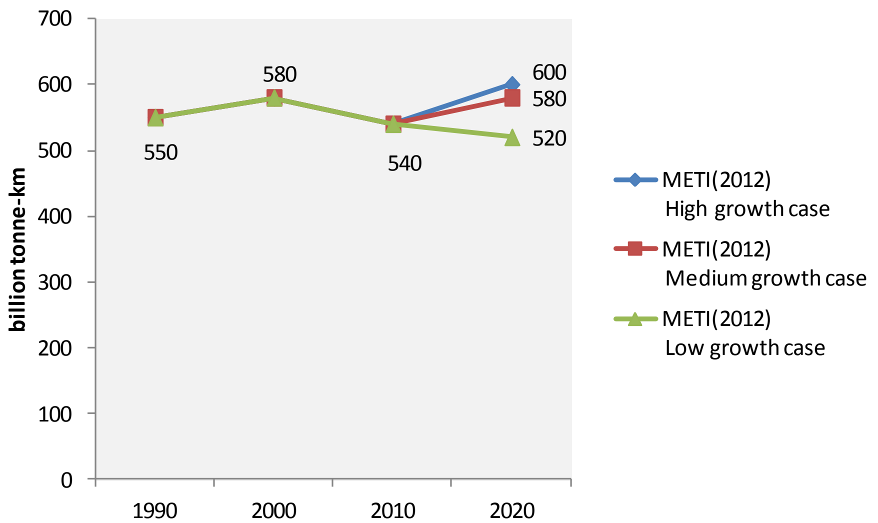
Transport demand for passenger vehicle is assumed to decrease because of declining and aging of population. Meanwhile, demand for freight vehicle is assumed to increase due to economic growth. It expect increase of home delivery services for aged people and growing number of internet shopping. Floor area of commercial building is assumed to hit the peak at around 2020 and turn to decrease afterward due to declining population.

[13] People over 65 years old.



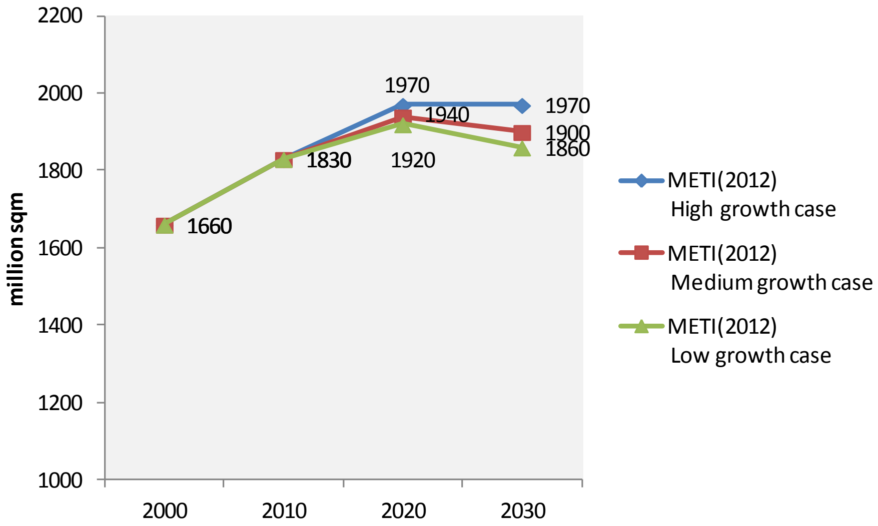
Source: METI, Basic data for draft of choice of energy mix, June 2012

Fig. 5-3 Comparison of passenger transport demand by case



Source: METI, Basic data for draft of choice of energy mix, June 2012

Fig. 5-4 Comparison of freight transport demand by case



Source: METI, Basic data for draft of choice of energy mix, June 2012

Fig. 5-5 Comparison of floor area

5.1.4 Comparison of fossil fuel prices

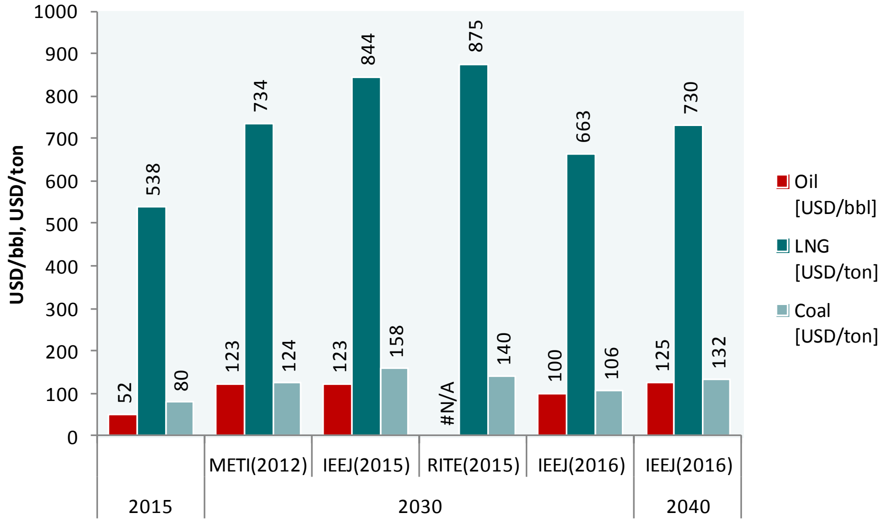
Assumption of fossil fuel price is important as it affect power generation cost. Although, in general, every analyses refer to the same source such like World Energy Outlook (WEO) of International Energy Agency (IEA), difference of publication year of reference publication create disparity in assumption.

For crude oil import price, every analysis assumes rise of price in a future. Background of this assumption is that oil demand is expected to increase globally, while production is expected to shift to higher cost oil field. Both METI(2012) and IEEJ(2015) assume crude oil import price to rise as high as USD 123 per barrel (bbl). Although a base year of real price differ, it can be regarded to think that they set almost the same assumption. Meanwhile in IEEJ(2016), it assumes lower import price of USD 100/bbl and USD 125/bbl in 2030 and 2040, respectively, reflecting the latest oil market trend.

In general, Japan's LNG import price is determined by coefficience of crude oil price. METI(2012) assume relatively lower LNG price compared to RITE(2015) and IEEJ(2015) since its base year is 2010 which is before we see LNG price surge after the East Japan Great Earthquake. However, in general, every analysis assume same level of LNG price in 2030 which is approximately USD 800/ton. On the other hand in IEEJ(2016), it expect ease of so called "Asia premium" of LNG price thanks to LNG export from North America, hence assume lower LNG price compere to others which is USD 660/ton and USD 730/ton in 2030 and 2040, respectively.

Assumption of coal import price is similar to LNG. While METI(2012), RITE(2015), and IEEJ(2015) assume about the same price level from USD 124/ton to USD 158/ton in 2030, IEEJ(2016) assume slightly lower USD 106/ton in 2030.

Meanwhile, no analysis change fossil fuel price in different scenarios.



Prices are in real term depending on different base year.
Conversion factor of natural gas; average heat value of imported LNG after 2013 = 13,141kcal/kg

Source: METI, Basic data for draft of choice of energy mix, June 2012; IEEJ, Toward choosing energy mix, January 2015; RITE, Analysis of energy mix and outlook of GHG emission projection, March 201, IEEJ Asia/World Energy Outlook 2016

Fig. 5-6 Assumptions of fossil fuel price

5.1.5 Technology availability

Regarding demand side technology, we compared the IEEJ(2016) scenario with the METI(2012) scenario.

Demand side technology

In IEEJ(2016)'s Advanced Technology Scenario, maximum CO_2 emission reduction measures are implemented with their opportunity for application and acceptability to society taken into account. It estimates that Japan will strongly implement aggressive energy conservation and decarbonisation policies contributing to securing a stable energy supply and to enhancing climate change measures while accelerating the development and introduction of innovative technologies. It assumes that national GHG emissions reduction targets and the relevant stricter environmental regulations will drive the development of technology and its associated international cooperation. As a consequence, more energy efficient equipment is then expected to be deployed in the demand side market in Japan.

In METI(2012), it assume 10% reduction of electricity consumption and 20% reduction of primary energy supply in 2030 relative to 2010. To this goal, it selects range of possible energy efficiency technologies in industry, commercial, residential, and transport sector. It also estimate deployment amount of each technologies and calculate attainable conservation amount to meet the reduction target in 2030.

The table below compares the assumptions of energy conservation measures.

Tab. 5-2 Comparison of energy conservation measures

	IEEJ	METI
Industry	Under sectoral and other approaches, best available technologies for industrial processes (steelmaking, cement, paper-pulp, etc.) will be deployed.	Higher efficiency air condition, heat pump, lighting, furnace, boiler, and electric motor will diffuse. In energy intensive industries, adoption of new manufaturing process will progress.
Transport	Clean energy vehicles (highly fuel efficient vehicles, hybrid vehicles, plug-in hybrid vehicles, electric vehicles, fuel cell vehicles) will diffuse further.	Introduction of next generation vehicles which have high energy efficiency (HEV, EV, PHEV, FCV, CDV) will be assisted. Freight transportation will shift to more efficient means.
Building& Household	Efficient electric appliances (refrigerators, TVs, etc.), highly efficient water-heating systems (heat pumps, etc.). efficient air conditioning systems and efficient lighting will diffuse further, with heat insulation enhanced.	Application of higher heat insulation, more efficient small water boiler, lighting, apprainces will progress.

Source: METI, Basic data for draft of choice of energy mix, June 2012, IEEJ Asia/World Energy Outlook 2016

Supply side technology

IEEJ(2016) estimates the available technology as follows.

Renewable energy: Wind power generation, solar PV power generation, concentrated solar power generation, biomass-fired power generation, marine power generation and bio-fuel will become more common.

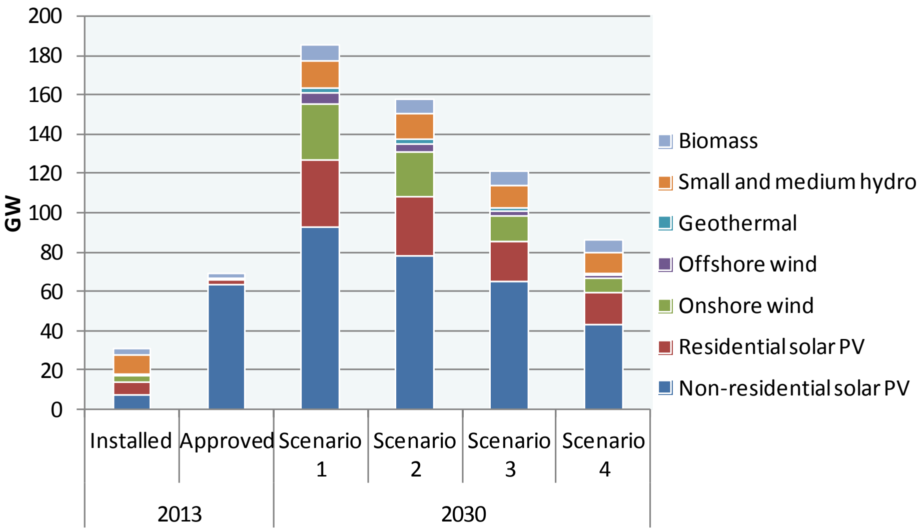
Nuclear promotion: Nuclear power plant construction will be accelerated with improved capacity factors.

Highly efficient fossil fuel-fired power generation technology:
Coal-fired power plants (USC, IGCC, and IGFC) and natural gas MACC (More Advanced Combined Cycle) plants will become more common.

5.1.6 Assumed potential for the use of renewable energy sources

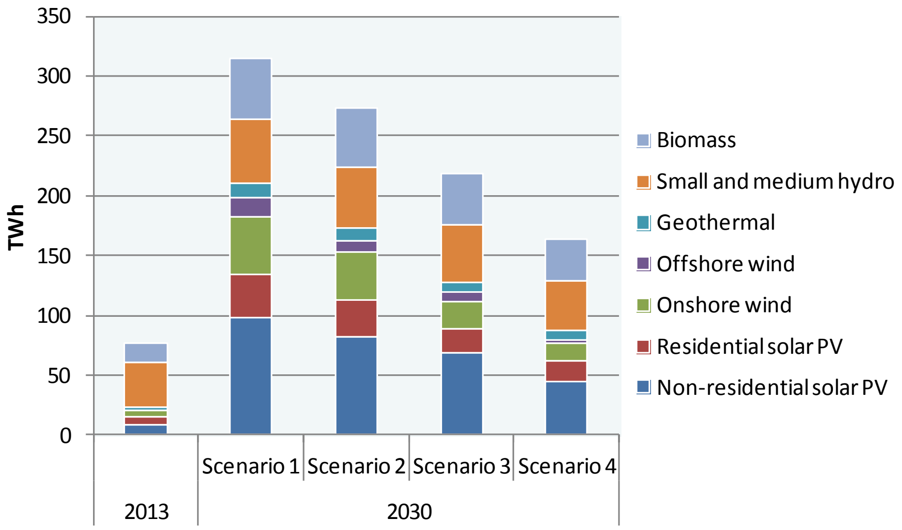
IEEJ(2016) estimates that renewables (including hydro) will increase their share of primary energy consumption in the Advanced Technology Scenario. Wind and solar photovoltaic will drive expansion of the renewable energy share. Factors which will accelerate the spread of wind, solar PV and other intermittent electricity sources include the reduction of construction and system costs. In addition, development of technologies that can enhance the flexibility of the grid (e.g. power generation prediction, output control, storage technologies, and their combination) are anticipated to play an important role in increasing the use of intermittent renewable electricity.

In IEEJ(2015), it expects the rapid diffusion of various renewable energy sources. Installed capacity for non-residential solar photovoltaic (roof top solar PV), though decelerating from its present explosive growth, may expand 6-to-13-fold from the present level. Meanwhile, installed capacity for offshore wind and geothermal are limited due to the need for technological development and long project lead times respectively.



Source: IEEJ Towards choosing energy mix

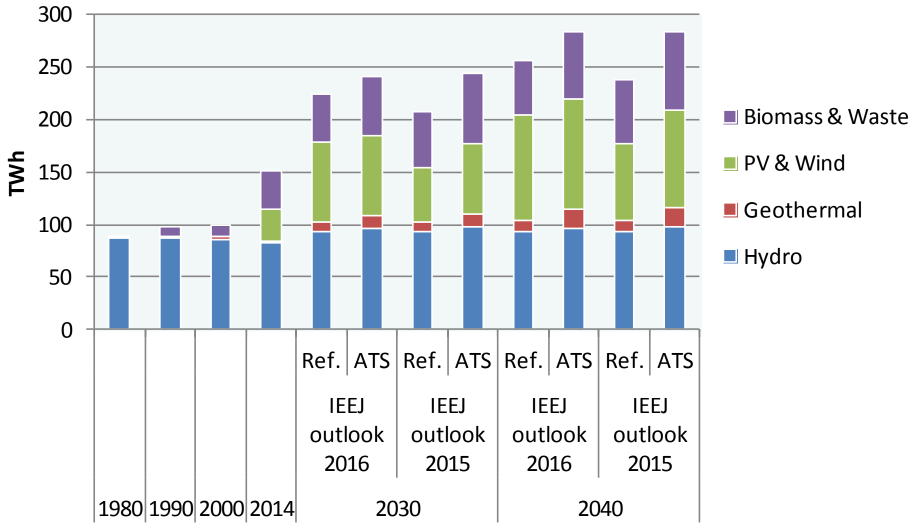
Fig. 5-7 Installed capacities of renewable sources in IEEJ(2015)



Source: IEEJ Towards choosing energy mix

Fig. 5-8 Net domestic electricity generation from renewable sources in IEEJ(2015)

IEEJ Asia/ World Outlook 2016, compared to 2015, estimates further renewable power development in both reference scenario and advances technologies scenario, especially in PV and wind power sector by reflecting recent development.



Ref. = reference scenario, ATS = advanced technology scenario

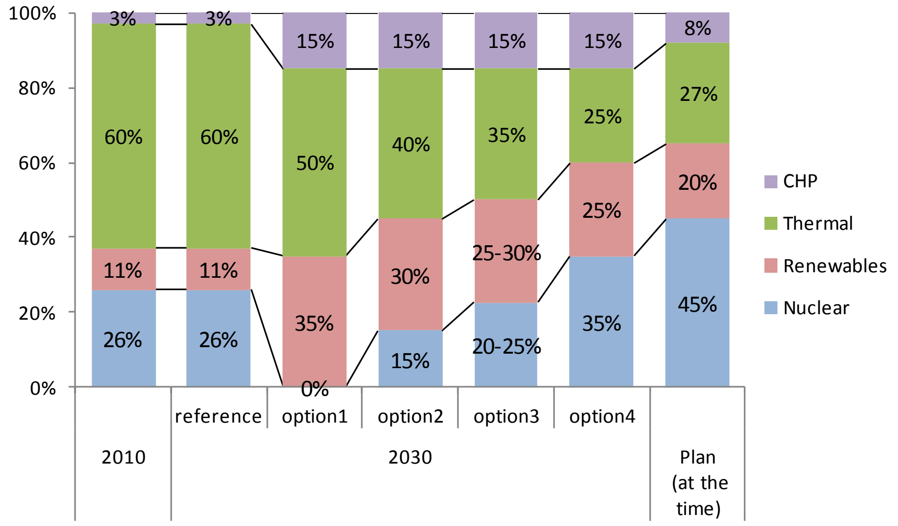
Source: IEEJ, ASIA/ WORLD ENERGY OUTLOOK 2015 & 2016

Fig. 5-9 Electricity generation by renewable energy in IEEJ

5.1.6.1 Assumption of power generation mix

Except IEEJ(2016), the analyses developed scenarios for different power generation mix. This is because of their aim to quantitatively evaluate consequent effect of different power generation mix reflecting accident of Fukushima Daiichi nuclear power plant in 2011. In another word, the analyses tried to evaluate different combination of nuclear power, renewable power, and fossil power in view of 3Es (energy security, economic efficiency, environmental sustainability). Every analysis include “no nuclear power” scenario. They developed the scenarios to analyze 1) how much nuclear power can substituted by renewable power in view of economic efficiency, and 2) how much fossil power can be utilized in view of energy security and environmental sustainability.

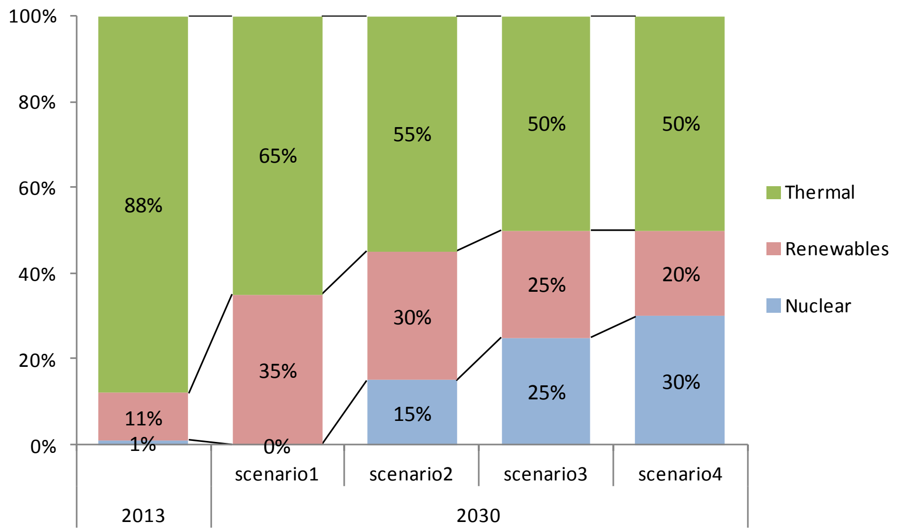
The METI(2012) prepared five scenarios including reference scenario, which assume the same power generation mix as in 2010. Contribution of nuclear power in power generation mix range from 0% to 35% that has largely reduced from 45% in the previous plan. Meanwhile renewable power, its share vary from 25% to 35% that has greatly increased from 20% in the previous plan.



Source: METI, Basic data for draft of choice of energy mix, June 2012

Fig. 5-10 Power generation mix scenario in METI(2012)

IEEJ(2015) present four power generation mix in 2030. Share of nuclear power range from 0% to 30%, and renewable power range from 20% to 35%. Developed scenarios are similar, particularly option1 an doption2 are the same, to that of METI(2012). ("CHP" is included in "Thermal")

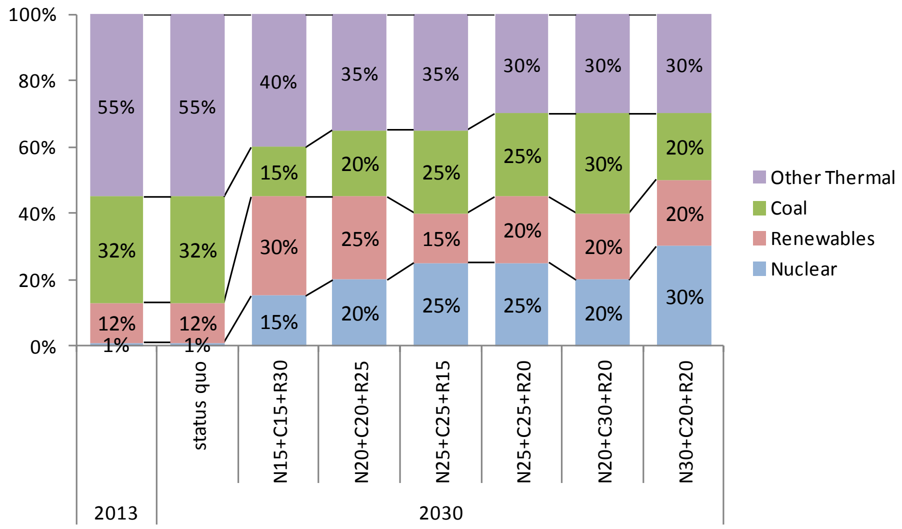


Note: Therm"Thermal" include CHP (combined heat and power)

Source: IEEJ, Toward choosing energy mix

Fig. 5-11 Power generation mix scenario in IEEJ(2015)

RITE(2015) presented six power generation mix scenarios together with Status quo as a baseline of comparison that assume the same mix as was in 2013.[14] RITE(2015) is unique in their focus of analysis, which is different from that of METI(2012) and IEEJ(2015), that evaluate effect of base load power generator. It assume contribution of nuclear power from nearly zero (1%) in Status quo to 30%. Share of renewable energy is assumed from 12% in Status quo to 30%.



N=nuclear power, C=coal power, R=renewable power

Source: RITE, Analysis of energy mix and outlook of GHG emission projection, March 2015

Fig. 5-12 Power generation mix scenario in RITE(2015)

Every subjected analysis is equally assumes maximum 30% share of renewable power. In addition, assumption of nuclear power contribution is placed at almost same range, 30% in IEEJ(2015) and RITE(2015), and slightly higher 35% in METI(2012)

5.1.6.2 Assumed potential for energy efficiency improvements

IEEJ(2016) estimates energy efficiency improvements as follows.

The building sector, which is less conscious of energy cost, has failed to result in efficiency improvement compared to the industry sector. Therefore, Japan has great potential to save energy consumption in the building sector. Since kerosene, liquefied petroleum gas (LPG), city gas, and other fuels are used for water and space heating in various different ways, fuel consumption can be greatly reduced in this field. However, electricity conservation through power and lighting savings will account for more than half of the savings across the whole of the buildings sector.

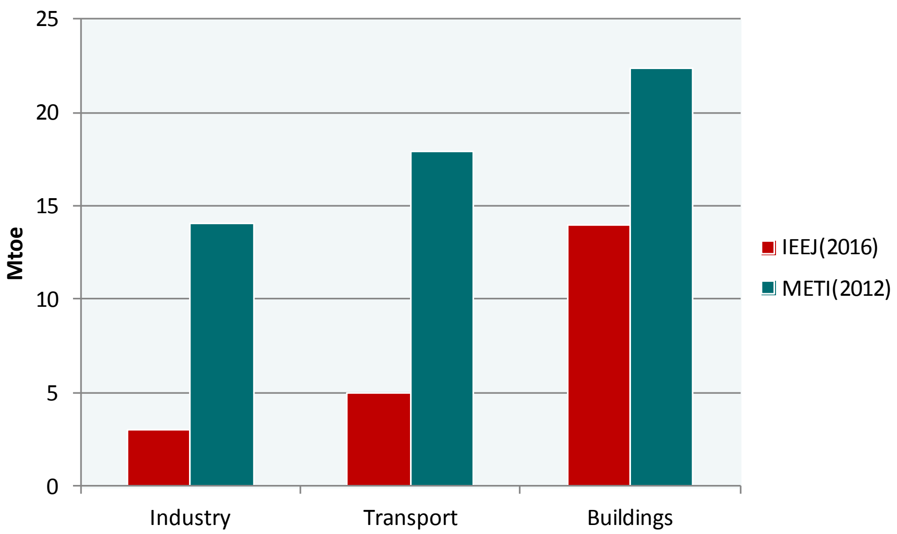
[14] Although RITE(2015) analysed many other scenarios, this study choose Status quo and major six scenarios to represent them.

In the transport sector, fuel economy and vehicle fleet mix improvements will make further progress. For vehicle fleet mix, hybrid and electric vehicles are expected to become more common.

In the industry sector, the outlook assumes the sector will deploy more currently available high-efficiency technologies for steel, chemical, pulp and paper, and other energy-intensive industries.

METI'(2012) assumes the gradual and smooth replacement to more efficient technology, equipment, and buildings when the lifetimes expire, thanks to regulatory and financial support.

In both IEEJ(2016) and METI(2012), energy conservation in the buildings sector will be the largest contributor of all the sectors. METI(2012) expect a larger potential for energy efficiency improvement, when compared to that of IEEJ(2016).



IEEJ: Difference between the Reference scenario and Advanced technology scenario
METI: Difference between with and without energy conservation measures

Source: METI, Basic data for draft of choice of energy mix, June 2012, IEEJ, Asia/ World Energy Outlook, 2016

Fig. 5-13 Energy Saving Potential in 2030

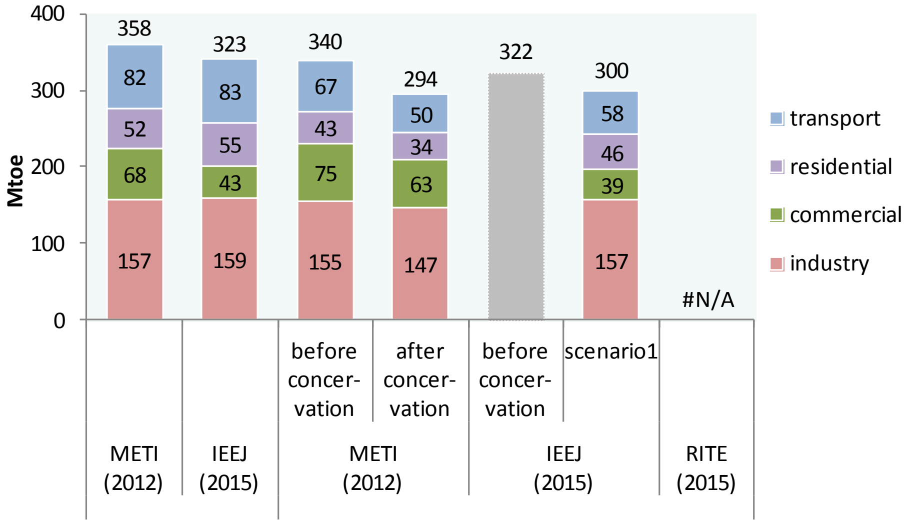
5.1.7 Comparison of key outcomes

This section will discuss key outcomes of energy supply-demand. Outcomes of economic impact will discuss in the Chapter 7.

5.1.7.1 Key Outcomes of final energy demand

Final energy demand (FED) does not show significant difference between scenarios. Although IEEJ(2015) estimate smaller demand than METI(2012) when comparing FED before conservation, both estimate similar amount when comparing FEC after conservation. However, since actual FEC in 2010 is different between two analyses, reduction rate against 2010 is 7% in IEEJ(2015) while METI(2012) estimate 18%. One should noticed that baseline of analysis, employed energy balance table, is different between METI(2012) and IEEJ(2015).

When looking at each sector, even every sector shows decreasing trend, FEC in transportation and residential sector are estimated to present relatively larger decrease of demand than industry and commercial sectors. This difference comes from their nature, besides progress of energy conservation, sector which is directly affected by economic growth and sector which is more affected by population decrease. Further, larger FED for commercial in METI(2012) compared to IEEJ(2015) can be mostly explained by difference of actual demand in 2010.

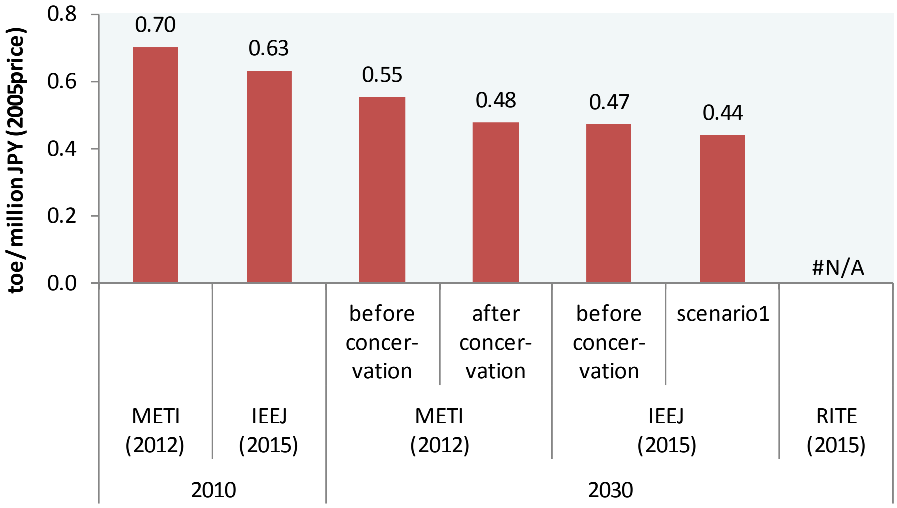


** Difference comes from use of difference energy balance table.*

Source: METI, Basic data for draft of choice of energy mix, June 2012; IEEJ, Toward choosing energy mix, January 2015

Fig. 5-14 Comparison of final energy demand

Also, one need to pay attention for difference of assumed GDP growth rate. METI(2012) assume AAGR of 0.9% (2010-2030), while IEEJ(2015) assume 1.5% (2013-2030). When comparing change of energy demand per unit GDP (energy intensity of unit GDP) to levelize this difference, METI(2012) and IEEJ(2015) assume similar improvement, 32% and 30% reduction against 2010, respectively. Therefore , different of change of absolute energy demand can explained by different assumption of economic growth rate.

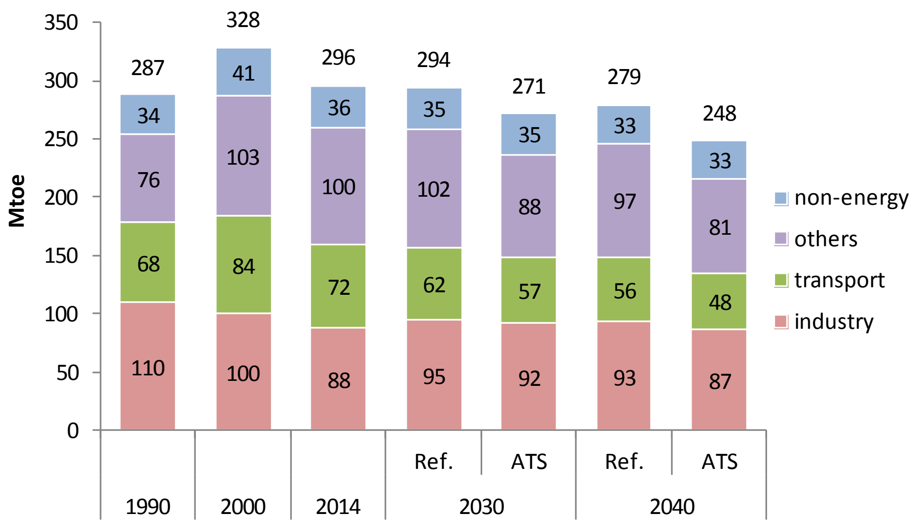


Source: METI, Basic data for draft of choice of energy mix, June 2012; IEEJ, Toward choosing energy mix, January 2015

Fig. 5-15 Comparison of final energy demand intensity per GDP

IEEJ(2016) analyze energy supply-demand based on IEA's energy balance table. Final energy demand (FED) in 2030 does not present noticeable change from 2014 in the reference scenario. Meanwhile in the advanced technology scenario (ATS), TFC decrease by 8% during the same period.

In 2040, ATS estimate 16% reduction of FED against 2014. Although energy demand in industry sector is estimated to increase compared to 2014, significant reduction is anticipated in transport sector due to smaller vehicle number and higher efficiency.



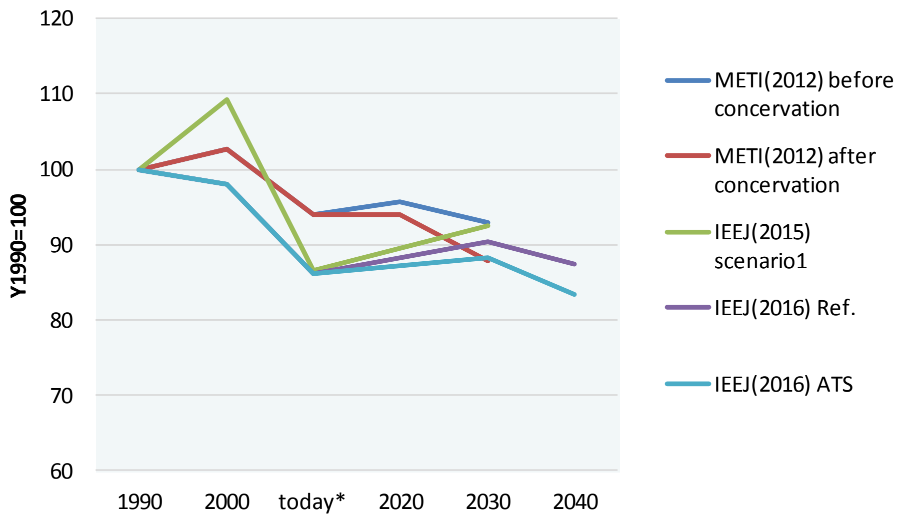
Ref. = reference scenario, ATS = advanced technology scenario

Source: IEEJ, ASIA/ WORLD ENERGY OUTLOOK 2016

Fig. 5-16 Comparison of final energy demand in IEEJ(2016)

Below compare energy consumption trend by sector (year 1990=100).

Every analyses present similar declining trend of energy consumption in industry (including non-energy use). It is supposed that they assume further efficiency improvement will offset increase of energy consumption due to moderate increase of production trend. However, in general, large amount of additional conservation might difficult as major and easy options had already implemented during 1970s. Therefore, every analysis regardless of scenario estimate approximately 10% reduction in 2030 compared to 1990, which is not significant amount.

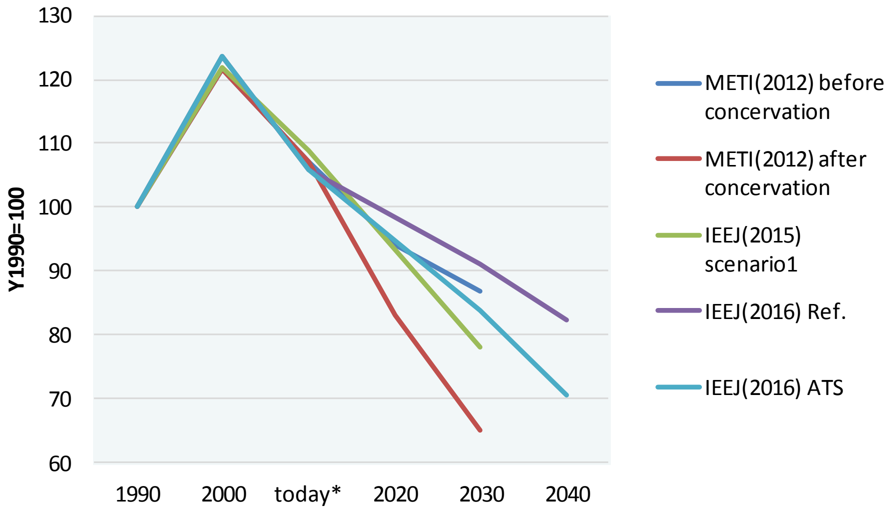


*„Today“ represents 2010 for METI(2012), 2013 for IEEJ(2015), and 2014 for IEEJ(2016).
Ref. = reference scenario, ATS = advanced technology scenario
Note: IEEJ(2016) excludes demand in agriculture.

Source: METI, Basic data for draft of choice of energy mix, June 2012; IEEJ, Toward choosing energy mix, January 2015; RITE, Analysis of energy mix and outlook of GHG emission projection, March 2015, IEEJ, ASIA/ WORLD ENERGY OUTLOOK 2016

Fig. 5-17 Comparison of industry energy demand (incl. non-energy use)

Transport sector is estimated to consume less energy after peaked in around 2000. In road transportation, largest part of transport sector, vehicle number has already started to decrease reflecting declining population. In addition, efficiency of vehicle is rapidly improving thanks to policy such like the top runner program. Every analysis expects continue such trend toward future, hence estimate significant decrease of energy consumption in this sector.



*„Today" represents 2010 for METI(2012), 2013 for IEEJ(2015), and 2014 for IEEJ(2016).

Ref. = reference scenario, ATS = advanced technology scenario

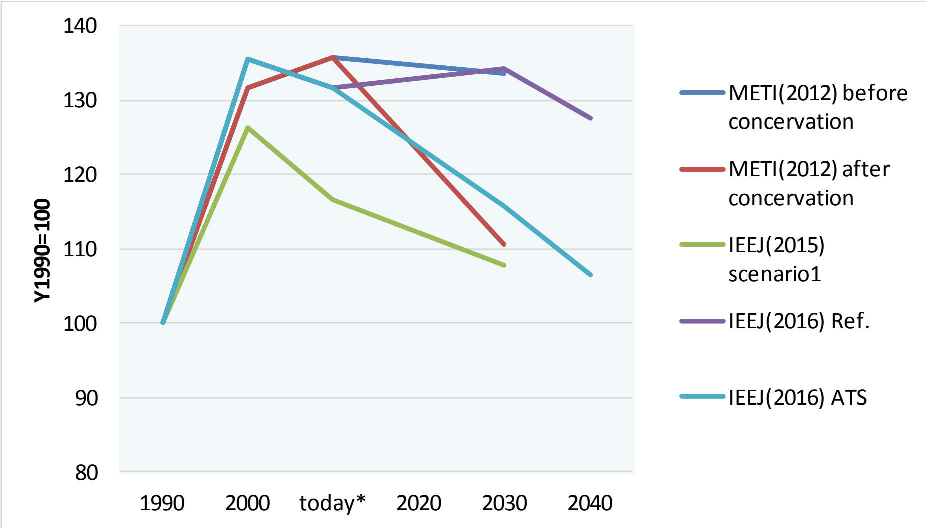
Source: METI, Basic data for draft of choice of energy mix, June 2012; IEEJ, Toward choosing energy mix, January 2015; RITE, Analysis of energy mix and outlook of GHG emission projection, March 2015, IEEJ, ASIA/ WORLD ENERGY OUTLOOK 2016

Fig. 5-18 Comparison of transport energy demand

Building is delayed in energy efficiency improvement compared to other sectors. However, the sector is estimated to reduce energy consumption after around 2000s to 2010s. As demonstrated in energy efficiency scenario of METI(2012) and IEEJ(2016), large potential of energy conservation is anticipated in the sector. Energy consumption in household is expected to decrease due to declining population and efficiency improvement of appliances. Meanwhile in commercial sector, reduction of energy consumption is estimated to become smaller because of trend to shift to service economy.

Electricity demand is most important assumption for every analyses except IEEJ(2016) since they developed scenarios for different power generation mix.

In METI(2012), although it employs four different economic models, common value of electricity demand is shared among them. Electricity demand (final demand plus transmission and distribution loss) for economic impact analysis in 2030 does not include additional efficiency improvement, which resulted to small increase of electricity demand from 1,100 TWh in 2010 to 1,200 TWh in 2030.



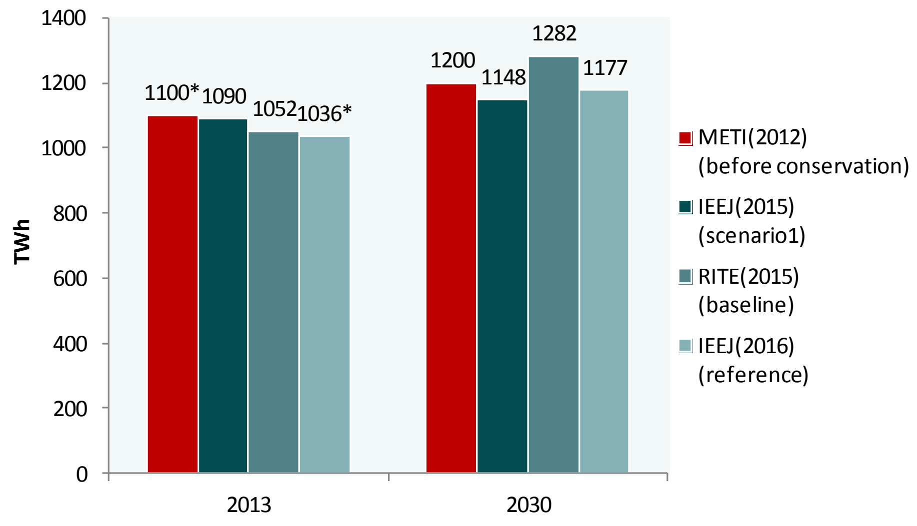
** „Today“ represents 2010 for METI(2012), 2013 for IEEJ(2015), and 2014 for IEEJ(2016).*

Ref. = reference scenario, ATS = advanced technology scenario

Note: IEEJ(2016) includes demand in agriculture.

Source: METI, Basic data for draft of choice of energy mix, June 2012; IEEJ, Toward choosing energy mix, January 2015; RITE, Analysis of energy mix and outlook of GHG emission projection, March 2015, IEEJ, ASIA/ WORLD ENERGY OUTLOOK 2016

Fig. 5-19 Comparison of building energy demand



**METI(2012) presents 2010 data and IEEJ(2016) presents 2014 data.*

Note; Electricity generation = Final electricity demand + transmission losses, etc.

Source: METI, Basic data for draft of choice of energy mix, June 2012; IEEJ, Toward choosing energy mix, January 2015; RITE, Analysis of energy mix and outlook of GHG emission projection, March 2015, IEEJ, ASIA/ WORLD ENERGY OUTLOOK 2016

Fig. 5-20 Comparison of electricity demand

IEEJ (2015) conducted scenario analysis based on electricity demand including additional efficiency improvement, which is smaller than that of METI(2012).

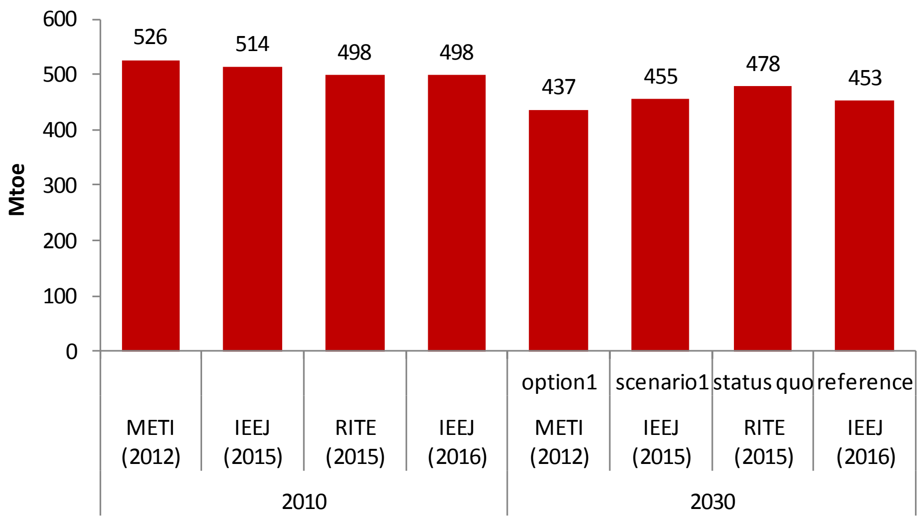
Meanwhile in RITE(2015), electricity demand is estimated in DEN21+ model to utilize some assumptions such like sectoral production activity and service demand which are calculate by assuming GDP. The highest assumption of GDP among analyses results in largest amount of electricity demand.

Reference scenario of IEEJ(2016) estimate slightly lower than 1,200TWh of electricity demand by reflecting historical trend of technological advancement and policy direction.

As a whole, every analysis present the same level of electricity demand in 2030, around 1,200 TWh.

5.1.7.2 Key Outcomes of primary energy supply

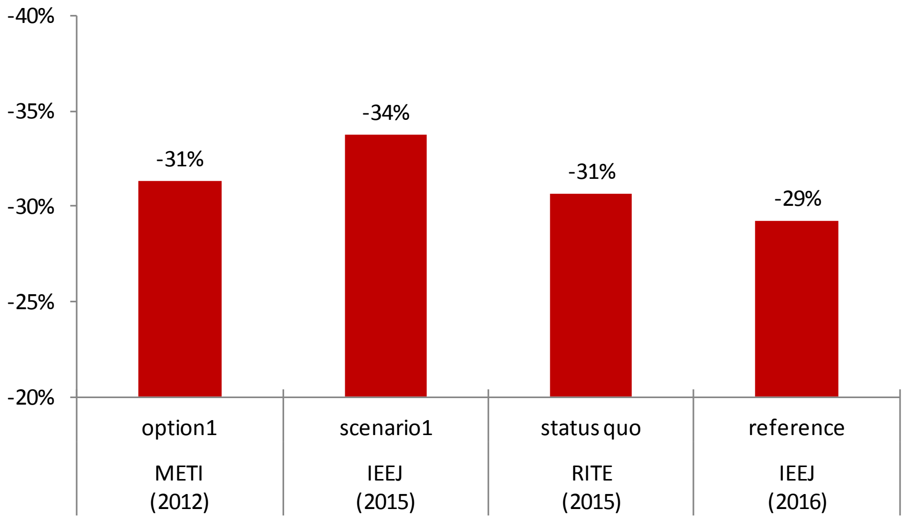
One needs to understand difference of energy balance table which is a basis of calculation when comparing primary energy supply (PES). RITE(2015) and IEEJ(2016) hire IEA's energy balance table, while METI(2012) and (IEEJ2015) utilize their own energy balance table. For example, conversion factor of hydroelectric power, wind, and solar PV to primary energy supply is 40% (average thermal efficiency of fossil power generation) in METI(2012) and IEEJ(2015). On the other hand in IEA's balance table, its conversion factor is 100%. Therefore, difference of PES becomes wider when share of renewable power generation become larger.



Source: METI, Basic data for draft of choice of energy mix, June 2012; IEEJ, Toward choosing energy mix, January 2015; RITE, Analysis of energy mix and outlook of GHG emission projection, March 2015, IEEJ, ASIA/ WORLD ENERGY OUTLOOK 2016

Fig. 5-21 Comparison of primary energy supply

Further, one shall remind of difference in assumed GDP. Although absolute value differ, when comparing in terms of primary energy intensity of GDP (USD/toe), every analysis estimate 30% reduction in 2030 compared to 2010 which does not show significant difference.



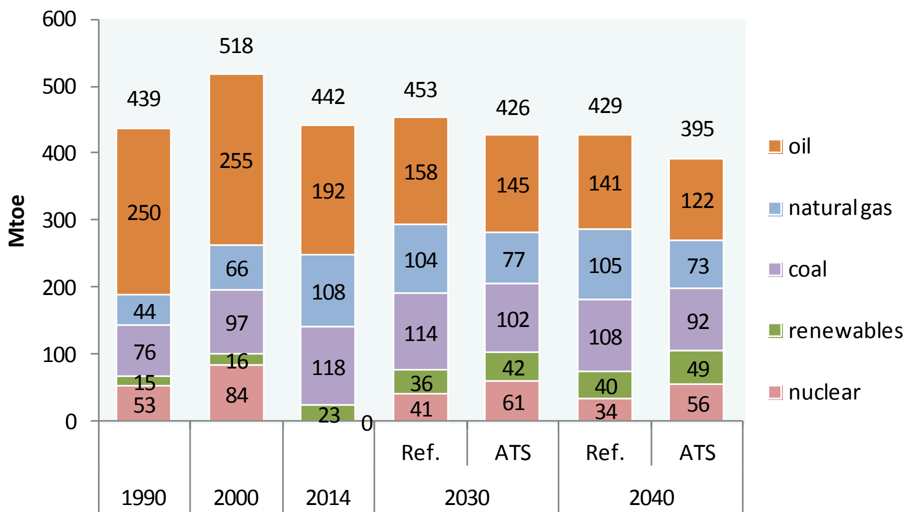
Source: METI, Basic data for draft of choice of energy mix, June 2012; IEEJ, Toward choosing energy mix, January 2015; RITE, Analysis of energy mix and outlook of GHG emission projection, March 2015, IEEJ, ASIA/ WORLD ENERGY OUTLOOK 2016

Fig. 5-22 Comparison of change rates of primary energy supply per GDP (2010-2030)

However, structure of PES differ largely by scenarios. As explained before, every analyses except IEEJ(2016) developed their scenarios for different power generation mix. Therefore, structure of power generation is a assumption rather than calculate result, hence not appropriate to compare them in this section.

When looking at outlook drawn in IEEJ(2016), fossil fuel share large part of PES mix even in 2040, 83% in reference scenario and 73% in advanced technology scenario (ATS). Nuclear estimated to play some role, 8% in reference scenario and 14% in ATS. Meanwhile, contribution of renewable energy estimated to remain at low, 12%, even in ATS. [15]

[15] Conversion ratio of renewable energy to primary energy is 100%.



Ref. = reference, ATS = advanced technology scenario

Source: IEEJ, ASIA/ WORLD ENERGY OUTLOOK 2016

Fig. 5-23 Comparison of primary energy supply in IEEJ(2016)

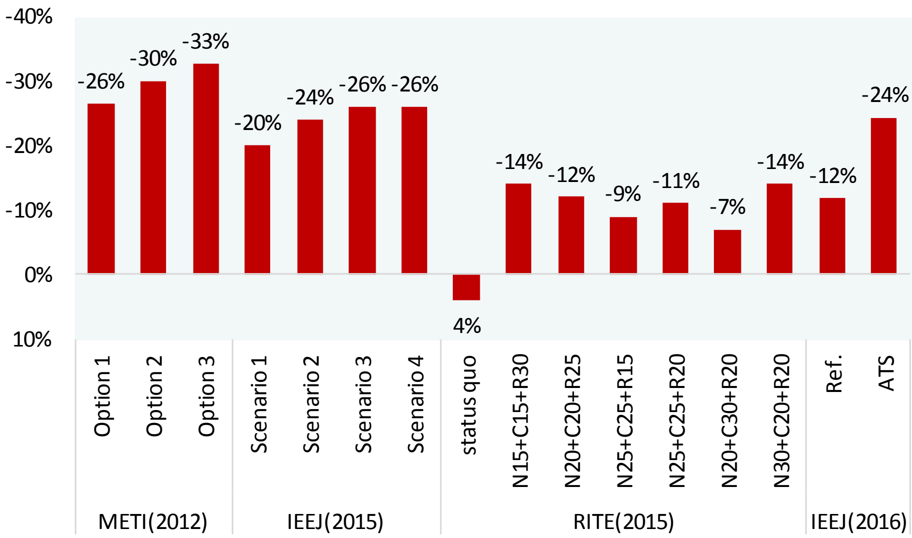
5.1.7.3 Comparison of Energy-related CO2 emissions

CO2 emission from fossil fuel burning differ by structure of primary energy supply, hence structure of power generation. Every analysis regard amount of CO2 emission as important evaluation axis.

In 2015, Japan committed to reduce energy-related CO2 emissions by 25% until FY2030 compared to FY2013, which can be translated to reduce 24% compare to FY2005. The scenarios than can meet this target are all the scenarios in METI(2012), scenario 2 - 4 in IEEJ(2015), and advanced technology scenario (ATS) in IEEJ(2016). All the scenarios in METI(2012) assume more than 35% of non-fossil power generation in power generation mix. Similarly, scenario 2 - 4 in IEEJ(2015) assume large contribution (45%) of non-fossil power generation. Even scenario 1 in IEEJ(2015) assume 35% share of non-fossil power generation source, which is same as that of option 1 of METI(2012), assumed higher economic growth generate larger energy demand to emit more CO2. ATS in IEEJ(2016) assume 45% contribution of non-fossil power generation.

CO2 emission in all the scenarios in RITE(2015) are not reaching to national target. Even in a scenario which assume highest share of non-fossil power generation (30% of nuclear plus 20% of renewable), reduction against 2005 is 14%.

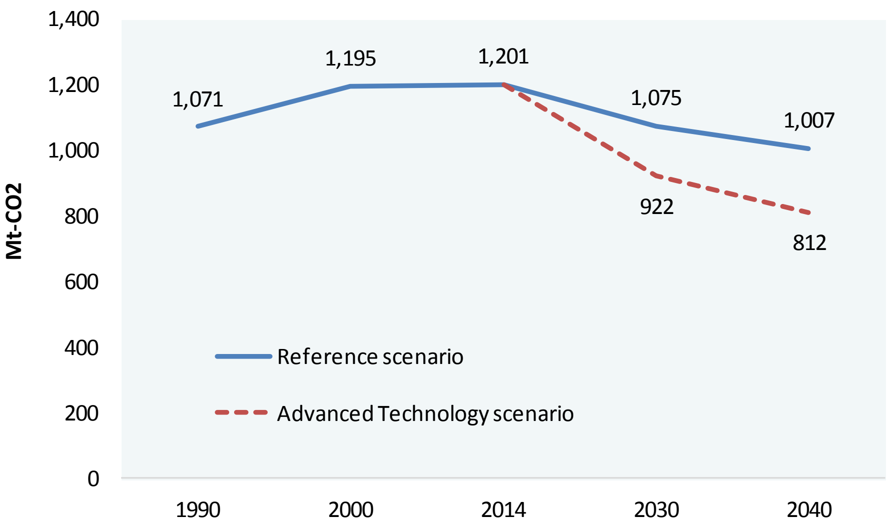
In RITE(2015), type and amount of energy used other than for electricity is estimated by considering carbon price, USD 37/ton-CO2 in the case of IEA WEO 2014 new policy scenario equivalent. Even assuming higher carbon price, USD 100/ton-CO2 : IEA WEO2014 450 scenario equivalent, RITE estimate that CO2 emission can only reduced by 17%. This result indicate that additional marginal CO2 abatement cost (MAC) is very high in Japan, because Japan has already implemented lower cost mitigation measures, hence cannot meet with government's goal even apply USD 100/ton-CO2 of burden. Meanwhile in METI(2012), MAC, equal carbon price, is calculated by model, and four different model similarly present more than USD 100/ton-CO2 (exchange rate : USD 1 = JPY 100) of MAC (please refer to Chapter 7).



N= nuclear power, C=coal power, R=renewable power
Ref. = reference, ATS = advanced technology scenario

Source: METI, Basic data for draft of choice of energy mix, June 2012; IEEJ, Toward choosing energy mix, January 2015; RITE, Analysis of energy mix and outlook of GHG emission projection, March 2015, IEEJ, ASIA/ WORLD ENERGY OUTLOOK 2016

Fig. 5-24 Comparison of change in energy-related CO2 emissions compared to 2005



Source: IEEJ, ASIA/ WORLD ENERGY OUTLOOK 2016

Fig. 5-25 Comparison of energy-related CO_2 emissions in IEEJ(2016)

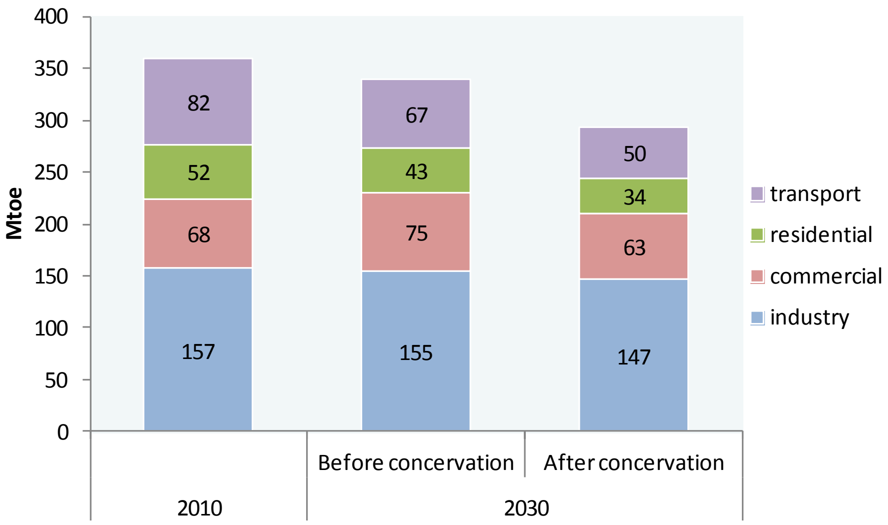
The Reference scenario in IEEJ(2016) is based on the policy that are currently implemented and envisaged to be implemented in a foreseeable future. While the advanced technologies scenario (ATS) assumes maximum efforts to reduce CO_2 emission to an extent of possible opportunity and of social acceptance.

Every scenario presents large drop of CO2 emission from present because of increasing use of cleaner energy and efficiency improvement than today. In the ATS, CO2 emission can reduced by 12% in 2040 compared to reference scenario, which is equivalent to 33% reduction compared to 2005.

5.1.7.4 Key Outcomes from METI analysis

METI(2012) applied four CGE models of four organizations. As they use same assumption to their possible extent, differences of calculate result caused by models can clearly observed. However, since their primary objective of analysis put on economic impact, calculated result of energy system does not presented in the report.

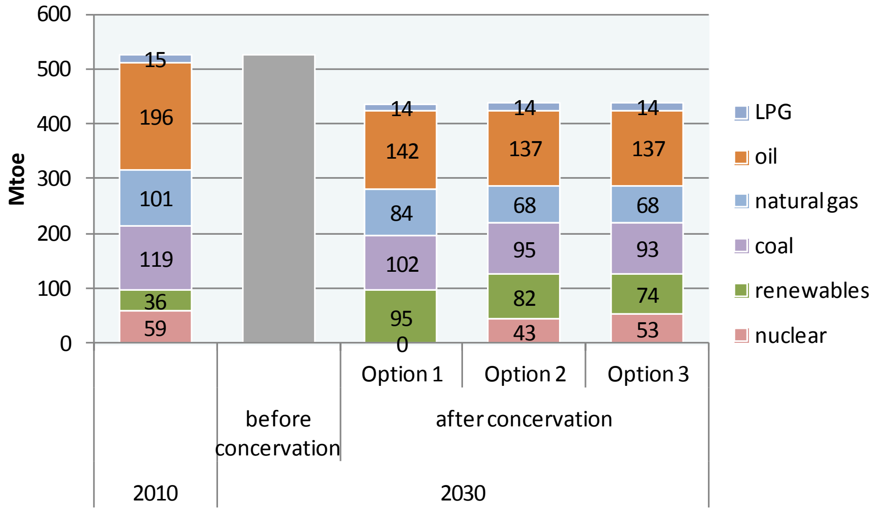
METI provided common assumption for energy supply-demand structure. Estimated final energy demand (FED) is gradually decreasing even without implementing additional efficiency measures because of population decrease and past effort of efficiency improvement. They assume approximately 20% reduction of FED by adopting stronger efficiency measures. Scenario analysis of economic impact has made on this basis.



Source: METI, Basic data for draft of choice of energy mix, June 2012

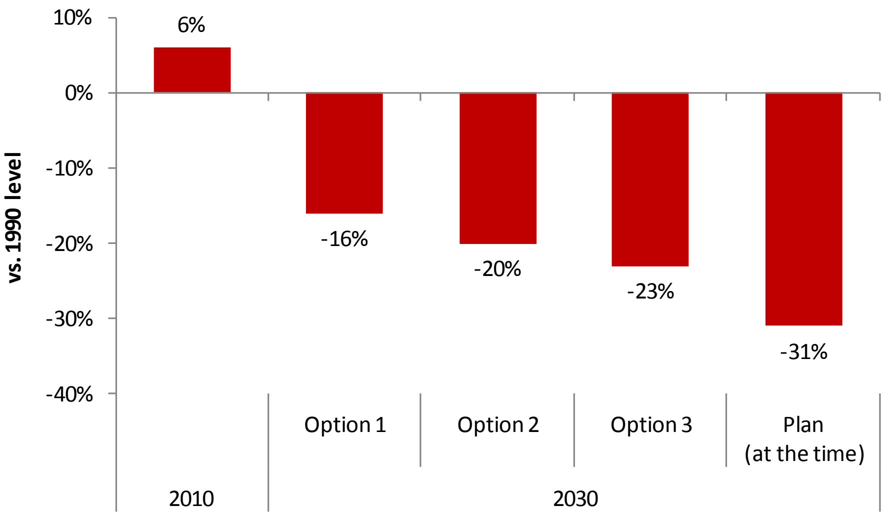
Fig. 5-26 Comparison of final energy demand in METI(2012)

Primary energy supply (PES), sum of FEC, fuel for power generation, and so on, will reduced around 20% due to efficiency improvement. Structure of PES widely differ by different power generation mix scenario. It also creates difference in energy related CO2 emission from 16% to 23% depending on scenario.



Source: METI, Basic data for draft of choice of energy mix, June 2012

Fig. 5-27 Comparison of primary energy supply in METI(2012)

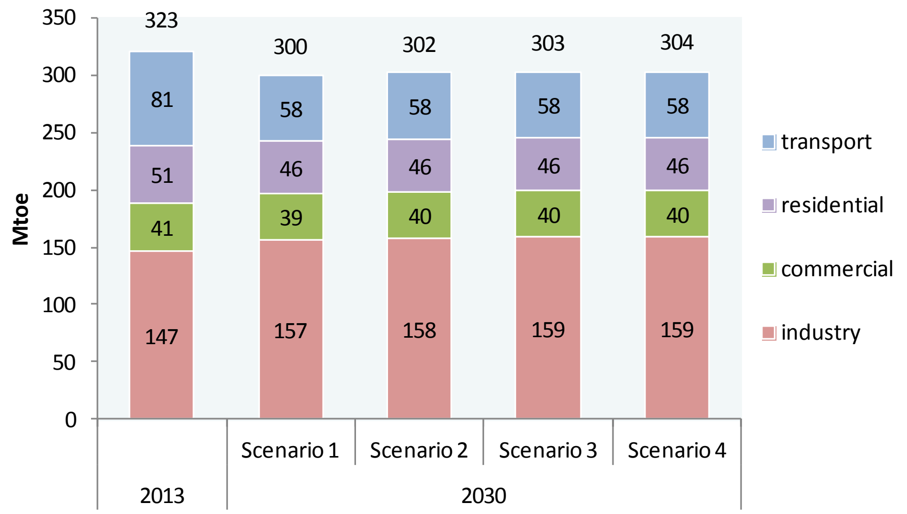


Source: METI, Basic data for draft of choice of energy mix, June 2012

Fig. 5-28 Comparison of energy-related CO2 emission reduction in METI(2012)

5.1.7.5 Key Outcomes from IEEJ analysis

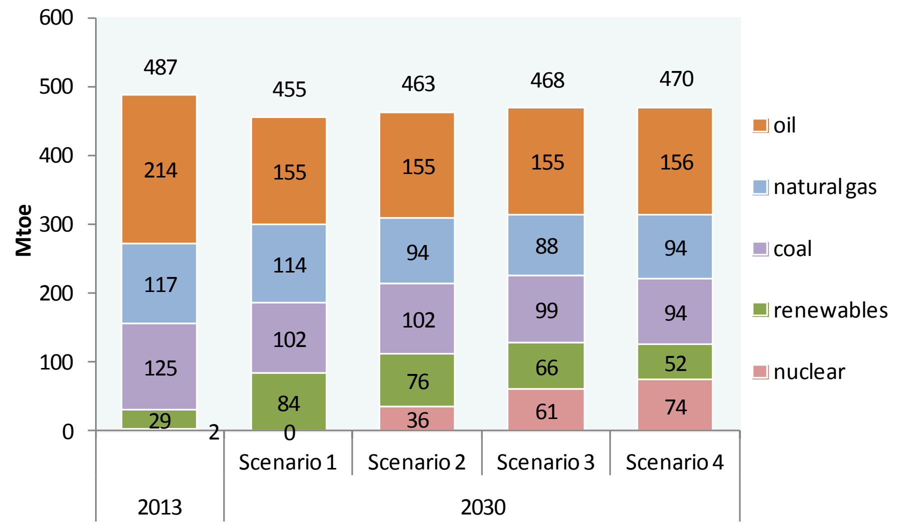
Model in IEEJ(2015) consistently computed economic structure and energy supply-demand. Difference of power generation mix will affect energy demand by function of power generating cost, commodity price, and economic activity. Scenario 1 estimates smallest FED because of higher electricity cost due to zero nuclear and larger contribution of renewable power. Meanwhile, scenario 4, where assuming highest share of nuclear, resulted in largest energy demand.



Source: IEEJ Toward choosing energy mix

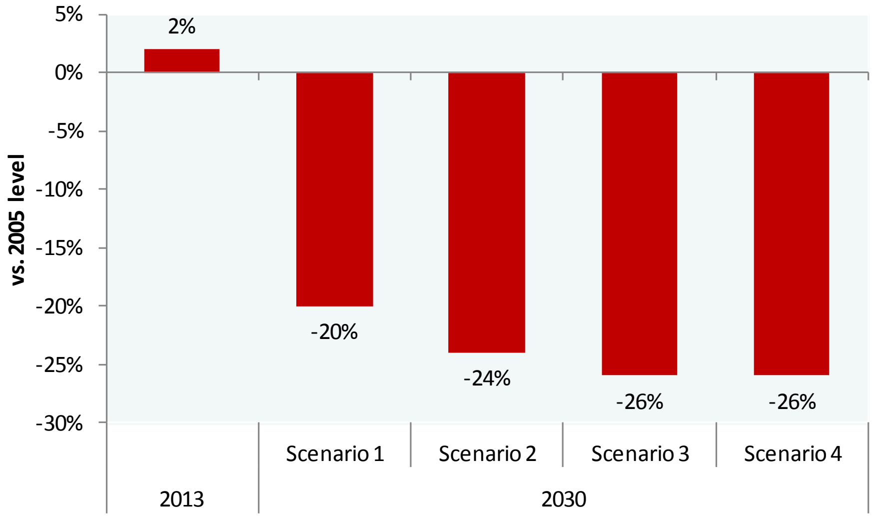
Fig. 5-29 Comparison of final energy demand in IEEJ(2015)

Difference of amount of primary energy supply (PES) among scenarios can be explained by amount of final energy demand. Meanwhile, structure of PES largely affected by power generation mix. It creates differences in reduction amount of energy related CO_2 emission which is ranging from 20% to 26% reduction from 2005 depending on scenarios. IEEJ also looked at status of energy security estimating energy self sufficiency from 19% to 28% depending on scenarios. Both CO_2 emission reduction and energy self sufficiency become highest in scenario 3 and 4 where assume lowest share of fossil power generation.



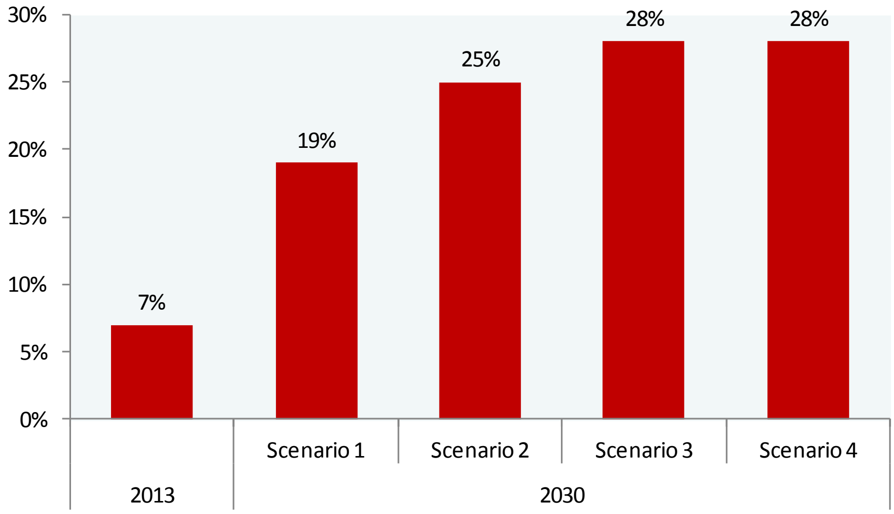
Source: IEEJ Toward choosing energy mix

Fig. 5-30 Comparison of primary energy supply in IEEJ(2015)



Source: IEEJ Toward choosing energy mix

Fig. 5-31 Comparison of energy-related CO2 emissions in IEEJ(2015)

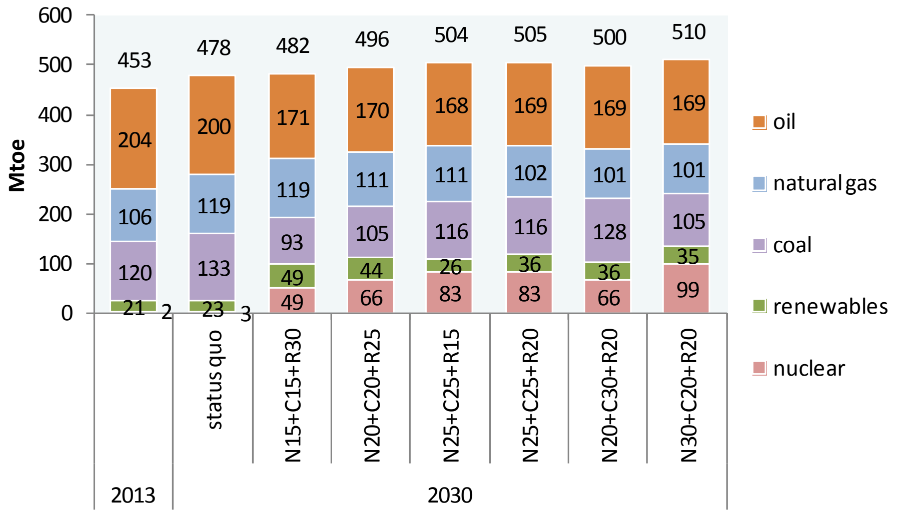


Source: IEEJ Toward choosing energy mix

Fig. 5-32 Comparison of energy self-sufficiency ratio in IEEJ(2015)

5.1.7.6 Key Outcomes from RITE analysis

RITE(2015) analyze economic impact of different power generation mix scenario. Contribution of low cost base load power, i.e. nuclear, coal, hydroelectric, and geothermal power, will affect electricity cost, hence energy demand. When assuming larger share of low cost, i.e. base load, power, low electricity cost will push up economy, hence energy demand is estimated to increase.

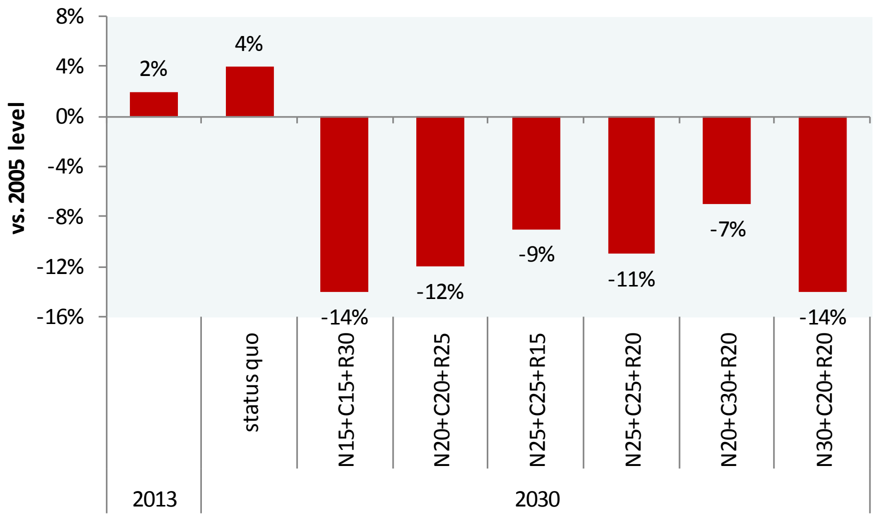


N=nuclear power, C=coal power, R=renewable power

Source: RITE, Analysis of energy mix and outlook of GHG emission projection, March 2015

Fig. 5-33 Comparison of primary energy supply in RITE(2015)

Reduction of energy related CO2 emission differs from 7% to 14% (compare to 2005) depending on scenarios. Reduction of CO2 emission become larger when assume higher share of non-fossil power generation. However, part of CO2 emission reduction effect will be offset by electricity demand increase when assume increase of low cost base load power such like nuclear power.



N = nuclear power, C = coal power, R = renewable power

Source: RITE, Analysis of energy mix and outlook of GHG emission projection, March 2015

Fig. 5-34 Comparison of change rates of energy-related CO2 emissions (2005-2030) in RITE(2015)

Box 3: Pathways to Deep Decarbonization in Japan

Although the study “Pathways to Deep Decarbonization in Japan” (Kainuma et al. 2015) analyze log-term scenarios up until 2050, we didn’t employ the study as a subject of this comparative analysis because it doesn’t present sufficient data set. However, since it indicate interesting result, we will overview the Pathways to Deep Decarbonization in Japan as a reference.

The study was jointly conducted by the national institute for Environmental Studies (NIES), Kyoto University, and Mizuho Information & Research Institute to submit the report in September 2015.

It basically applied a back-casting approach which is targeting to reduce GHG emissions by 80% by 2050 compared to 1990 level. The basic methodology is as follows: It employed the AIM (Asian Pacific Integrated Model)/Enduce model, which is a dynamic recursive, technology selection model, for evaluating energy supply-demand and resulting GHG emission. An AIM/CGE model, which is a general equilibrium model, was applied to evaluate the economic impact.

To analyze effects by different technology choices, three different deep-decarbonization scenarios were developed to achieve the 80% reduction of GHG emissions by 2050 compared to 1990 levels.

i) The Mixed Scenario achieves deep decarbonization under continued economic growth through strong action on the three pillars of decarbonization. It assumes that existing nuclear power pant will be decommissioned after 40 years operation and no capacity will be added, which means that contribution of nuclear power will become very small in 2050.

ii) The No Nuclear Scenario assesses the robustness of the decarbonization process under a complete phase-out of nuclear. It assumes no nuclear fleet will be operated after 2014.

iii) The Limited CCS Scenario is developed to alternate the above two scenario because those include the uncertainties in development and deployment of CCS technology. It assumes only half the amount of CCS capacity considered in the Mixed Scenario.

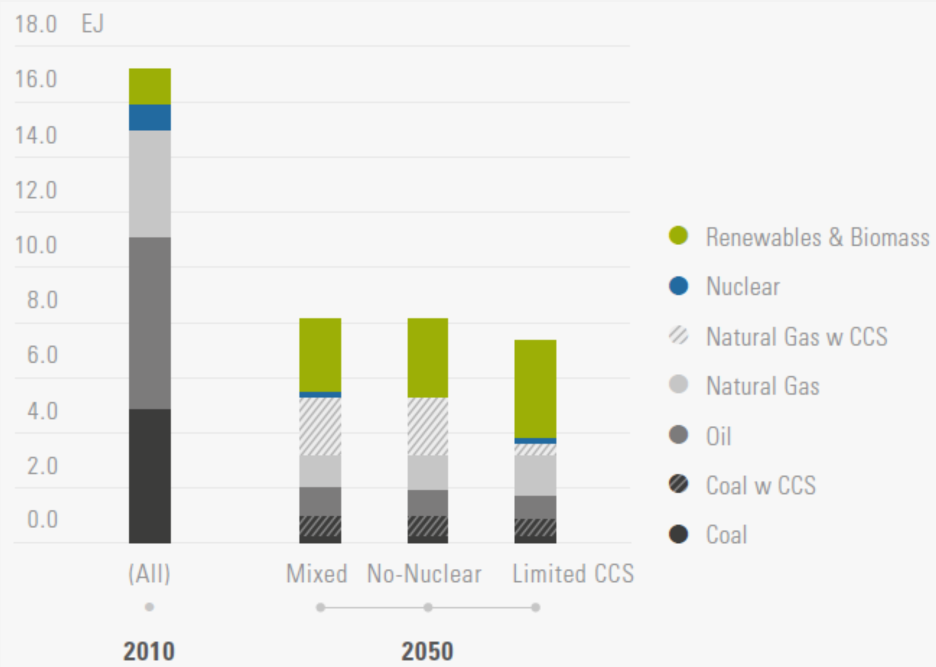
Total final energy demand in 2050 is calculated to decrease by more than 50% compared to 2010 level. The differences in final demand are negligible between the three scenarios as all scenarios commonly assume almost full introduction of possible energy efficiency measures.

In terms of primary energy supply, it decreases by approximately 50 to 60% depending on the scenarios. The composition of primary energy differs by scenarios. Although no major differences can be observed in the structure of the year 2050 between the Mix and the No Nuclear scenarios, the transitional state is different and it makes a great impact for the economy. The Limited CCS scenario results in a higher share of renewable energy to offset less application of CCS.

Energy-related CO_2 emissions in all scenarios are estimated to achieve 84% reduction in 2050, which exceeds 80% of reduction target in 2050 for GHG emissions.

Average investment from 2025 to 2030 reach four trillion yen annually or from 0.5% to 0.7% of GDP in 2030 which cannot be offset by energy saving effects. However, between 2045 and 2050, six trillion yen of annual investment cost will be mostly compensated by energy savings. Investment amounts become significant in the Limited CCS scenario since it requires larger penetration of renewable energy.

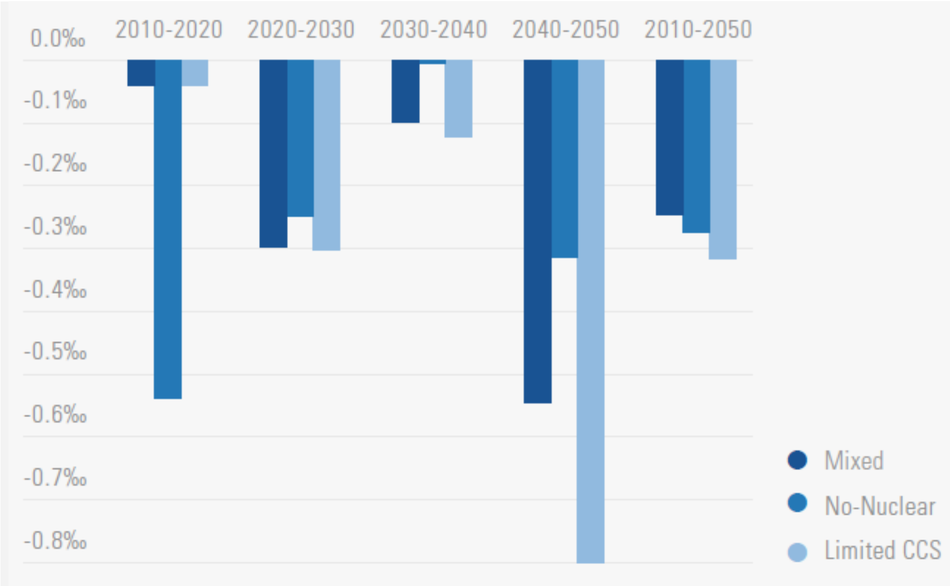
Fossil fuel import cost will be reduced by 56% to 65% depending on the scenarios. The largest reduction will be achieved in the Limited CCS Scenario as it assumes a more ambitious increase of renewable energy and decrease of fossil fuels.



Source: Pathways to deep decarbonisation in Japan (2015)

Fig. 5-35 Primary energy supply

As a whole, in terms of GDP, all the deep decarbonisation scenarios result in negative impacts compared to the reference scenario that assumes 0.95% of average annual growth rate. When comparing changes by decade and by scenarios, it presents interesting result. Firstly, the Mixed Scenario, which implies use of nuclear, gives the smallest impact on GDP during the period. Secondly, the No Nuclear Scenario will give the significant negative impact on economy during the first decade. Although the detail has not been presented in the report, it can be conceived that larger fossil fuel import requirements to substitute nuclear power will greatly dampen Japan’s economy.



Source: Pathway to deep decarbonisation in Japan (2015)

Fig. 5-36 GDP change by scenario compare to the reference scenario

5.2 Germany

In this section, the five energy transition scenarios for Germany are analysed and systematically compared regarding the key assumptions on which the scenarios are based (Section 5.2.1) and the resulting outcomes for the energy system developments (Section 5.2.2).

5.2.1 Comparison of key assumptions

Comparison of key socioeconomic assumptions

To determine the effects of different policy scenarios, a reference case has to be established. It is based on a set of socio-economic assumptions regarding the development of population, households, employment structure, fossil fuel prices, CO_2 prices, GDP, etc. and serves as a baseline case. These assumptions are exogenous and neither directly nor indirectly influenced by the energy efficiency or renewable energy targets of the scenarios. By modifying parameters according to the policy scenario of interest, changes in the model outcomes can be observed. Results of policy scenarios cannot easily be compared when they use different reference scenarios and thus different underlying socio-economic assumptions as well as different assumptions on future energy system developments. This is the case for the scenarios analysed in this study (Table 5-3). [16]

Tab. 5-3 Target and reference scenarios in different studies

Studies	Referring studies17	Target scenario	Reference scenario
KS80 BMUB 2015		Includes investments (renewable energies and energy efficiency) to reach a reduction in GHG emissions of 80% compared to the level of 1990.	Current-state of energy and climate policy (includes policy measures until October 2012)
ZS BMWi 2014		Additional investments in climate protection measures (renewable energies and energy efficiency)	Most probable development of the energy sector (authors' perspective)
EWS UBA 2013a		Additional investments in climate protection measures (renewable energies and energy efficiency)	Current-state of energy and climate policy (includes policy measures until July 2011)
BMUB 2012	BMU 2011	Additional investments in the development of renewable energies	No development of renewable energies after the year 1995
	Ifeu et al. 2011	Additional investments in the development of energy efficiency	Not fully developed/partly based on the energy scenarios of the Energy Concept 2010

Therefore, the differences in reference and target scenarios across the selected studies need to be considered, when results are compared. For example, in the

[16] Because of a limited number of studies available which also contain an analysis of the macroeconomic effects of the energy transformation based on comparable reference scenarios, there was no alternative to studies and scenarios selected for this analysis. Scenario KS 95 is not included in the macroeconomic analysis, as this scenario lacks the assessment of macroeconomic effects.

[17] Studies in which scenarios were originally developed.

BMU (2011) study, which is the reference scenario for the renewable energy development scenario of BMUB (2012), the reference scenario assumes no development of renewable energies after the year 1995 ("Zero-scenario"). Results therefore cannot be compared well with studies that are based on a current-state reference scenario or the expected future development of the energy sector in absence of additional energy policy measures.

The KS 95 scenario cannot be included in the macro-economic analysis as it did not measure macro-economic effects.

Not only energy system developments differ from one reference scenario to another, but so do key socioeconomic assumptions, although not by much in many cases. All studies assume a declining trend in the development of the population in Germany. Regarding the number of households, there is no uniform trend. BMWi (2014) and BMUB (2015) assume an increase in the number of households until 2030/2040. Afterwards, the number falls again, to 40.2 million in 2050 in both studies. BMU (2011) assumes a continuous decline in the number of households until 2050, whereas Ifeu et al. (2011) expect a modest rise from 2020 to 2030.

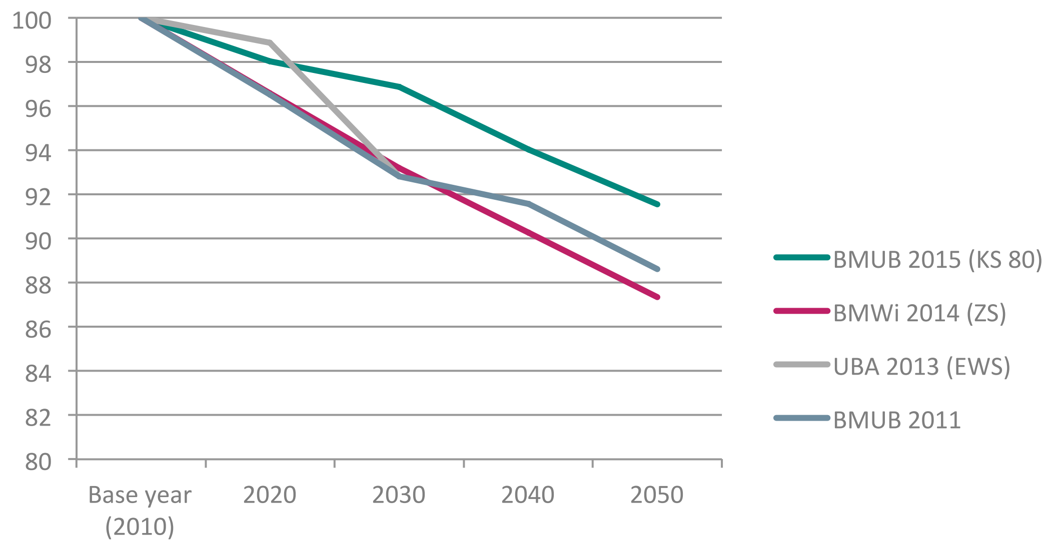
Tab. 5-4 Assumptions on population and household development

		Population (in million)				Households (in million)			
Studies		2020	2030	2040	2050	2020	2030	2040	2050
KS 80 BMUB 2015		78.8	77.8	76.2	74	40.3	40.7	41.1	40.2
ZS BMWi 2014		79.4	78.2	76.1	73.1	40.7	41.4	41.3	40.2
EWS UBA 2013a		79.9	77.4	NA	NA	40.4	40.1	NA	NA
BMUB 2012	BMU 2011	81.4	79.3	77.3	75.1	39.9	39.7	39.2	38.5
	Ifeu et al. 2011	80.5	79.1	NA	NA	40.7	41	NA	NA

Total employment is expected to decline continuously over the next decades, as the population is expected to decrease. All sectors lose employment or are at least stagnating across studies. The only exception is the development of the service sector from 2020 to 2030 in BMUB (2015). The study assumes that the number of people employed rises slightly from 29.7 million to 30 million.

Tab. 5-5 Assumptions on employed people (in million)

	KS 80 BMUB 2015		ZS BMWi 2014		EWS UBA 2013a	BMUB 2012	
						BMU 2011	
	2020/ 2030	2040/ 2050	2020/ 2030	2040/ 2050	2020/ 2030	2020/ 2030	2040/ 2050
Total employment	39.8/ 39.3	38.2/ 37.2	39.7/ 38.3	37.1/ 35.9	39.8/ 37.4	39/ 37.5	37/ 35.8
Agriculture and forestry (including fishery)	0.64/ 0.61	0.57/ 0.52	0.6/ 0.5	0.4/ 0.4	0.73/ 0.64	NA/ NA	NA/ NA
Manufacturing (including construction)	9.5/ 8.7	7.7/ 6.9	9.3/ 8.5	7.7/ 7.1	8.7/ 7.8	NA/ NA	NA/ NA
Construction	2.8/ 2.8	2.5/ 2.1	NA/ NA	NA/ NA	2.1/ 2.0	NA/ NA	NA/ NA
Services	29.7/ 30.0	29.9/ 29.7	29.9/ 29.4	29/ 28.4	30.4/ 28.9	NA/ NA	NA/ NA



Sources: Own figure based on BMUB (2011, 2015); BMWi (2014); UBA (2013b)

Fig. 5-37 Assumptions on total employment (Index)

Projections for gross value added are available in three studies. Total GVA is expected to grow continuously. With regard to specific sectors, GVA in manufacturing and services is expected to increase the most, while GVA in agriculture and forestry is assumed to stagnate or increase only slightly until 2050.

Tab. 5-6 Assumptions on gross value added (in billion EUR, unless noted otherwise)

	KS80 BMUB 2015		ZS BMWi 2014		EWS UBA 2013a	BMUB 2012		
						BMU 2011		Ifeu et al. 2011
	2020/ 2030	2040/ 2050	2020/ 2030	2040/ 2050	2020/ 2030	2020/ 2030	2040/ 2050	2020/ 2030
Total GVA (in trillion EUR)	2.5/ 2.7	2.9/ 3.0	2.4/ 2.7	2.9/ 3.2	2.2/ 2.4	NA/ NA	NA/ NA	NA/ NA
Agriculture and forestry (including fishery)	15/ 18	17/ 16	16/ 16	16/ 17	23/ 23	NA/ NA	NA/ NA	NA/ NA
Manufacturing (including construction)	604/ 646	678/ 718	691/ 769	836/ 908	649/ 677	NA/ NA	NA/ NA	NA/ NA
Construction	79/ 80	77/ 78	NA/ NA	NA/ NA	NA/ NA	NA/ NA	NA/ NA	NA/ NA
Services	1858/ 2031	2180/ 2313	1690/ 1901	2092/ 2280	1557/ 1717	NA/ NA	NA/ NA	NA/ NA

Projections for GDP are available in all studies. However, annual growth rates differ. This may be mainly due to different base years. Highest growth is expected in BMU 2011. An average annual growth rate of 1% as assumed in BMWi 2014 (ZS), for BMUB 2015 the number is a bit lower. In general, the average annual GDP growth rates seem optimistic but plausible if compared to real GDP growth rates since 2010.

Tab. 5-7 Assumptions on GDP

	KS80 BMUB 2015		ZS BMWI 2014		EWS UBA 2013a		BMUB 2012*			
	Base year (2010)		Base year (2011)		Base year (2008)		BMU 2011		ifeu et al. 2011	
	2020	2030	2020	2030	2020	2030	2020	2030	2020	2030
Real GDP (in billion)	2752	3009	2688	3031	2437	2632	2700	3070	2437	2632
Real GDP (index, base year = 100)**	110.3	120.6	109.6	123.6	107.4	115.9	118.9	135.2	107.4	115.9

* Base years (2008)

** own calculations

Prices for oil, natural gas and hard coal are generally expected to increase over the coming years and decades. The strongest increase of oil and natural gas prices is assumed in BMUB (2015). Oil prices rise from 13.3 EUR/GJ in 2020 to 25 EUR/GJ in 2050 while gas prices rise from 8.1 EUR/GJ in 2020 to 13.9 EUR/GJ in 2050. Regarding hard coal, the highest increase is expected in BMU (2011). Projections for lignite prices are only available in two studies. Both assume stagnating prices; 1.7 EUR/GJ in BMUB (2015) and 0.4 EUR/GJ in UBA (2013b).[18] In

[18] There are no public markets in Germany on which lignite prices can be observed. However, based on data from utility companies, estimates for lignite costs can be derived. The large difference between the cost es-

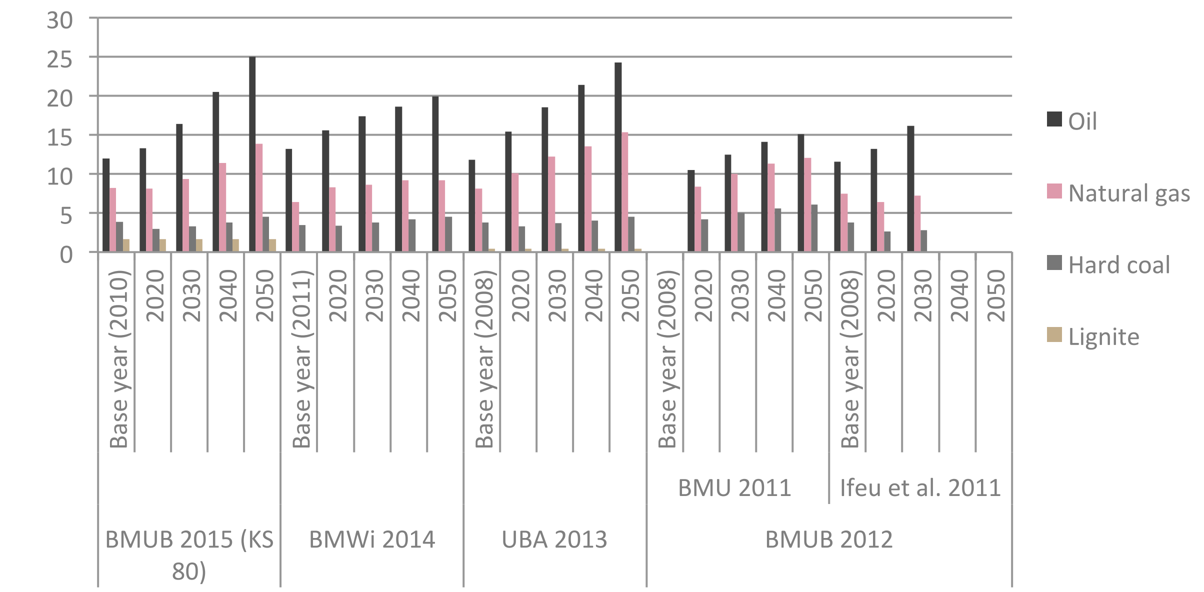
all scenarios the price of CO_2 certificates in the EU Emissions Trading System is expected to increase compared to today's low level, although price assumptions vary considerably for the post-2030 period.

Tab. 5-8 Assumptions on energy prices (in EUR/GJ) and CO_2 prices (in EUR/t)

	KS80 BMUB 2015		ZS BMWi 2014		EWS UBA 2013a		BMUB 2012		
							BMU 2011		Ifeu et al. 2011
	2020/ 2030	2040/ 2050	2020/ 2030	2040/ 2050	2020/ 2030	2040/ 2050	2020/ 2030	2040/ 2050	2020/ 2030
Oil	13.3/ 16.4	20.5/ 25	15.6/ 17.4	18.6/ 19.9	15.4/ 18.5	21.4/ 24.3	10.5/ 12.5	14.1/ 15.1	13.2/ 16.1*
Natural gas	8.1/ 9.4	11.4/ 13.9	8.3/ 8.6	9.2/ 9.2	10.1/ 12.2	13.5/ 15.3	8.4/ 10	11.3/ 12.1	6.4/ 7.2*
Hard coal	3/ 3.3	3.8/ 4.5	3.4/ 3.8	4.2/ 4.5	3.3/ 3.7	4/ 4.5	4.2/ 5	5.6/ 6.1	2.6/ 2.8*
Lignite	1.7/ 1.7	1.7/ 1.7	NA/ NA	NA/ NA	0.4/ 0.4	0.4/ 0.4	NA/ NA	NA/ NA	NA/ NA
CO_2**	23/ 50	90/ 130	10/ 40	65/ 76	20/ 30	40/ 50	30/ 35	40/ 45	20/ 30

** own computation*

*** The BMUB (2015) study assumes different CO_2 price developments for its three scenarios. The table shows the price development for the KS 80 scenario, while lower CO_2 prices (2020: 14€, 2030: 30€, 2040: 40€, 2050: 50€) are expected to be in line with a reference scenario and higher prices (2020: 30€, 2030: 87€, 2040: 143€, 2050: 200€) are expected to be in line with the more ambitious GHG reduction scenario KS 95.*



Sources: Own figure based on BMUB (2012), BMUB (2015); BMWi (2014); UBA (2013b)

Fig. 5-38 Assumed market prices for energy (in EUR/GJ)

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timates in these two studies appears to be due to one of them (UBA 2013) referring only to the short-term operating costs of lignite extraction, while the other one (BMUB 2015) also includes long-term operating costs and investment costs (BMUB 2015).

Comparison of methodology

The methodology used for energy scenario development is relatively similar in all of the analysed Germany studies.[19] Each of the scenarios is developed based on several sector-specific and technologically detailed bottom-up models. Future energy demand in the various sectors is derived based on a range of assumptions, including population development, GDP growth and diffusion of new technologies in the energy transformation sector and the end-use sectors.

The studies generally apply a simulation modelling approach, although the dispatch of non-renewable power plants is typically modelled by using optimization (cost-minimisation) models. The modelling framework for all analysed studies is therefore generally similar[20] and the differences in scenario outcomes can probably be attributed to a greater extent on differences in input assumptions such as technology availability and diffusion. Assumptions on future renewable energy or CCS deployment, diffusion of energy efficient technologies and – to some extent – consumer behaviour (see Section 6.2.5) are adjusted in a way so as to end up with plausible pathways that reach key energy transition targets, specifically a certain long-term GHG emission reduction target.

Assumptions on technology availability and technology costs

As is usually the case in energy scenario development, none of the analysed scenarios assume any drastic new technologies (such as nuclear fusion or radically different ways to harness wind or solar power) to become available on the market until 2050. In line with the current legislation, all scenarios assume that the use of nuclear power in Germany will be phased out by 2022 (or between 2020 and 2025 in the case of the LS 09 scenario).

Two of the analysed scenarios (KS 95 and EWS) assume that CCS technology will be used to reduce industrial emissions from the year 2030 on. The authors of the KS 95 scenario explicitly mention that there still is a massive need for research and development regarding large-scale capture plants for industrial processes as well as CO_2 storage. The other analysed scenarios do not assume that CCS technology will be applied in the industrial sector. Furthermore, none of the scenarios (including KS 95 and EWS) assume that any fossil fuel power plants will be equipped with CCS technology, with one of the studies (BMWi 2014) explicitly citing a lack of public acceptance for CCS technology in Germany.

In the transport sector, all scenarios assume that electric cars will further improve in regard to costs and vehicle range. Especially the KS 95 scenario also assumes that between 2030 and 2050, hydrogen will increasingly be produced from electrolysis and will in part be transformed to synthetic fuels for the transport sector.

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[19] The following remarks at least apply to four of the five analysed scenarios. The study containing the LS 09 scenario (BMU 2009) contains only very little information on how the scenario was developed.

[20] However, an in-depth analysis and comparison of the various models is beyond the scope of this work.

In the analysed scenario studies, which were selected based on the criteria suggested in the Terms of Reference (see Section 4.2), there is for the most part no detailed discussion of technology cost assumptions. This lack of a focus on cost assumptions may be due to the fact that technology diffusion in all analysed scenarios is not strictly cost-driven (no full cost optimisation is pursued, as mentioned above). However, for two scenarios (ZS and LS 09), cost assumptions for some electricity generation technologies are provided. In one case (ZS), these are investments costs, in the other case (LS 09) they are electricity generation costs. In both scenarios, further cost reductions are assumed for renewable energy technologies, with the decline strongest for PV and wind (especially offshore) technologies. A comparison of future electricity generation cost assumptions between German and Japanese studies is provided in the Joint Conclusion in Chapter 9.

Assumed potential for CO_2 storage

Only two of the analysed scenarios (KS 95 and EWS) assume that CO_2 will be captured and stored. For one of these scenarios (KS 95), the CO_2 storage potential is briefly discussed, with BMUB 2015 citing two studies (BMU 2007 and Knopf et al. 2010) which have estimated this potential for Germany. The authors of the KS 95 scenario point out that the most conservative estimate in these two studies is an available storage potential of 6.3 Gt of CO_2. They relate this number to the less than 50 Mt of CO_2 that need to be stored annually by 2050 and conclude that there is sufficient potential for the envisioned use of CCS in that scenario for the foreseeable future.

Assumed potential and costs of energy efficiency improvements

None of the analysed studies offer a detailed discussion of the costs of energy efficiency improvements. Again, this lack of a focus on cost assumptions may be due to the fact that technology diffusion in the analysed scenarios is not strictly cost-driven. Specific assumptions on the potential for energy efficiency improvements are embodied in the various sector-specific bottom-up models used for developing the scenarios. A comparison of technology-specific assumptions on energy efficiency between the scenarios is beyond the scope of this study and is in any way difficult, as the studies often provide different kinds of information on certain technologies. However, Sections 5.2.2.1 and 6.2.2 provide some aggregated information on the final energy efficiency improvements the scenarios deem to be feasible.

Box 4: Estimates of the potential of renewable energy use in Germany

Since the turn of the century, several studies on the potential of renewable energy use in Germany have been conducted. These include UBA (2010), BMU (2004), BMVI (2015), UBA (2013e), BWE (2011), Paschen et al. (2003) and Scholz (2010). The studies differ in regard to what types of energy sources and technologies they analyse. Most of the studies focus on electricity generation technologies, with several studies looking exclusively at the potential of onshore wind power. The studies also differ in regard to how they define renewable energy potentials.

It is typically differentiated between the theoretical potential, the technical potential, the economic potential and the market potential of an energy source. The theoretical potential is largest and includes all energy fluxes (e.g. all sunshine reaching earth). The technical potential is the fraction of the theoretical potential that can be harnessed by using conversion technologies available today or expected to be available in the future. The economic potential is the fraction of the technical potential which can be used economically at any given point in time, taking into account all social costs and assuming perfect information. Finally, the market potential is the fraction of economic potential which can be realised on markets at any given point in time, given market imperfections such as external costs. (Fischedick et al. 2011)

Furthermore, some additional definitions of renewable energy potential are sometimes used when criteria other than economics are chosen to break apart the technical potential. The socio-technical potential, for example, can be defined as the share of the technical potential that can be achieved under constraints such as landscape aesthetical aspects and acceptance within the local community (Jäger et al. 2015). The technical-ecological potential on the other hand focuses on ecological aspects, assuming for example that no plants are build in nature conservation areas.

Based on several available potential studies, the German Environment Agency (UBA 2014) derived conservative estimates for the technical-ecological potential of renewable energy sources for electricity generation in the year 2050. These estimates are depicted in the following table, complemented by an estimate for the potential of open space PV plants from BMVI (2015), as open space PV plants were not considered in the UBA study.

Compared to today's electricity generation in Germany from renewable energy sources, the potential additional electricity generation is highest in regard to wind onshore, PV and wind offshore, followed by geothermal energy. Generally, only very little potential is seen for expanding the use of hydropower generation. Some authors, including those from UBA (2014), argue that electricity generation from biomass should be reduced in the future compared to today.

Tab. 5-9 Technical-ecological potential of renewable energy sources for electricity generation for Germany in the year 2050

	Estimated potential		Electricity generation from renewables in 2016 (in TWh/a)
	Installed capacity (in GW)	Output (in TWh/a)	
Technology			
PV on available structures	275	248	38
PV on open spaces	143	129 [b]	
Onshore wind	333 [a]	1,000	65
Offshore wind	45	180	12
Hydro	5.2	24	21
Geothermal	6.4	50	0
Waste biomass	as required	23	52
TOTAL		1,654	188

[a] *No estimate for the installed capacity is provided in UBA 2014, so here average annual full load hours of 3,000 are assumed, in line with the assumptions in UBA 2010.*

[b] *No estimate for the output is provided in BMVI (2015), so here average annual full load hours of 900 are assumed, in line with the assumption for PV plants on available structures in UBA (2014).*

Sources: UBA 2014, BMVI 2015.

It should be noted that the estimate for the potential of onshore wind power appears to be a rather rough estimate by UBA (2014). Estimates for the potential of onshore wind power plants vary widely in the literature, due to differences in the definition of potential as well as other methodological differences. The UBA (2014) estimate is based on an earlier study by UBA (2013e), which estimated the technical-ecological potential of onshore wind power in Germany to be as high as 1,190 GW or 2,900 TWh/a. This estimate was lowered by UBA (2014) to 1,000 TWh/a, as the UBA (2013e) study was unable to account for restrictions that can only be identified by case-by-case assessments. These restrictions include spatial development objectives of local authorities, a lack of social acceptance at the local level from site owners or affected residents, and potential demands of civil or military radar systems.

An older study on renewable energy potentials for Germany (Scholz 2010) found a much lower potential for onshore wind power generation than UBA (2014) of about 90 TWh, but a higher potential for offshore wind power generation of about 320 TWh.

While even very conservative estimates of the available renewable energy potential suggest that Germany may be able to meet its future final electricity demand entirely by domestic renewable energy sources, this may not be feasible in regard to overall energy demand (UBA 2014). However, the potential for renewable electricity generation in Europe and North Africa combined is expected to be many times higher than any foreseeable future energy demand in these regions (Scholz 2010). In other words, if Germany wants to radically reduce its energy-related CO_2 emissions by relying to a large extent on renewable energy sources in primary energy supply, it may sooner or later rely on electricity or – more generally – energy imports from renewable energy sources abroad. This is suggested by several climate change mitigation scenarios for Germany, especially those that describe far-reaching GHG emission reductions of about 95 % compared with 1990 (UBA 2014, BMUB 2015, BEE 2016).

It should be emphasized that the technical-ecological potential of electricity generation from renewable energy sources as depicted in the table does not take into account that some of this potential may not be economically realisable. According to the knowledge of the authors of this report, no recent estimates are available that estimate the future *economic* potential of renewable electricity generation in Germany, taking social and environmental restrictions into account. However, an older study (SRU 2011) found that by 2050, about 450 TWh of renewable electricity generation could be generated in Germany for up to 6 to 7 ct/kWh and about 600 TWh could be generated for up to 9 ct/kWh. However, this study strongly underestimated the cost decline of PV power plants and assumes a much lower technical-ecological potential of onshore wind power than UBA (2014) does. Consequently, more of the technical-ecological potential may be realisable at costs of up to 6 to 9 ct/kWh than suggested by SRU (2011). Updated estimates of the cost curve for realising the technical-ecological potential of renewable electricity generation in Germany would be very informative.

Looking beyond electricity generation, several studies assess the sustainable potential of biomass use for energy purposes in Germany. For several reasons (including competition with food production and adverse effects on nature and the environment), the sustainable potential for cultivating biomass to be used as an energy source is limited. There is no consensus in the literature on the acceptable amount of cultivated biomass to be used in the future. While some studies argue that only waste biomass should be used (UBA 2014), other studies also envision that some cultivated biomass can be used for energy purposes. Based on a discussion of previous studies, a WWF (2009) report estimated that the sustainable biomass use in Germany could be around 1,200 PJ/a by 2050, consisting of about 700 PJ of waste and residual biomass and about 500 PJ of cultivated biomass. At about 1,100 PJ, today's biomass use in Germany is already close to this estimated long-term limit (AG Energiebilanzen 2016, 2017b). A related question that will not be discussed here is how to allocate the available biomass potential to the energy conversion and end-use sectors (such as electricity generation, transport, buildings).

Finally, a recent study by Prognos et al. (2015) estimates the solar thermal energy potential for heating in buildings to be 190 to 250 PJ, and the corresponding ambient heat potential to be 210 to 360 PJ. Only a fraction of these sources potential is currently used.

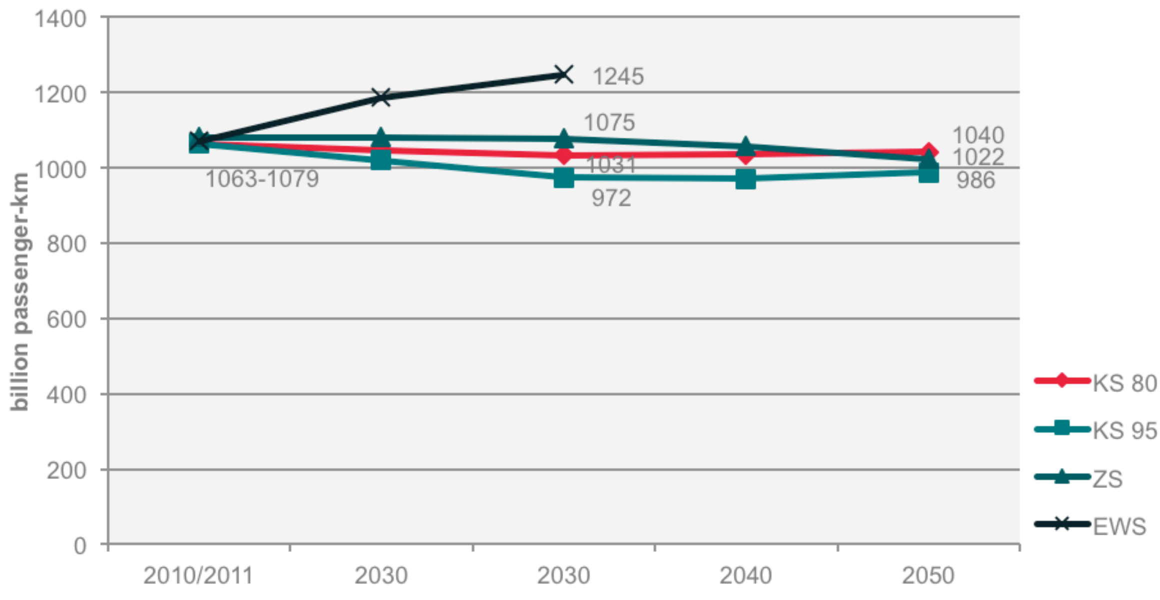
5.2.2 Comparison of key outcomes

5.2.2.1 Comparison of final energy demand and key indicators of energy service demand

In a first step key indicators of the energy service demand (e.g. pkm, tkm, floor area) will be compared, followed by a comparison of final energy demand in the scenarios.

Starting with indicators that provide further insights on the expected developments in the transport sector Figure 5-39 shows the development of the number of passenger km, which the different scenarios anticipate. Aviation is not included in this comparison, as aviation is defined differently in the scenarios. Most scenarios expect a relative stable development with a slight decline in passenger-km over time. A main reason for the assumed decline are the expected demographic changes (UBA 2006). One exception to these observations is the development in the EWS scenario, which makes considerably different assumption in regards to the number of passenger-km, resulting in a significant increase until 2030.

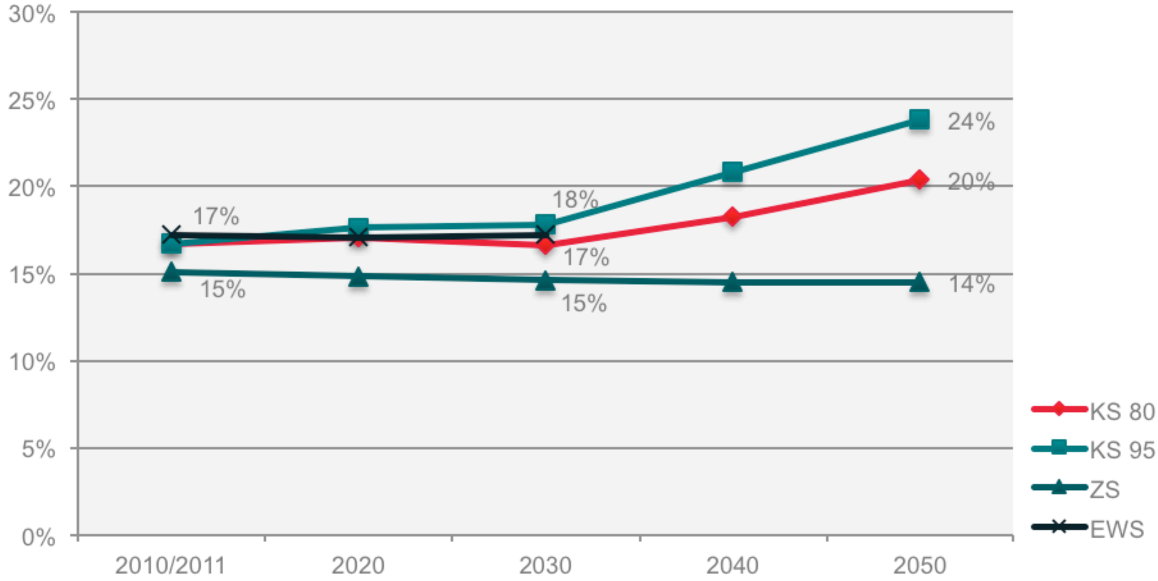
The development of passenger-km in the EWS scenario is a reflection of a strong increase in passenger-km in all modes of transport, but especially in motorised private transport. While it is difficult to precisely explain the differences in assumptions about future passenger-km based on the information provided in the scenarios studies, differences in transport costs probably play an important role. For example, a considerable increase in the mineral oil tax is explicitly mentioned in the KS 80 and KS 95 scenarios to contribute to a reduction in future motorised private transport.



Sources: Own figure based on BMUB (2015); BMWi (2014); UBA (2013b)

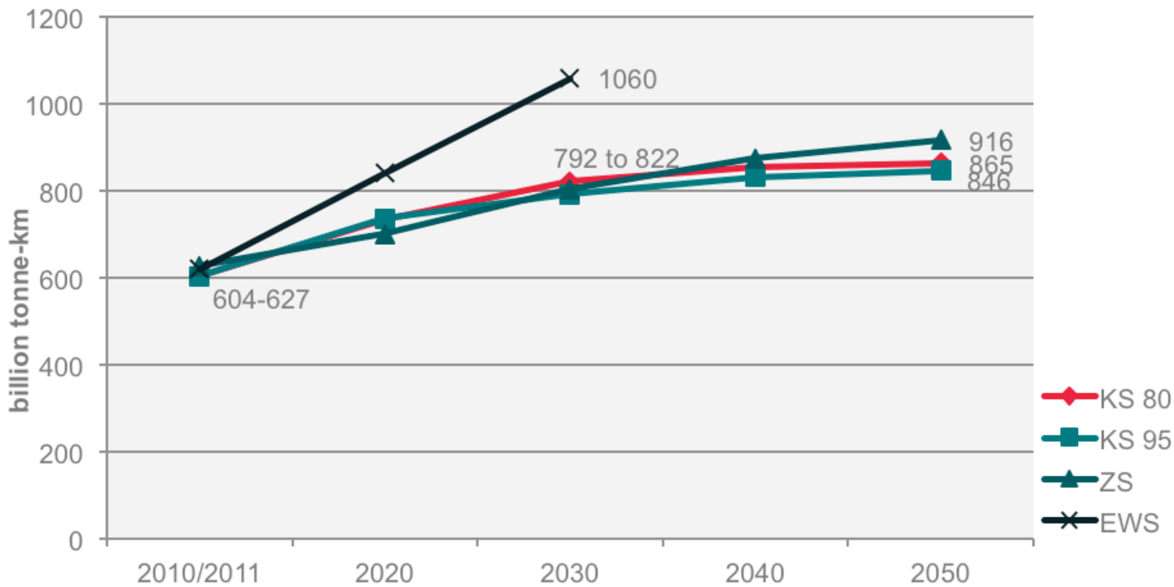
Fig. 5-39 Passenger-km (in billion pkm, without aviation)

In regards to the share of local public transport and rail in land-based passenger transport (Figure 5-40), the majority of scenarios expect a relatively stable share until 2030. However, after 2030 the KS 80 and KS 95 scenarios expect local public transport and rail transport to increase by between 3% and 6%. The reasons mentioned in the study for this increase are a higher attractiveness of public transport and the simultaneously higher costs for motorised private transport, making passenger car ownership less attractive. While the costs for private car transport are assumed to rise as a result of an increase of the mineral oil tax and the introduction of a car toll, taxes in the KS 80 and KS 95 scenarios are assumed to be reduced for fuels that are used in the public transport sector (BMUB 2015).



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 5-40 **Combined share of local public transport and rail in land-based passenger transport (in %)**

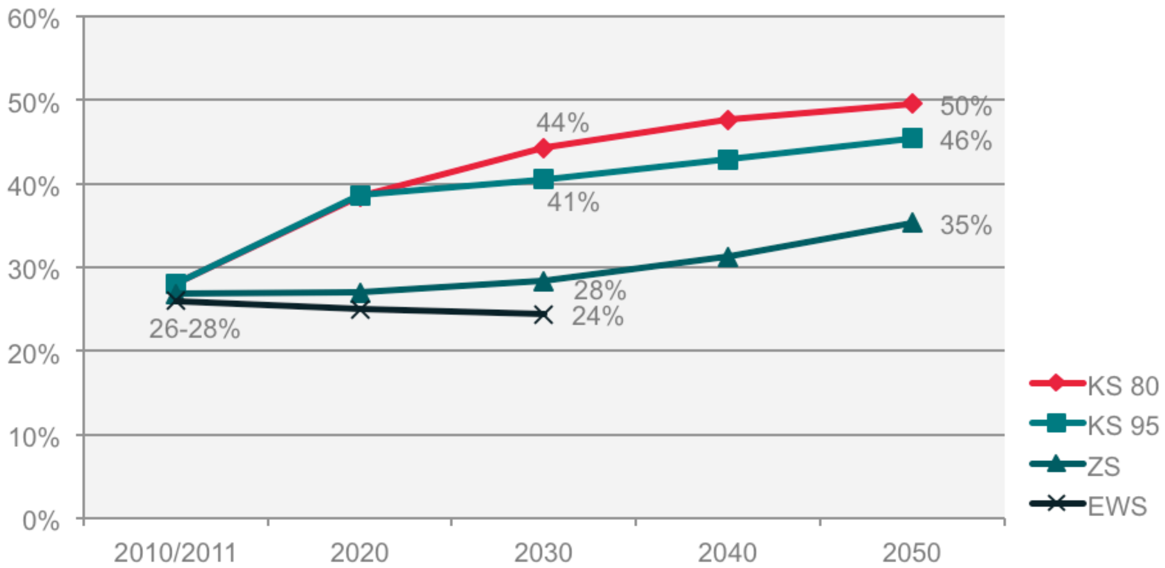


Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 5-41 **Transport volume in tonne-km (in billion pkm, without aviation)**

The transport volume, expressed in tonne-km in Figure 5-41, is expected to continue to grow significantly in all scenarios until 2030. After 2030, the growth is expected to continue, albeit at a lower rate. While the three scenarios KS 80, KS 95 and ZS make very similar assumptions regarding the growth rate, the EWS scenario anticipates a much stronger growth.

Taking a closer look at the type of transport, Figure 42 presents the share of rail and domestic shipping in land- and water-based freight transport. It can be observed that the scenarios make very different assumption regarding this aspect. The KS 80 and KS 95 scenarios anticipate a strong increase of the rail and domestic shipping share in land- and water-based freight transport, increasing from 28% in 2010 to more than 40% by 2030 and to 46% (KS 95) and 50% (KS 80) in 2050. The ZS scenario on the other hand expects the growth to be much slower with only a two percentage points increase until 2030 and a nine percentage points increase until 2050 compared to 2010/2011. The EWS scenario even anticipates a decline of two percentage points until 2030, as road transport is expected to increases significantly in this scenario.



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

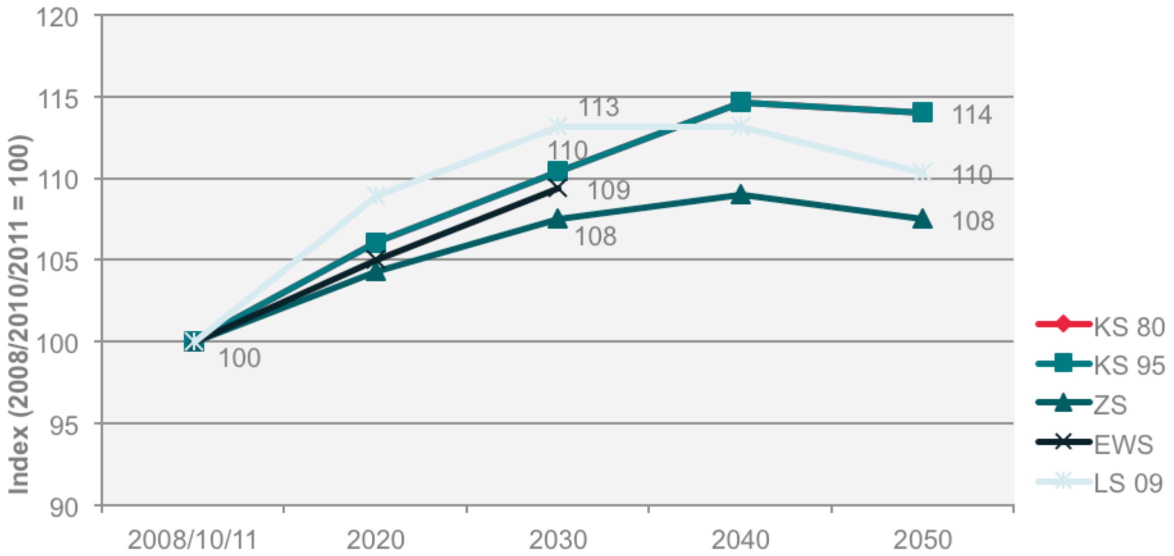
Fig. 5-42 Share of rail and domestic shipping in land- and water-based freight transport (in %)

The strong short-term growth of rail and domestic shipping in freight transport in the KS 80 and KS 95 scenarios can be attributed to the shift of freight transport from road to rail. This shift is based on the assumption that tolls for trucks will be increased and that this – together with increasing fuel costs – will lead to a shift from road to rail. In the mid and long term, the KS 95 scenario assumes that overhead lines will be built on many highways to allow trucks to run on electricity for at least some parts of their trips. As this infrastructure is not assumed to be available in the KS 80 scenario, freight transport decarbonisation in this scenario requires a higher share of rail and domestic shipping compared to the KS 95 scenario.

The development in the opposite direction anticipated by the EWS scenario, on the other hand, can be explained by the fact that in contrast to the KS scenarios, the costs for road transport are expected to be reduced. Thereby the attractiveness of road transport is further increased compared to rail and shipping, which are less flexible in terms of delivery locations and distribution networks.

After presenting key indicators for the transport sector it is also important to take a closer look at indicators relevant for the residential and commercial sectors. The indictors that can be compared with the data from the meta-analysis include the household living area (Figure 5-43) and the service sector floor area (Figure 5-44). For both of these indicators the KS 80 and KS 95 scenarios assume identical developments.

In regards to household living area (Figure 5-43), the scenarios show similar developments with continuing growth of about 8 to 13% until 2030 compared to 2008/2010/2011, despite the trend of demographic decline in Germany. This means that the increase of living area per capita is expected to be even higher.



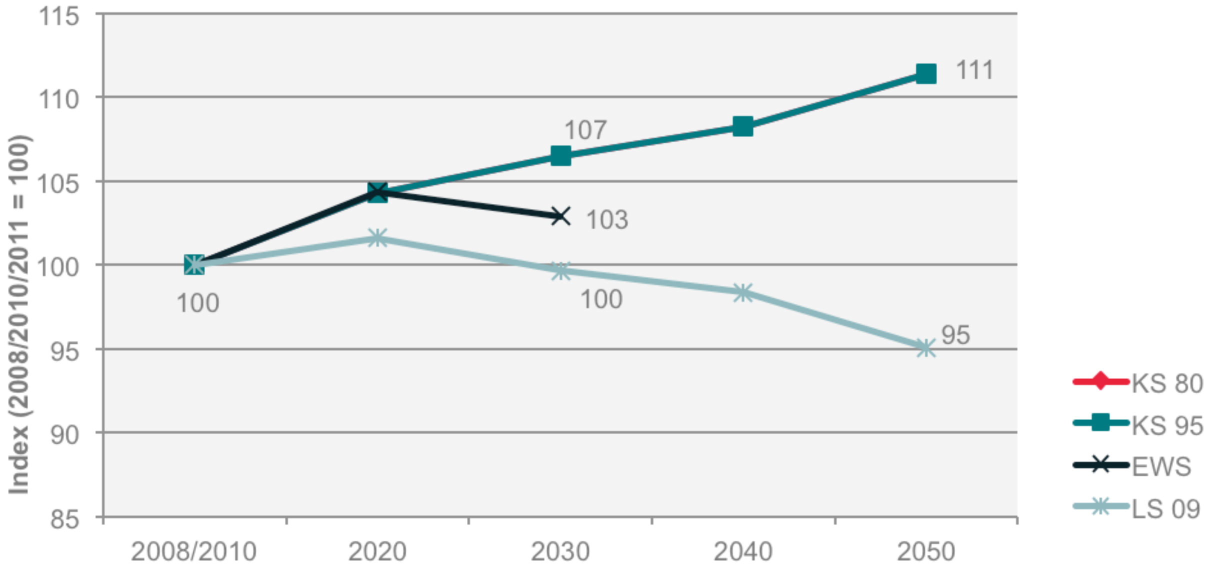
Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 5-43 Household living area (index, 2008/2010/2011 = 100)

After 2030, both KS scenarios are expecting the growth to further continue at a consistent rate, while the ZS scenario assumes stabilization until 2040. After 2040 the development changes its direction towards a slight reduction of household living area until 2050 in both the KS scenarios and the ZS scenario.

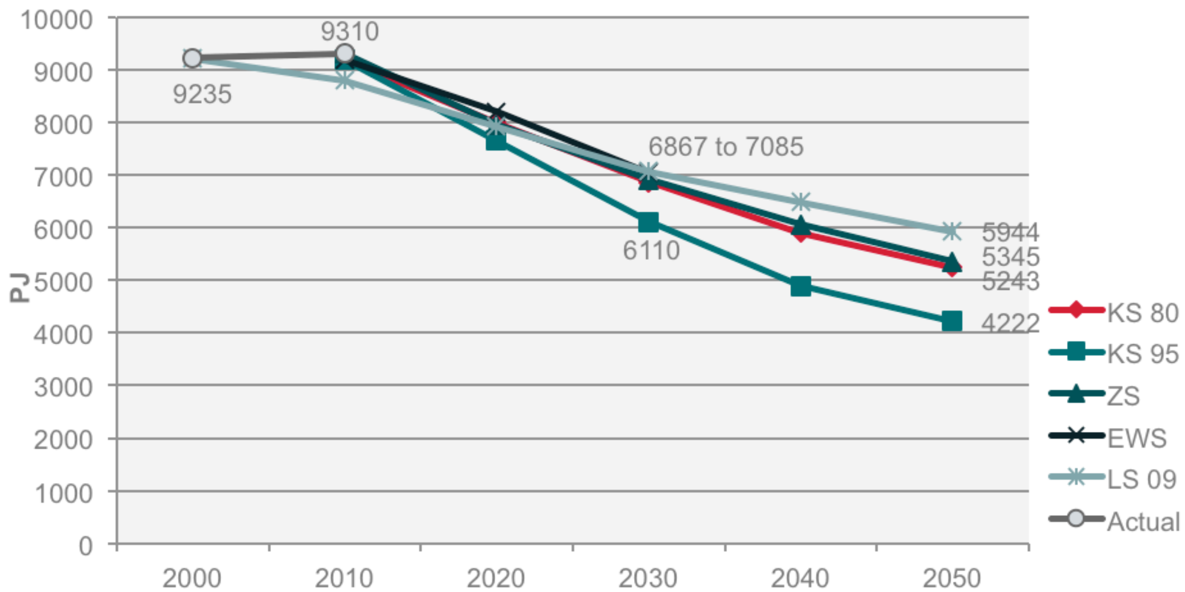
The expected development of the LS09 scenario is similar but with slightly different ranges and a steeper increase until 2030 and higher decline from 2030 to 2050. In all scenarios however, the household living area is expected to be higher in 2050 than it was in the base years.

In regard to the service sector floor area, the expected developments until 2050 defer significantly (Figure 5-44). While all scenarios expect modest growth until 2020, the EWS and the LS 09 scenario assume a decline in the service sector floor area afterwards, whereas the KS scenarios expect a continuing increase until 2050.



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 5-44 Service sector floor area (index, 2008/2010 = 100)

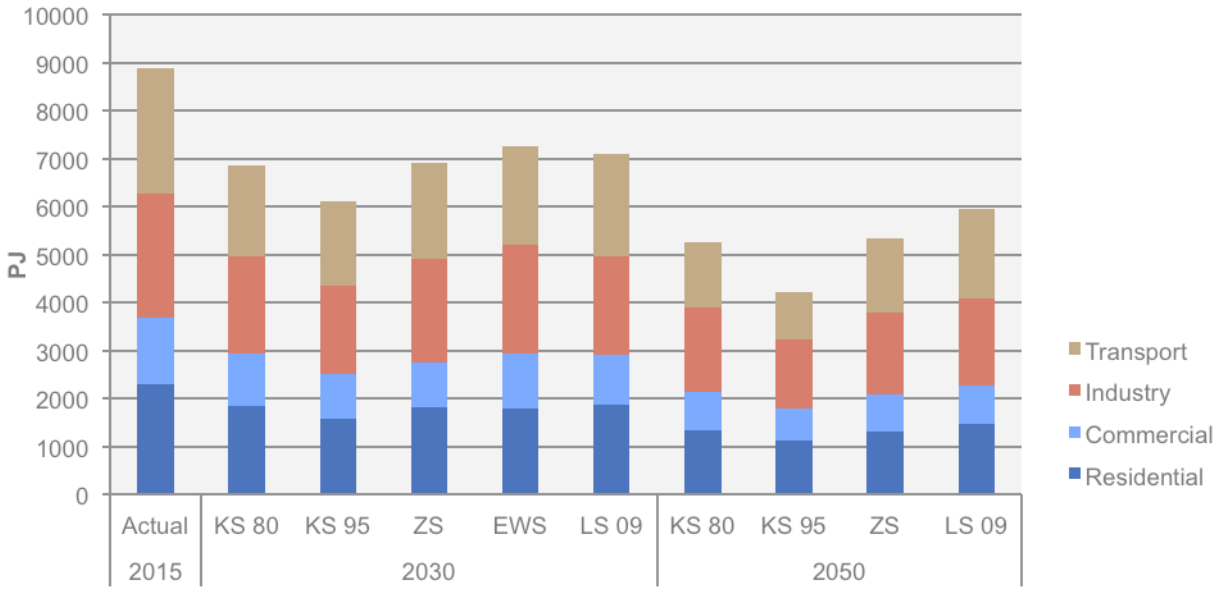


Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 5-45 Final energy demand (without international maritime traffic) (in PJ)

All five scenarios expect a considerable decline of final energy demand already until 2030 (Figure 5-45). In all scenarios the decline is considerably stronger in relative terms than the projected demographic decline. The strongest decline can be observed for the KS 95 scenario, which in 2030 is about 14% lower than the LS09 scenario, which shows the lowest decrease of the final energy demand in the group of analysed scenarios. One reason for the substantial reduction of final energy demand in KS 95 is the high share of electricity in final energy demand in this scenario, which in many cases (e.g. electric engines, heat pumps) allows more energy efficient technologies to be used in the end use sectors.

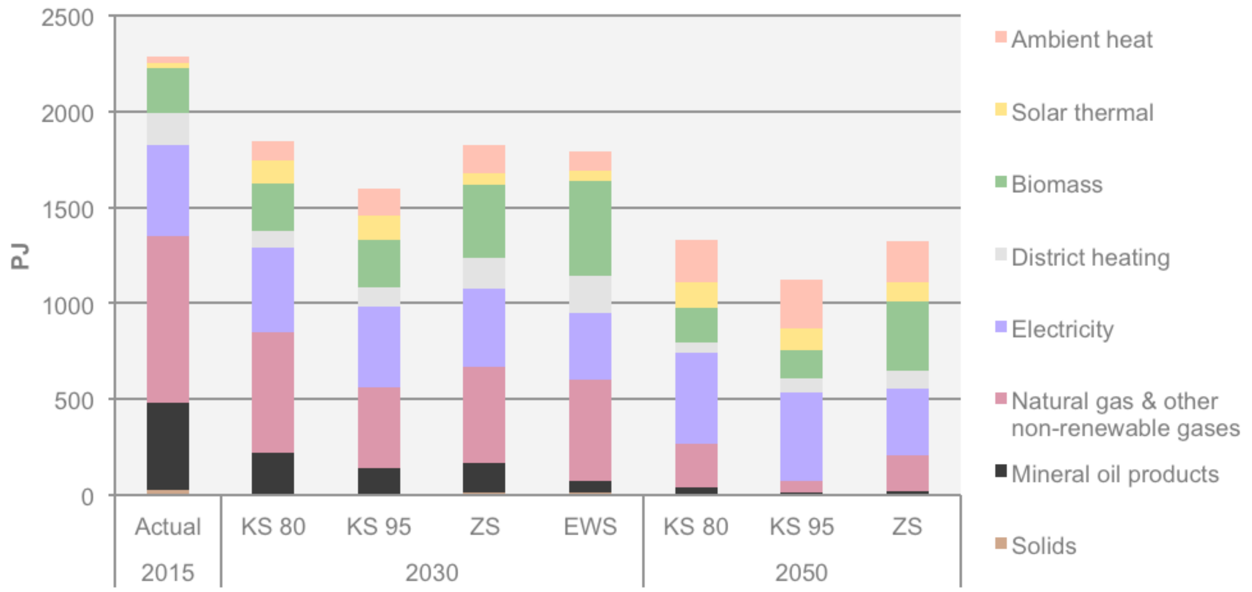
Figure 5-46 takes a look at final energy demand by sector. One noticeable difference between the scenarios is that final energy demand in KS 95 declines disproportionally strong in the transport sector from 2030 to 2050 compared to the KS 80, ZS and LS 09 scenarios, which also provide data for 2050. Key reasons for this strong decline in the KS 95 scenario is the assumed increase in (more energy efficient) public transport as well as the strong increase in electricity use in both passenger and freight transport, especially after 2030 (see Section 6.2.3). For the LS scenario, which expects the highest final energy demand of all scenarios for 2050, the decline is considerably lower not only for the transport sector but also for the residential sector.



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

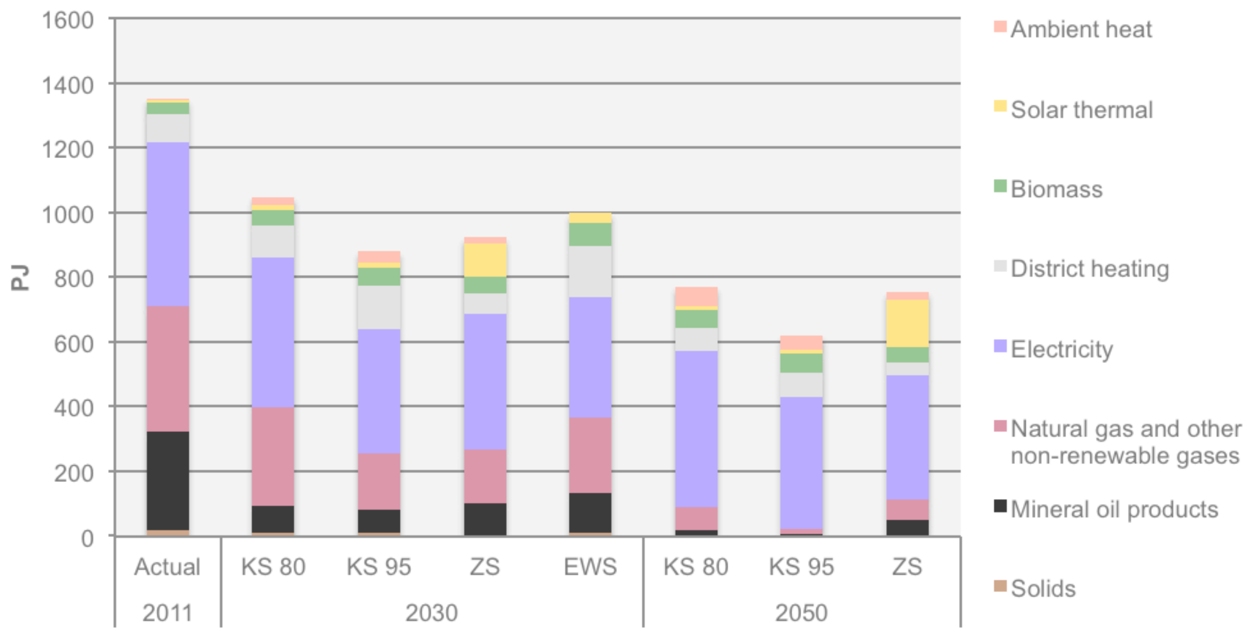
Fig. 5-46 Final energy demand by sector (without international maritime traffic) (in PJ)

Comparing the final energy demand by energy source for the four sectors (Figures 5-47 – 5-50), it can be observed that fossil fuels are expected to be more and more displaced by efficiency increases, more direct use of renewables and - in most scenarios - a higher share of electricity. In regards to the direct use of renewables, the scenarios consider solar thermal energy, ambient heat and in some scenarios also more biomass.



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 5-47 Final energy demand of residential sector by energy source (in PJ)



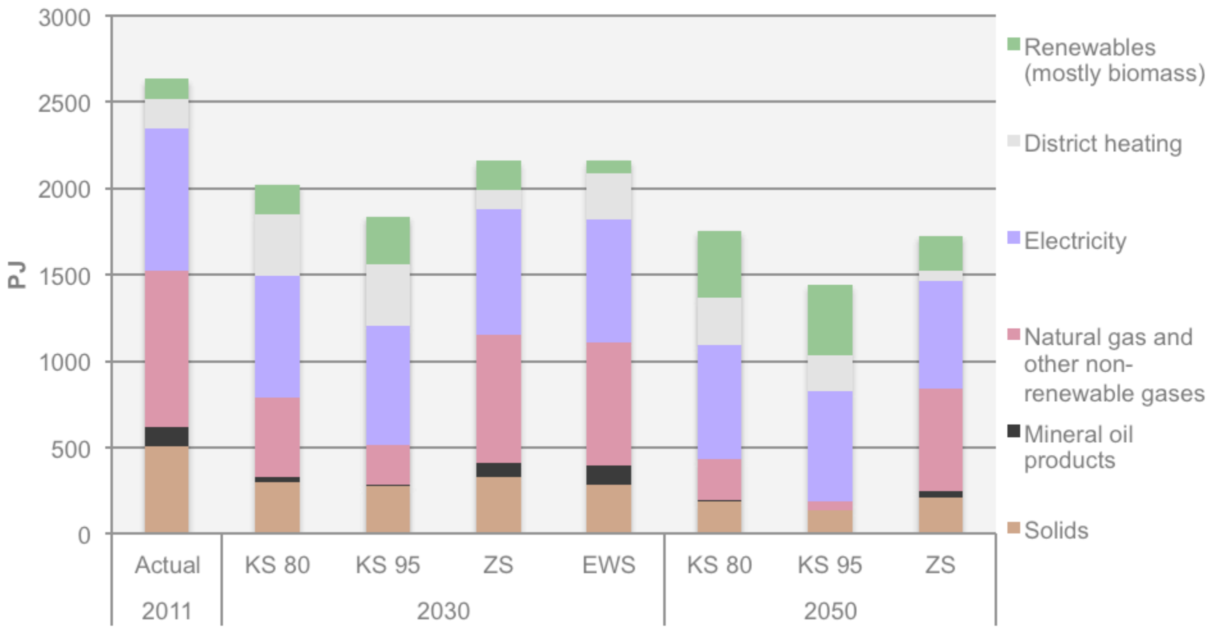
Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 5-48 Final energy demand of commercial sector by energy source (in PJ)

What can be observed for both the residential and the commercial sector is the gain in importance of electricity in all scenarios, especially by 2050. Although, the absolute amount of electricity only slightly increases in most scenarios, the share of electricity in the final energy demand increases significantly until 2050.

For the industrial sector, it should be noted that the definition of district heating compared to the direct use of fossil fuels apparently differs between the studies, so care needs to be taken when comparing the scenarios in regard to the energy sources used in the industrial sector. Nevertheless, it can be observed that while all scenarios see the potential to reduce final energy demand in the industrial sector, there are differences in the extent of this reduction (Figure 5-49)

Furthermore, the scenarios evaluate the future role of biomass use in the industrial sector differently. Especially the two KS 80 and KS 95 scenarios foresee quite a high share of biomass in this sector. The other two scenarios, EWS for 2030 and ZS, on the other hand, expect natural gas (and other renewable gases) to continue to be of high relevance in the industry sector in 2030 and 2050.



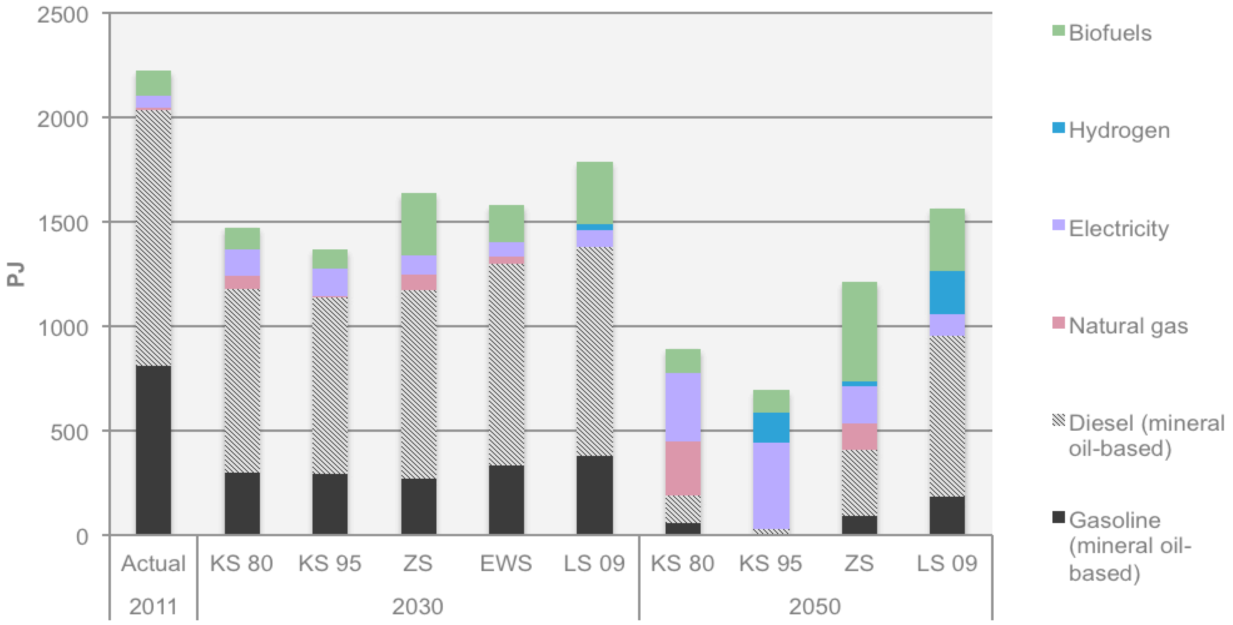
Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 5-49 Final energy demand of industry sector by energy source (in PJ)

Taking a closer look at the transport sector, it can be seen in Figure 5-50 that while electricity use is already higher than today in all scenarios by 2030, electricity only really gains relevance in the transport sector after 2030. Fossil fuels in contrast continue to have high relevance until 2030, but face a steep decline until 2050 in three out of the four scenarios that provide data for 2050. Only in the LS09 scenario, mineral-based diesel remains of high significance for the transport sector until 2050.

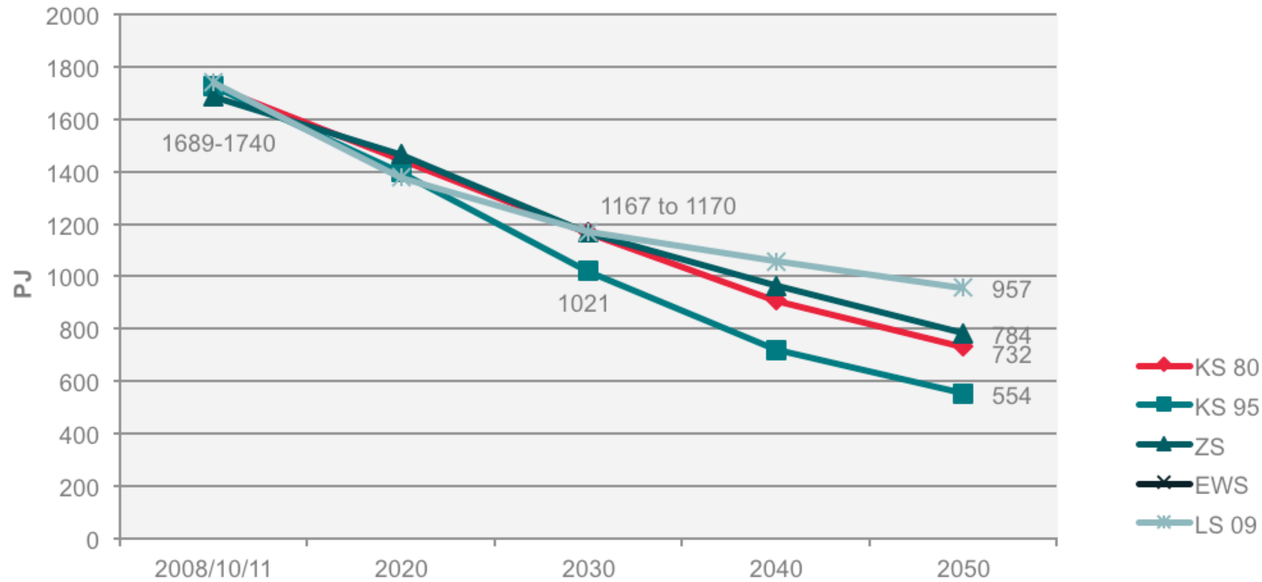
In regards to electricity, a strong negative correlation between the share of electricity and the amount of final energy demanded in the transport sector can be observed. One of the main reasons for this development is the fact that electric engines have a much higher efficiency compared to combustion engines and therefore require less energy.

Next to electricity, biofuels are expected to gain relevance for the transport sector, but the scenario comparison in Figure 5-50 shows that already in the mid-term (2030), conflicting visions exist between the scenarios, with the LS 09 and the ZS scenario foreseeing relatively high biofuel contributions, while the KS 80, KS 95 and EWS expect only a limited biofuel share. In the long-term, both the role of biofuels as well as the role of electricity is seen quite differently in the scenarios. The same holds true for the use of hydrogen in the transport sector. However, in very ambitious mitigation scenarios (such as KS 95), the long-term role of electricity and hydrogen in the transport sector are apparently of particular importance, replacing fossil fuels nearly completely by 2050.



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 5-50 Final energy demand of the transport sector by energy source (without aviation and international maritime traffic)[21] (in PJ)



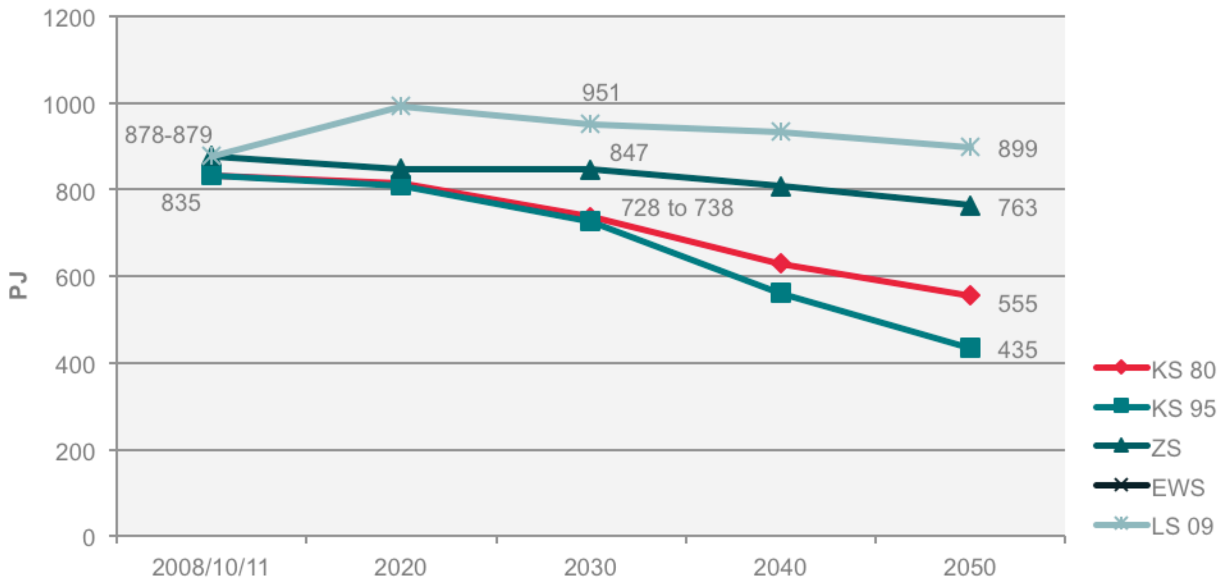
Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 5-51 Final energy demand of the passenger transport sector (in PJ)

[21] The scope of aviation differs between the scenarios, therefore aviation is excluded here.

In addition to the comparison of final energy demand by energy source, for the transport sector in general it can also be of interest to take a closer look at the development of final energy demand for passenger and freight transport , respectively (Figure 5-51 and 5-52). However, it should be noted that there are probably differences between the scenarios in regard to what kind of international transport is included in the models.

Figure 5-51 shows that the final energy demand of the passenger transport sector is reduced considerably in all scenarios, although to a different extent. Compared to the scenarios' base years, demand is reduced by at least around 30% until 2030. Again, and especially in the long term, demand reduction is highest in scenarios like KS 95, with a high share of electricity.



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

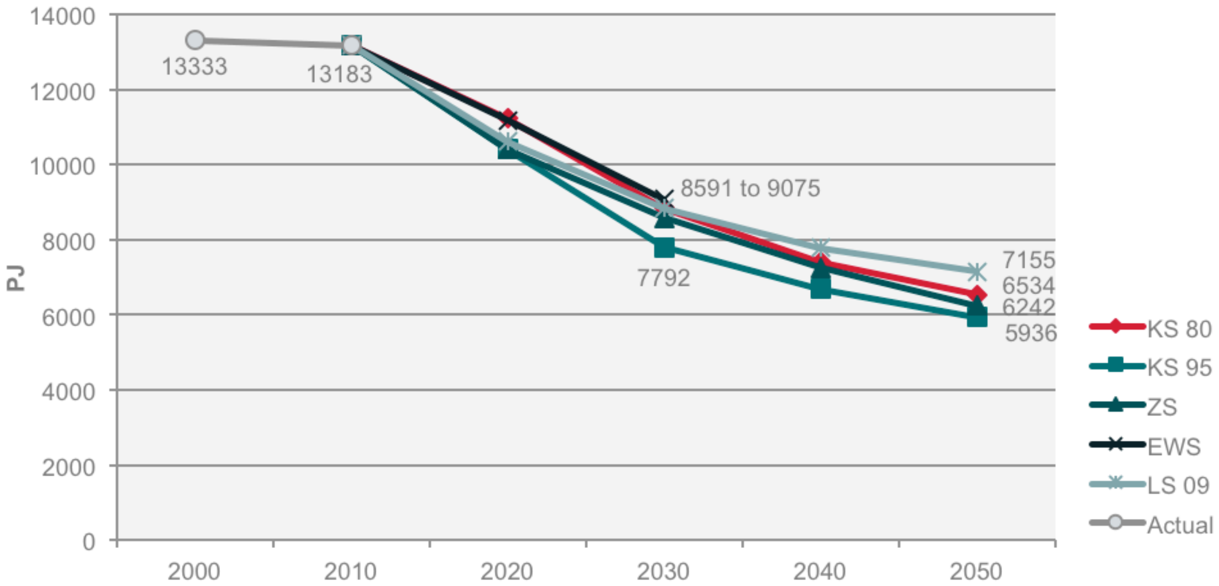
Fig. 5-52 Final energy demand of the freight transport sector (w/o international maritime traffic) (in PJ)

Compared to final energy demand of passenger transport, the scenarios show even higher variations for final energy demand of freight transport (Figure 5-52). Demand is either expected to be relatively stable (LS 09, ZS) or to decline (KS 80, KS 95) considerably, especially after 2020. These differences between the scenarios might largely be attributed to different assumptions regarding the modal split in international freight transport. However, the variations are also partly due to differences in the amount of electricity and hydrogen expected to be used, as these can be used in more efficient engines.

5.2.2.2 Comparison of primary energy supply

In this section the scenarios will be compared in respect to the development of primary energy supply they describe. As Figure 5-53 shows, all five scenarios suggest that primary energy consumption needs to be reduced considerably in the coming decades in order to move towards a sustainable energy system.

Until 2030, the amount of primary energy consumed is relatively similar in most scenarios, with a reduction between 30 to 35% compared to 2010 in all but one scenario. Only the highly ambitious KS 95 scenario aims at reducing the consumption even further with a drop of about 40% compared to 2010. In the long-term until 2050, primary energy consumption is reduced in all scenarios by about 45% to 55% below the 2010 level. The reduction of primary energy consumption is expected to be achieved in all scenarios through efficiency improvements in all sectors (including those realised through electrification) as well as the expansion of renewable energy electricity generation (with primary energy efficiency defined to be 100% when converting wind and solar power to electricity).[22]



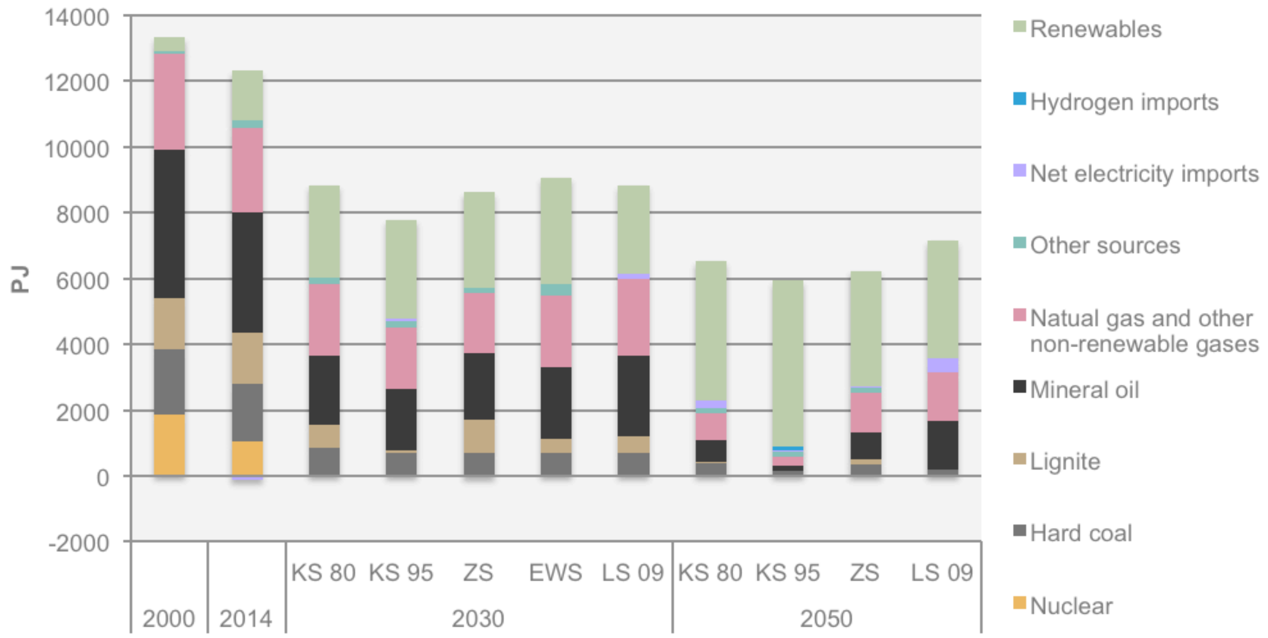
Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 5-53 Primary energy consumption (w/o non-energetic use) (in PJ)

Taking a closer look at the primary energy consumption by energy source, which is presented in Figure 5-54, (renewables are presented without net electricity imports from renewable energy sources) it can be observed that in all scenarios fossil fuel use, especially coal, lignite and oil is reduced considerably by 2030. Natural gas use is also reduced, but not to the same extent as coal, lignite and oil. Especially in the ZS and the LS 09 scenarios, natural gas remains a significant energy source also after 2030. The decline in the use of fossil fuels is accompanied by a

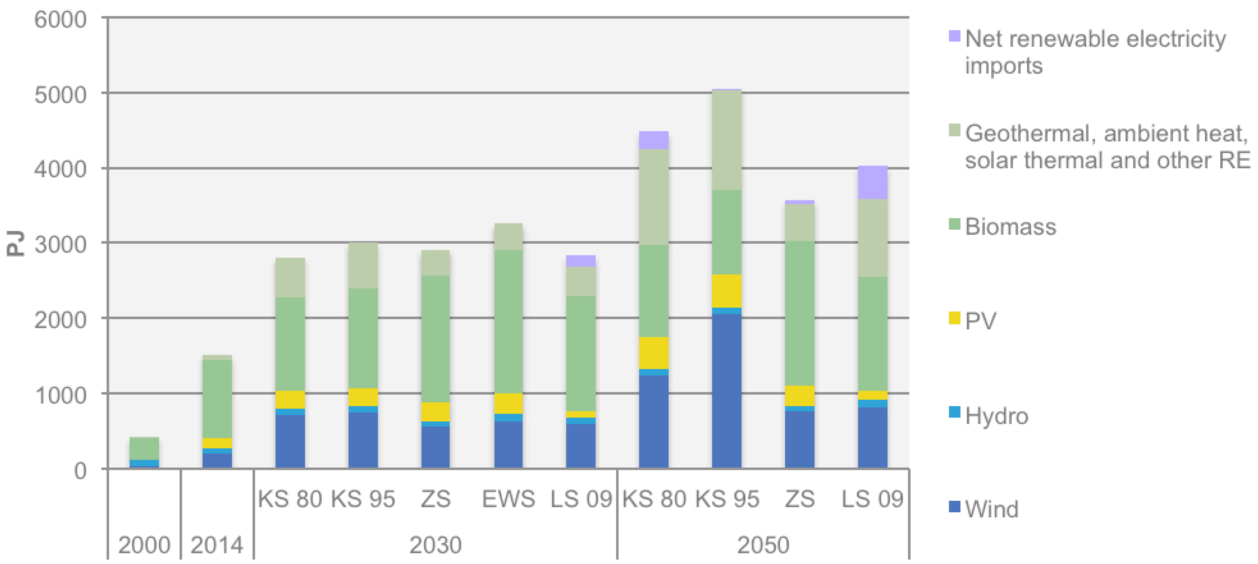
[22] In the KS 95 scenario, for example, primary energy consumption between 2010 and 2050 is reduced by 55%. A significant part of this reduction is the result of the considerable expansion of wind and solar PV electricity generation (and the simultaneous displacement of electricity generation from thermal power plants). This can be illustrated by calculating primary energy consumptions in the hypothetical case of no new wind and solar PV plant expansions between 2010 and 2050 (only replacement of existing wind and solar PV plants). For this case we assume that the "missing" electricity generation would instead be provided by fossil fuel power plants and we further assume that these plants would achieve an average conversion efficiency of 50%. In this case the combined share of wind and solar PV in total net electricity generation would only be 7% in 2050, instead of 91% in the actual KS 95 scenario. Primary energy consumption in this case would be about 8.250 PJ in 2050, instead of about 5.940 PJ in the actual KS 95 scenario. That is, primary energy consumption in the actual KS 95 scenario is some 2.300 PJ lower than it would be without the post-2010 expansion of wind and solar PV, as in that case conversion losses in electricity generation would still be significant in 2050. Without the expansion of wind and solar PV, primary energy consumption would only be reduced by 38% instead of 55% between 2010 and 2050 (and only by 29% if an average conversion efficiency of thermal power plants of 40% were assumed, as is the case in Germany today (Ecofys 2016)).

significant expansion in the use of renewables. Compared to 2014, their contribution until 2030 increases in the scenarios by 77% to 114%. By 2050, the share of renewables in primary energy consumption is expected to be at least 50% (LS 09) and up to 85% (KS 95).



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 5-54 Primary energy consumption by energy source (without non-energetic use) (in PJ)



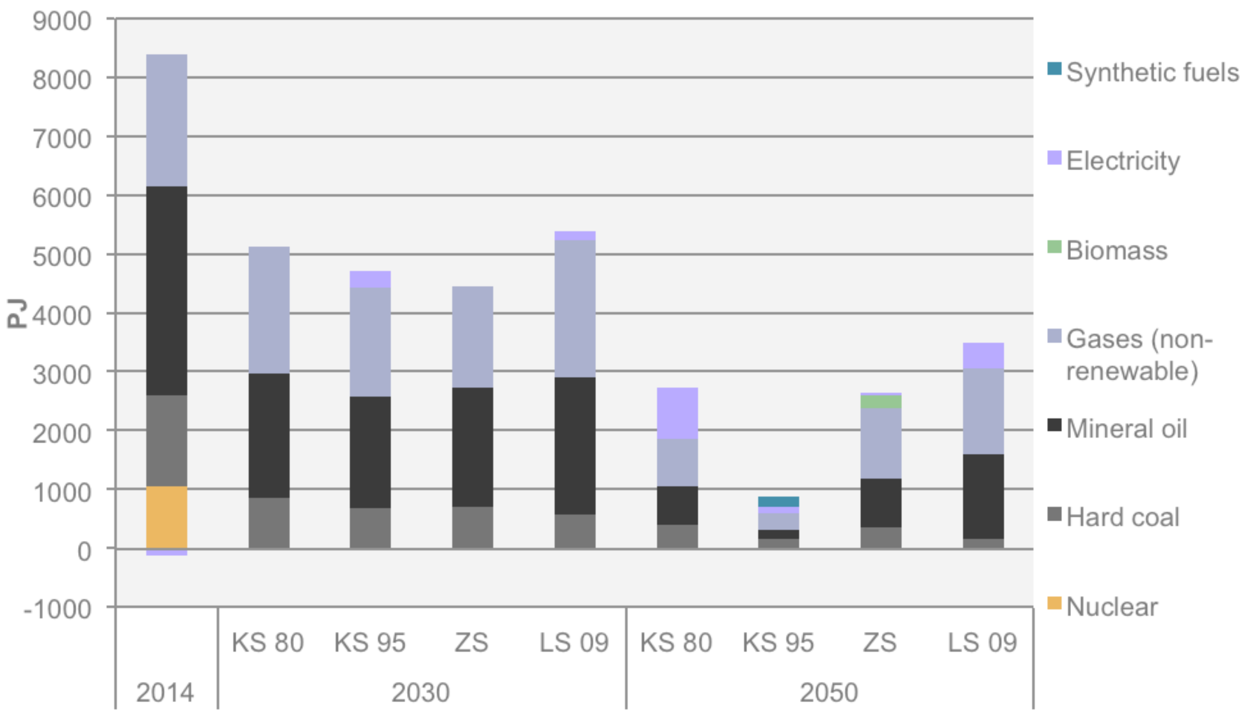
Note: Net renewable electricity imports assume that from 2030 on any net imports are entirely from renewable energy sources.
Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 5-55 Primary energy consumption of renewables by type (in PJ)

Figure 5-55 shows the types of renewable energy sources in the scenarios' respective primary energy consumption. All scenarios foresee a strong growth in the contribution of wind power (both onshore and offshore).

KS 80 and KS 95 both anticipate a particularly strong increase in wind power, but also in geothermal/ambient heat, although to a different extent. In all but one scenario (LS 09), the use of solar PV is also expanded compared to today. In the ZS scenario in particular but also in the LS 09 scenario, biomass use also increases significantly compared to today.

Comparing the primary energy imports by energy source (Figure 5-56), it can be observed that imports are reduced significantly in all scenarios but that the extent of the reduction varies greatly between the scenarios. By 2030, oil, hard coal and uranium imports are reduced strongly, while natural gas imports are not (LS 09) or only marginally reduced. Until 2050, however, also natural gas imports are much lower than today in all scenarios. In contrast, in all scenarios Germany becomes a net importer of electricity by 2050[23], and to a limited extent already by 2030 in the KS 95 and LS 09 scenarios.



It should be noted: Unless otherwise specified in the studies, it is assumed here that from 2030 on, oil, natural gas and hard coal are entirely imported, biomass and lignite are entirely from domestic sources

Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

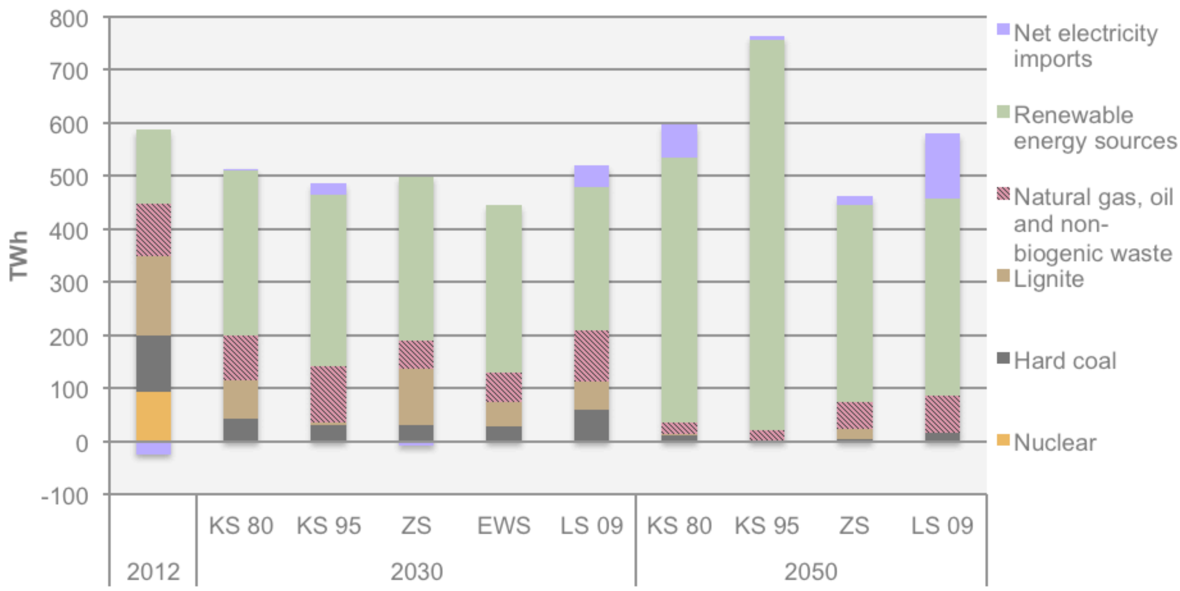
Fig. 5-56 Net primary energy imports by energy source (w/o non-energetic use) (in PJ)

[23] It is typically assumed that electricity based on renewable sources can be generated more cheaply at suitable locations in other parts of Europe or in the Middle East and North Africa (MENA) region. Therefore, in many scenarios it is assumed that either electricity based on renewable energy or (in the case of the KS 95 scenario) synthetic fuels based on such electricity is imported to Germany some extent in the middle to long term.

5.2.2.3 *Comparison of the electricity supply sector*

Following the comparison of the developments of the final and primary energy demand, this section will provide an overview of the electricity supply sector developments in the analysed scenarios.

In regards to the net electricity generation by source presented in Figure 5-57, it can be observed that electricity generation is rapidly converted to being based mostly on renewable energy sources in all scenarios. Coal and lignite electricity generation is reduced considerably already by 2030, although to a lesser extent in the ZS scenario. By 2050, the role of fossil fuels, with the exception of natural gas in the ZS and LS 09 scenarios, becomes marginal in all scenarios. In contrast, net electricity imports are envisioned to play an increasing role in electricity supply. While in recent years Germany has been a net exporter of electricity, by 2030 all but the ZS scenario foresee (mostly moderate) net electricity imports and by 2050, all scenarios envision these, although to a varying extent.



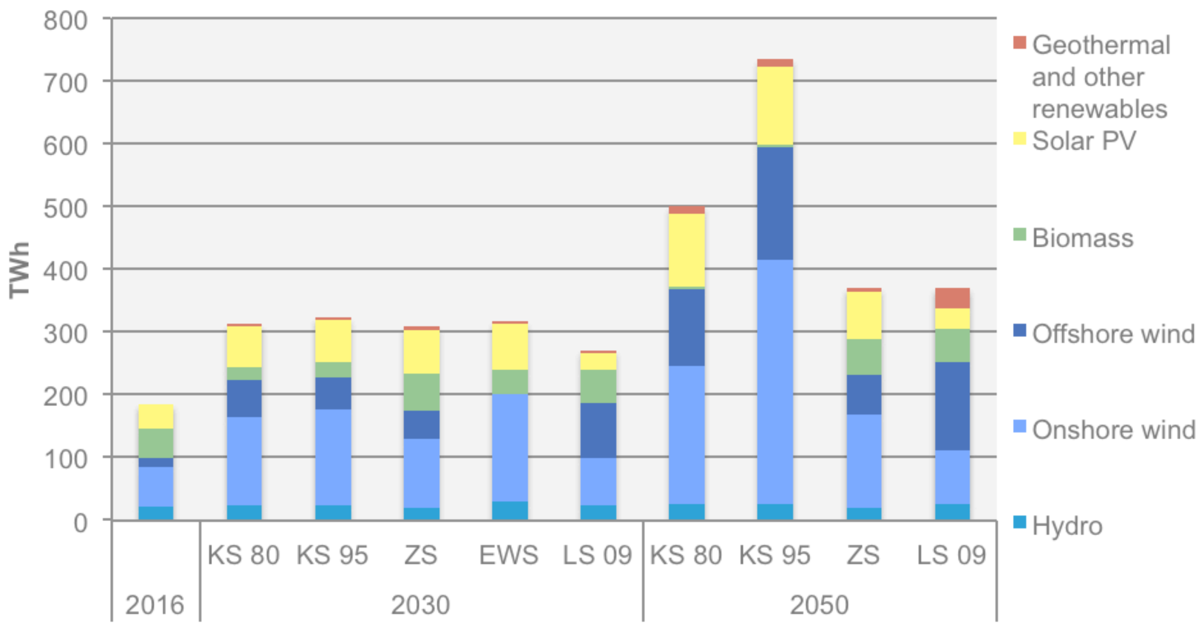
Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 5-57 Net electricity generation by source (without storage output) plus net electricity imports (in TWh)

European electricity market modelling is performed for the KS 80, KS 95 and ZS scenarios. Consequently, in these scenarios differences in the variable electricity generation costs between Germany and its neighbouring countries determine net electricity imports. Obviously, the precise model results depend on a large number of assumptions such as the assumed or modelled deployment of renewable energy technologies and conventional power plants in both Germany and the rest of Europe, fuel costs, CO_2 costs, electricity demand and transmission capacity. Both studies (BMWi 2014, BMUB 2015) do not provide a detailed discussion of most of these assumptions, so a closer examination of the reasons for the differences in net electricity imports between the scenarios cannot be provided here.

The scenario study for the LS 09 scenario provides no detailed explanation of the method used to derive electricity system results, but unlike for the other scenarios mentioned above, no electricity market model with a high temporal resolution appears to have been used for this scenario. The considerable net electricity imports assumed in the LS 09 scenario by 2050 are explained in the study by pointing towards the large potential for low-cost electricity generation from renewable energy sources (especially from the sun) in other parts of Europe and possibly also North Africa, particularly in the Mediterranean region. It is assumed in the scenario that some of this low-cost renewable electricity can be imported by Germany. The study also stresses the advantages of using thermal storage technologies in concentrating solar power plants in the Mediterranean region to help integrate high shares of fluctuation renewable energy sources.

Taking a closer look at the net domestic electricity generation from renewable sources, Figure 5-58 shows that wind (both onshore and offshore), and in most scenarios also PV will increase considerably between now and 2030. By 2050, the combined share of wind and PV electricity generation in total domestic electricity generation reaches about 60 to 90% in the five considered scenarios. The challenges and requirement of such a high share of intermittent renewables will be discussed in detail in Section 6.2.1 below. Biomass electricity generation will either increase only modestly (ZS and LS 09), or be reduced compared to today (KS 8 and KS 95). The role of geothermal energy is expected to remain relatively small, especially until 2030, while hydro power generation hardly increases in any of the scenarios.

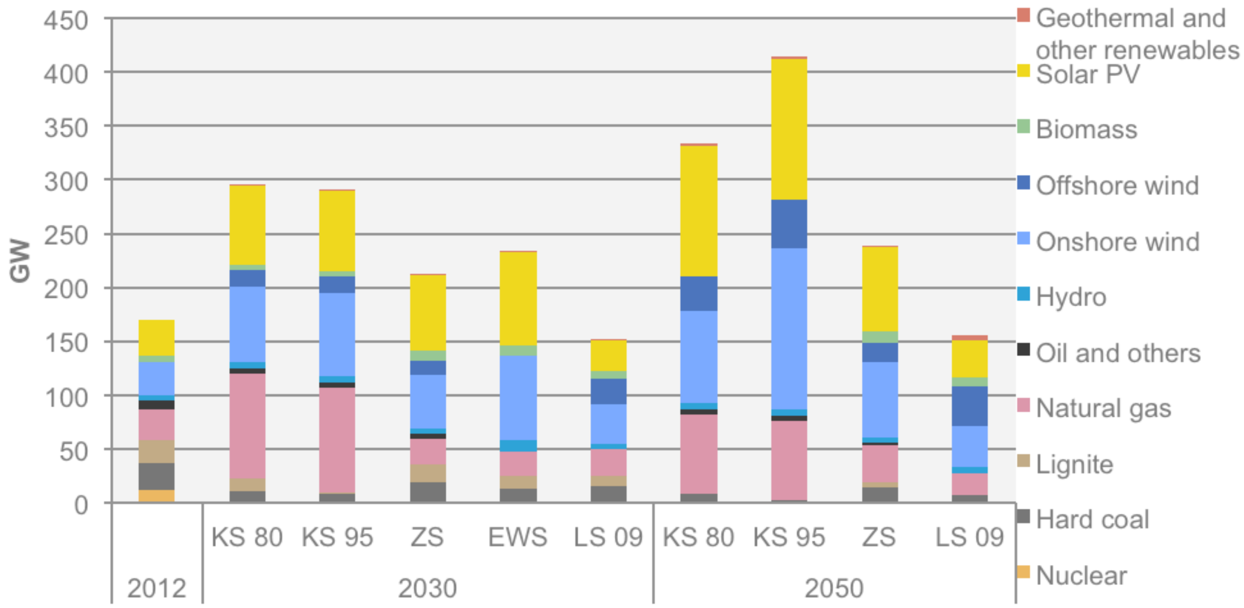


Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)
Please note: EWS onshore wind represent onshore and offshore wind combined

Fig. 5-58 Net domestic electricity generation from renewable sources (in TWh)

These changes in electricity generation from renewables are of course also reflected in the power plant capacities (Figure 5-59). Until 2030, the capacity of solar PV and onshore wind is expected to increase significantly in all but one scenario (LS

09). Offshore wind capacities are increasing until 2050, playing already a bigger role in the ZS and the LS 09 scenarios by 2030. Biomass power plant capacities remain of only minor importance, both in 2030 and in 2050.



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 5-59 Net power plant capacity (in GW)

In regards to the fossil fuel power plant capacities, a high increase of the natural gas capacities is expected by KS 80 and KS 95 already until 2030. These capacities decline again until 2050 but remain higher than in the other scenarios. This is probably explained by the fact that these two scenarios rely most heavily on the fluctuating renewable sources of wind and solar, and gas power plant capacities are well-suited to balance the power supply in a system with high shares of these renewables.

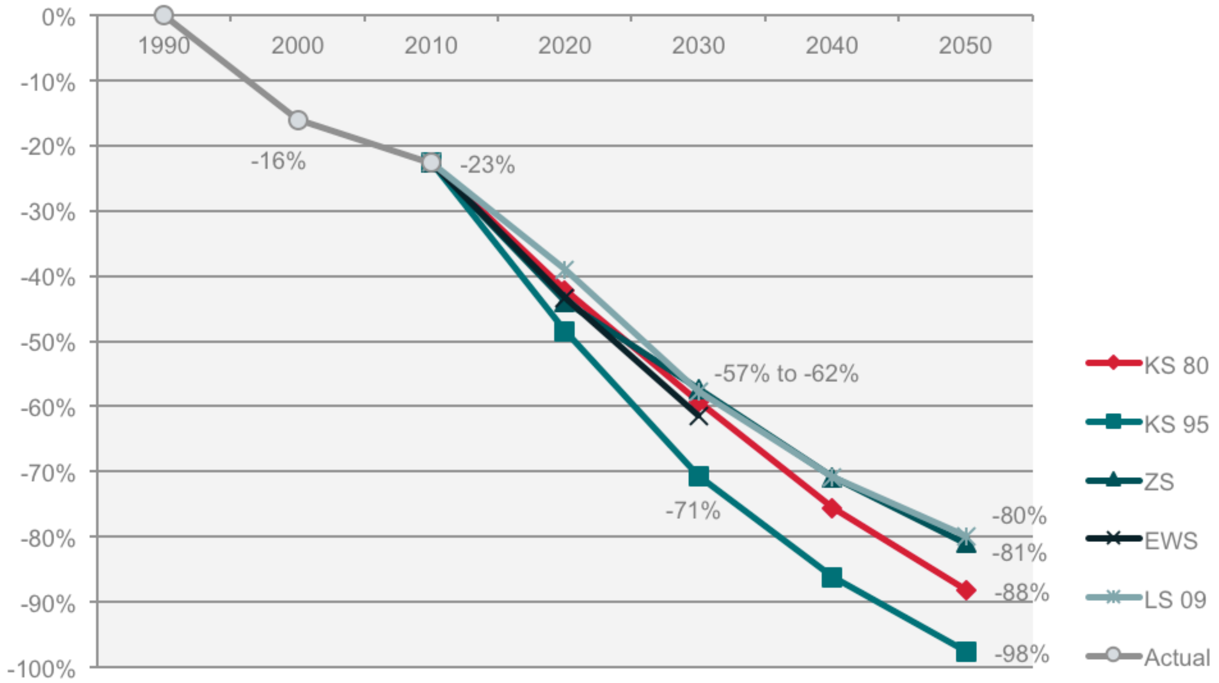
5.2.2.4 Comparison of GHG emissions

Reducing GHG emissions is a key objective of the German energy transition framework. The following figures compare the changes in energy-related GHG emissions (Figure 5-60), energy-related GHG emissions per capita (Figure 5-61) and energy-related GHG emissions by sector (Figure 5-62). It should be noted that as all of the analysed scenarios are developed in a way to reach certain GHG emission reduction targets by 2050, so the scenarios' GHG emission pathways are not independent outcomes in a strict sense, but are very much a reflection of the underlying GHG reduction targets pursued by the respective scenarios.

Figure 5-60 illustrates that energy-related GHG emissions[24] are expected to be reduced by 57% to 62% in all but one scenario by 2030 compared to 1990. In the

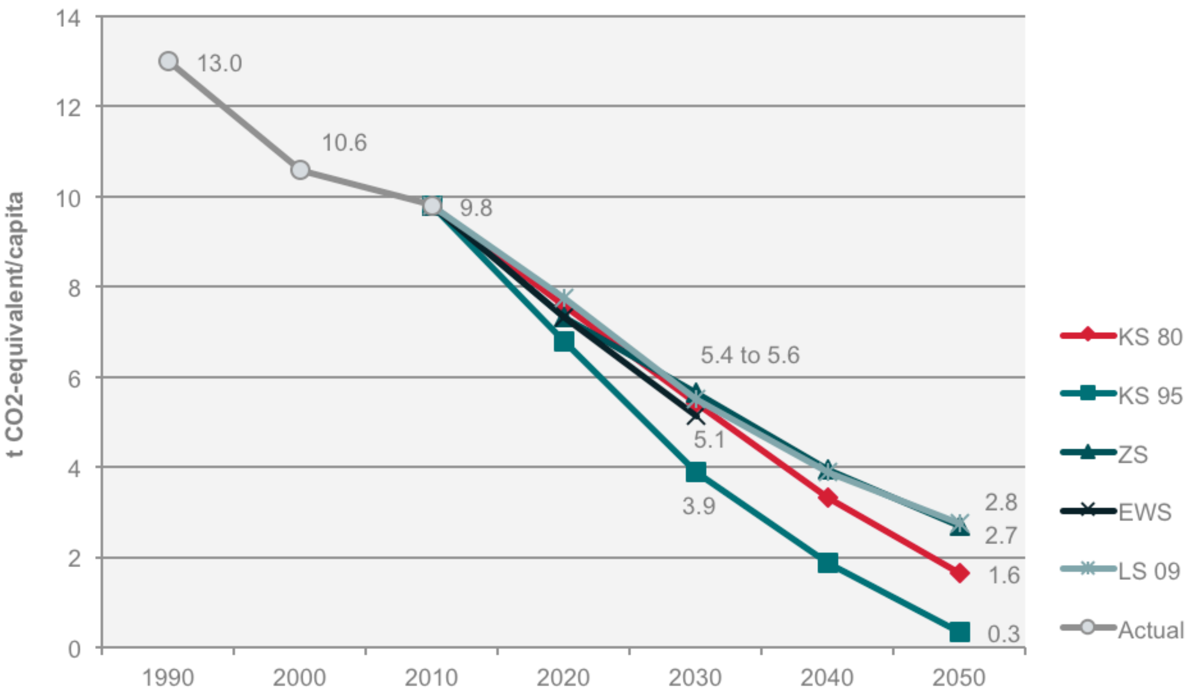
[24] It should be noted that here, as well as in the following figures on GHG emissions, emissions of the ZS scenario only refer to CO_2 emissions, i.e. energy-related non-CO_2 GHG emissions (which currently make up about 2% of total energy-related GHG emissions in Germany) are not included, as they are not reported for that scenario.

KS 95 scenario, these emissions are envisioned to be even lower, with a 71% reduction compared to 1990. By 2050, emissions are anticipated to be further reduced, being 80% to 98% lower than in 1990.



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 5-60 Energy-related GHG emissions (change compared to 1990)

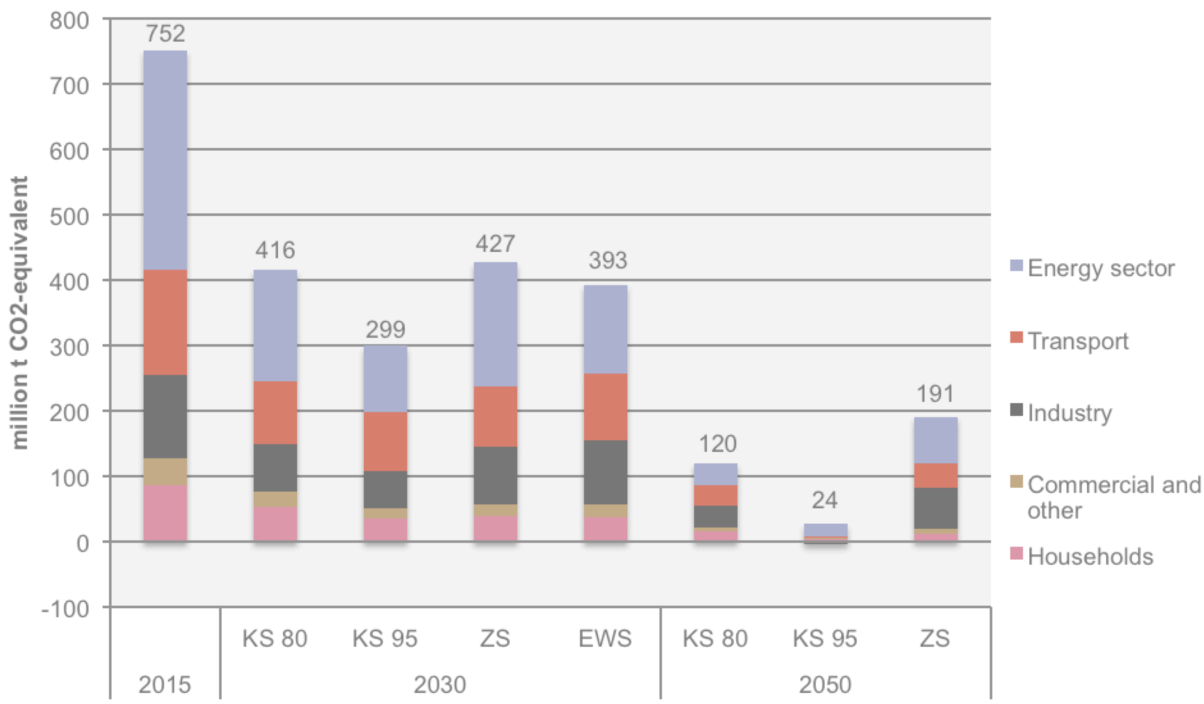


Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 5-61 Energy-related GHG emissions per capita (in t CO_2-equivalent)

The most ambitious scenario, KS 95, does not only foresee the lowest emissions in 2050 by far, but it also plans to reduce emissions much more aggressively in the short to medium term (until 2030). The energy-related GHG emissions per capita, shown in Figure 5-61, equally decline from 13 t of CO_2-equivalent in 1990 to 5.1 to 5.6 t in 2030 in all but the KS 95 scenario. In the KS 95 scenario, the per capita GHG emissions are even further reduced to about 3.9 CO_2-equivalent in 2030. By 2050, the per capita emissions are foreseen to be as low as 0.3t (Ks 95) to 2.8t (LS 09). In all scenarios, emissions are reduced in all sectors, although to a different extent. In the long term (until 2050), emission reductions are most pronounced in the KS 95 scenario, in which net emissions from the industrial sector even become negative in 2050, made possible by a combination of biomass use and carbon capture and storage (CCS) implementation.

According to Figure 5-62, the highest reduction will have to be achieved in the energy sector, with high reductions already foreseen until 2030 by all scenarios. With regards to reduction of GHG emissions in the transport sector, a significant decline is not expected until after 2030, even though limited reductions will already be achieved by 2030. Proportionally, although absolute emissions are expected to be reduced in the industrial sector as well, the role of this sector in overall energy-related GHG emissions increases, especially until 2050 in the KS 80 and ZS scenarios. The shares of energy-related GHG emissions from the residential and commercial sectors, in contrast, decrease continuously until 2050.



It should be noted that there are likely differences between the scenarios in how emissions are allocated to individual sectors. This especially concerns the differentiation between the energy sector and the industry sector.

Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 5-62 Energy-related GHG emissions by sector (without fugitive emissions) (in million t of CO_2-equivalent)

6 Closer look at key energy transition strategies

This Chapter takes a closer, more in-depth look (compared to Chapter 5) at a number of strategies pursued by the respective scenarios that are of key importance for the scenarios to reach certain energy transition objectives. The following analysis intends to complement Chapter 5 by presenting additional scenario insights for these key topics, discussing the insights at length and adding perspective, for example by referring to literature sources beyond the scenario studies where needed. The key energy transition strategies discussed in this Chapter are the following:

- The following strategies are discussed in this Chapter:
- Role of energy efficiency
- Role of renewable energy sources
- Role of CCS
- Role of nuclear power (only for Japan)
- Role of electrification (only for Germany)
- Role of behavioural changes (only for Germany)

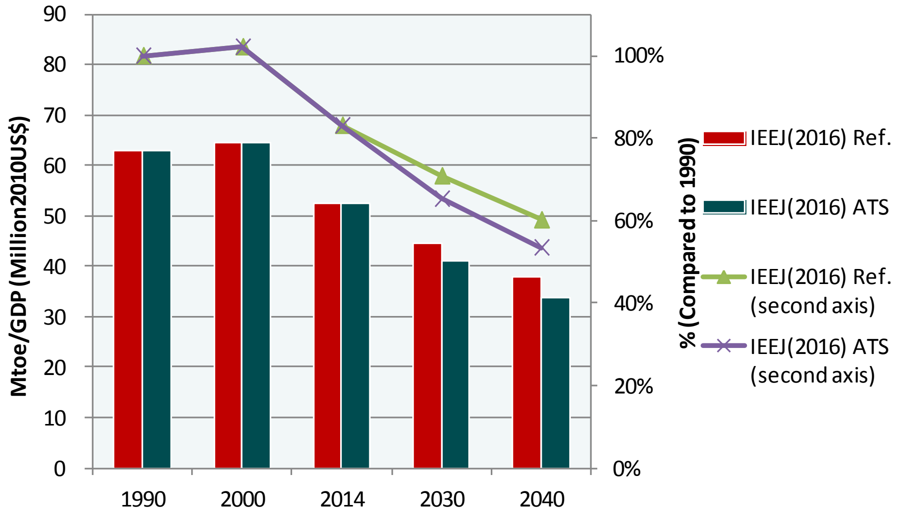
The discussed strategies are not entirely identical between Japan and Germany, as the scenarios' transition strategies between these countries vary to some extend. These differences are inter alia due to difference in energy transition priorities (see Chapter 9) and deviating time horizons of the scenarios (i.e. most of the German scenarios run until 2050, while most of the Japanese scenarios run until 2030).[25]

6.1 Japan

6.1.1 Role of energy efficiency to achieve energy transitions

The Law Concerning the Rational Use of Energy was enacted 1970s after experiencing oil shocks, which obligated companies over certain scale to rationalize energy use. Although it was revised many times and expanded its area, energy efficiency in private sector is not enough compared to industry sector. Thus, additional measures are required such as introduction of evaluation system for small and middle size companies which contribute to energy efficiency.

[25] A discussion of the reasons for differences in the key energy transition strategies pursued by Japanese scenarios compared to German scenarios can be found in the Joint Conclusion (Chapter 9).



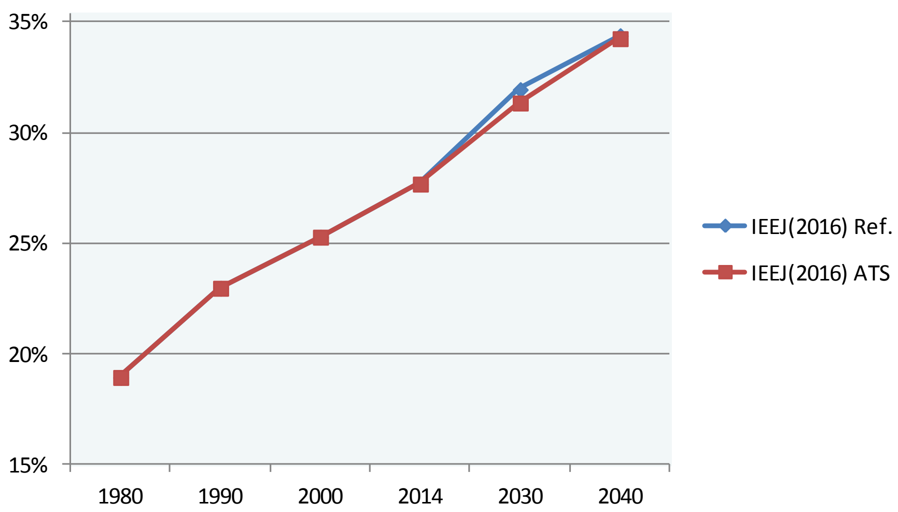
Ref. = reference scenario, ATS = advanced technology scenario

Sources: IEEJ Asia/World Energy Outlook 2016

Fig. 6-1 Final energy demand per capita in IEEJ(2016)

Final energy demand per GDP improved about 17% in 2014 compared to 1990 level. IEEJ estimates final energy demand per GDP will further improve about 30-35% in 2030 and about 40-47% in 2040 compared to 1990 level.

Improvement of living standard has increased demands for electricity. In addition to household sector, by development of advanced information-oriented society, role of electricity has become larger in every sector such as industry. Thus, IEEJ estimates share of electricity in final energy demand will be larger year by year in both scenarios.



Ref. = reference scenario, ATS = advanced technology scenario

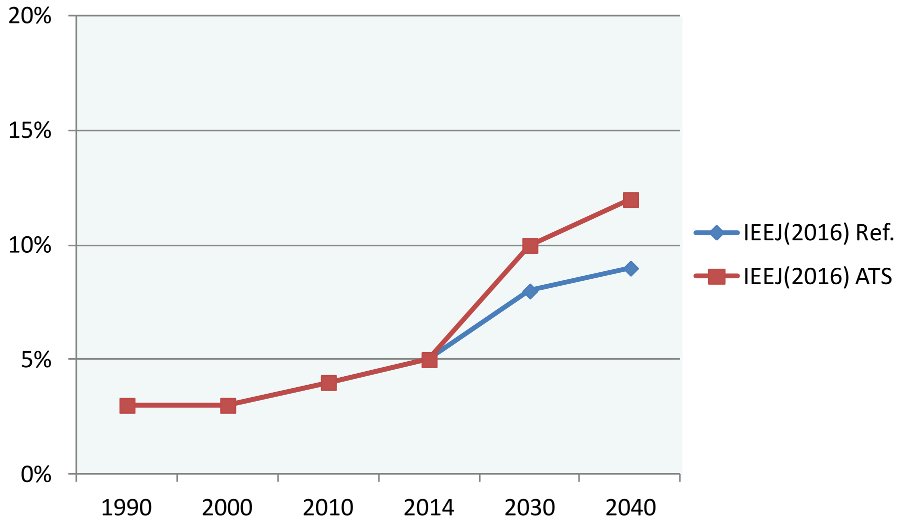
Sources: IEEJ Asia/World Energy Outlook 2016

Fig. 6-2 Electricity rate in final energy demand in IEEJ(2016)

6.1.2 Role of renewable energy to achieve energy transitions

Great expectations are placed on renewable energy, particularly solar PV in which cost will be further reduced. Renewable power generation capacity posted strong growth, while being affected by negative factors such as crude oil price plunges.

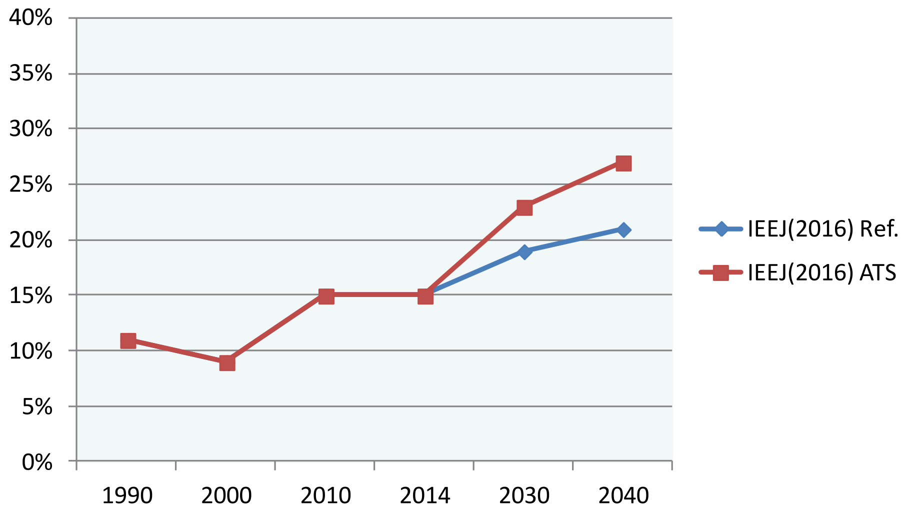
Renewable energy penetration contributes to expanding low-carbon electricity sources, reducing dependence on energy imports, and potentially holding down fossil fuel prices. Large-scale renewable energy penetration will depend on its cost reduction and harmonization of renewable energy with energy systems.



Ref. = reference scenario, ATS = advanced technology scenario

Sources: IEEJ Asia/World Energy Outlook 2016

Fig. 6-3 Share of renewables in primary energy supply in IEEJ(2016)



Ref. = reference scenario, ATS = advanced technology scenario

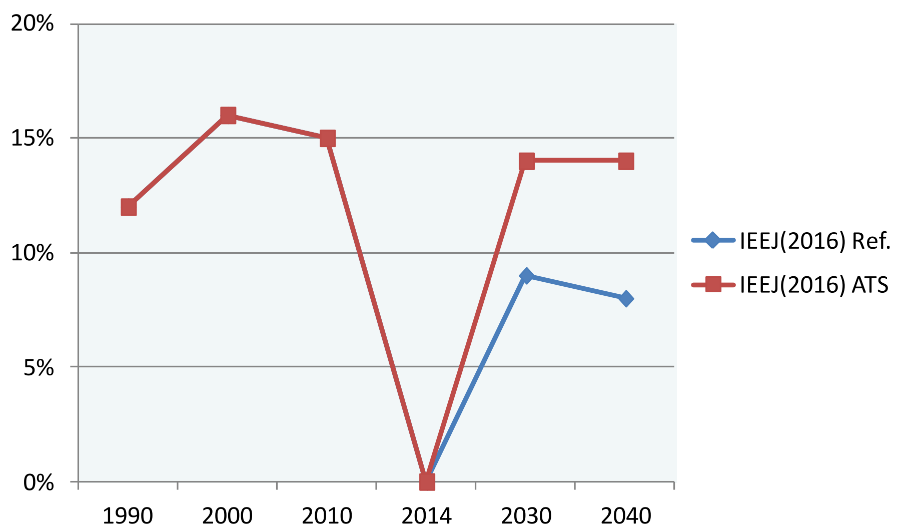
Sources: IEEJ Asia/World Energy Outlook 2016

Fig. 6-4 Share of renewable in electricity generation in IEEJ(2016)

Power generation mix by the government assumed that 64GW of solar PV will be commissioned by 2030 – 9GW of residential and 55GW of non-residential. 61GW out of this 64GW is the sum of the existing commissioned capacity (25GW) and the already approved capacities (36GW). The remaining 3GW is estimated to become certified under the future FiT budget proposed in the government's outlook. The government is implicitly assuming no solar PV will be built without support mechanisms despite the fact that rooftop solar PV has already proven to be economical without incentives in many countries. Currently, residential rooftop PV systems in Japan, on average, cost over 50% more than in Germany and Australia, both markets that have experienced PV system price reductions because PV system prices came down. The rooftop PV market in Germany and Australia is now fully competitive with electricity retail rates. There is no fundamental reason to assume Japan will not follow a similar trajectory, unless additional regulatory burdens are applied to prevent the uptake of rooftop solar PV.

6.1.3 Role of nuclear power to achieve energy transitions

Nuclear power generation capacity expanded in the 1990s before slowing down in the 2000s. After the Fukushima Daiichi Nuclear Power Station accident in 2011, the number of nuclear reactors in operation declined due to the temporary shutdown of reactors for the implementation of additional safety measures under new regulatory standards in Japan. On the other hand, given the risk of imported fossil fuel price fluctuations accompanying a shift from nuclear to natural gas, as well as climate change implications, all analysed scenarios assume the policy will maintain the use of nuclear power plants.



Ref. = reference scenario, ATS = advanced technology scenario

Sources: IEEJ Asia/World Energy Outlook 2016

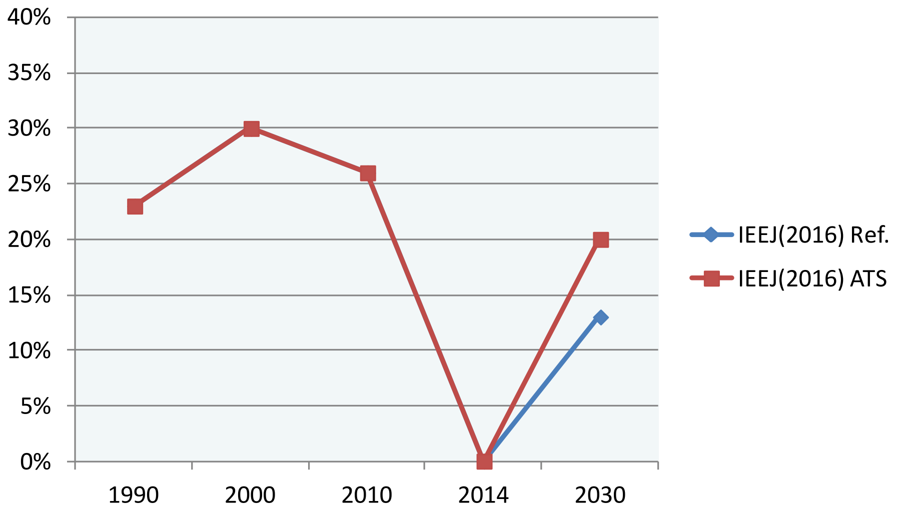
Fig. 6-5 Share of nuclear in primary energy demand in IEEJ(2016)

Nuclear power generation is expected to play an important role in achieving 3E+s. However, the development of nuclear in the future is highly uncertain. This is not only due to technical safety issues, but also a matter of social acceptance and political relations.

If a high nuclear scenario is in effect, nuclear becomes the base power source. This scenario assumes that nuclear power generation will benefit because its power generation cost is estimated to be lower than most renewable energy and comparable with coal and gas. In this scenario, improvement of CO_2 emissions, energy self-sufficiency, and power costs (economy) is highly expected.

On the other hand, if the low nuclear scenario is in effect, no new nuclear power generation plant will be constructed. In this case, CO_2 emissions increase significantly. Consequently, the low nuclear scenario will result in the issues of energy security and climate change.

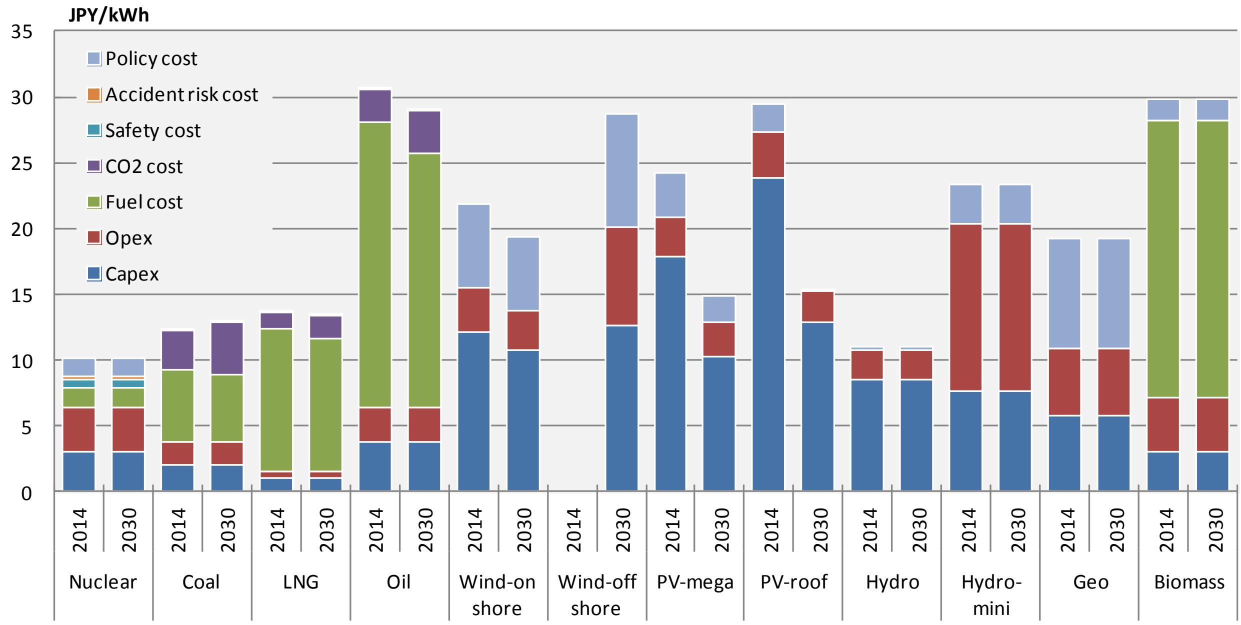
Regardless of high or low development level of infrastructure and technology, risks of nuclear incidents are never zero in countries that have nuclear facilities. It is necessary to make sincere efforts for keeping in mind that there is no end for challenging to improve safety, while nuclear can play an important role to achieve 3E+s.



Ref. = reference scenario, ATS = advanced technology scenario

Sources: IEEJ Asia/World Energy Outlook 2016

Fig. 6-6 Share of nuclear in electricity generation in IEEJ(2016)



Source: METI, Report from the working group to assess power generation cost, April 2015

Fig. 6-7 Power generation costs estimation in Japan (2030)

Box 5: Estimated balancing cost of VRE in Japan

In Japan, the Power Generation Cost Working Group reported (April 2015) their estimation of total balancing cost against variable renewable energy (VRE) in 2030. It estimates the following cost;

- Cost of lower thermal efficiency of thermal power plant due to run at lower road (e.g. 50% of designed capacity).
- Cost of increasing start and stop of thermal power plant.
- Cost of water pumping in pumped hydro power plant.
- Cost to reserve capacity (lower operating rate of thermal power plant).

Estimated result has summarized as following. It can be translated as balancing cost will roughly ranging from JPY 5/kWh to JPY 6/kWh.

Amount of VRE (share to total generation)	Share of RE to total generation	Balancing cost
80 TWh (8%)	21%	JPY 400 billion per annum
90 TWh (9%)	22%	JPY 500 billion per annum
120 TWh (12%)	25%	JPY 700 billion per annum

It should be reminded that the report doesn't cover or analyse other type of balancing cost such like transmission line investment cost, battery storage cost, and demand response cost.

6.1.4 Role of CCS to achieve energy transitions

IEEJ estimates in 2016 Outlook that carbon capture and storage (CCS) technology is being studied and developed as an indispensable tool for the substantial reduction of CO_2 emissions over long time. Particularly, the technology is expected to diffuse in the power generation and industry sectors that are large CO_2 emitters. Japan is conducting a large-scale CCS demonstration test for a CO_2-emitting oil refinery in Tomakomai. Since April 2016, more than 100,000 tonnes of CO_2 have been injected into a test storage. Japan's Strategic Energy Plan calls for research and development to commercialise the CCS technology around 2020.

Conceivable CO_2 storage sites include depleted oil and gas fields, unused coal layers and aquifers. On-going CCS projects are mostly related to enhanced oil recovery (EOR) and other technologies for operating into depleted oil and gas fields. Further technological and economic consideration will be required for using aquifers as stable CO_2 storage sites. In Japan, many institutes including RITE started research for CCS about ten years ago. The first and large-scale demonstration experiment started in Tomakomai, Hokkaido in 2012. It plans to storage annual 100 thousands tons of CO_2 in the ground as well as demonstrate simulation technology which is capable of CO_2 behaviour and base technologies such as monitoring technology. It is the nine-year business from 2012 to 2020. From 2016 to 2018, it has implemented 100 thousands tons scale CO_2 storage.

IEEJ developed the following 3 scenarios in the Outlook 2016 to assess effect of CCS and hydrogen technology. The Advanced Technology Scenario, which assumes stronger energy conservation measures compare to the reference scenario, is the baseline of these 3 scenarios.

Maximum CCS Scenario: In this scenario, CCS including aquifer CO_2 storage will be made available to the maximum extent in the world. The power generation sector will not exploit hydrogen. As hydrogen exploitation costs fail to decline sufficiently, fuel cell vehicle (FCV) penetration in the transport sector will be limited.

Lower Hydrogen Scenario: While CCS will fail to become globally available, the world will seek to substantially reduce CO_2 emissions. In regions where use of CCS in difficult and limited, hydrogen-fired power plants will substitute half of coal- and natural gas-fired power plants after 2035. CCS will fail to expand in the industry sector.

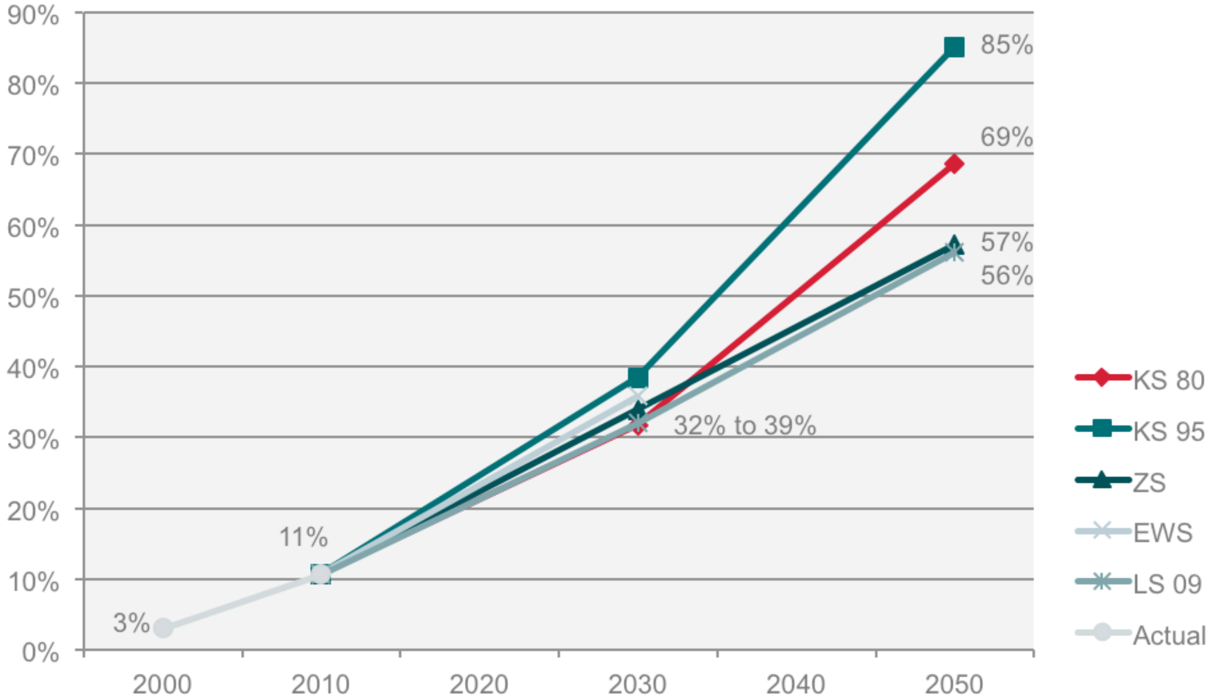
Higher Hydrogen Scenario: In order to assess the maximum hydrogen exploitation potential mainly in the power generation sector, hydrogen-fired power plants are assumed to be substituted for all coal- and natural gas-fired power plants after 2030 in limited CCS employment regions. Hydrogen supply costs will decline substantially while FCVs will penetrate on a worldwide basis faster than in the Advanced Technologies Scenario. FCVs will account for 13% of passenger car in new sales and 8% of car stock in 2050.

6.2 Germany

6.2.1 Role of renewables to achieve energy transitions

Renewable energies will have to play a key role in energy transition strategies in order to decrease the level of greenhouse gas emissions emitted in Germany. Furthermore, the expansion of renewable energies can also contribute to reducing the import dependency in the energy sector. Therefore, it is important to discuss the role renewables play and how their role in the overall energy mix influence the energy transition strategies in the analysed scenarios.

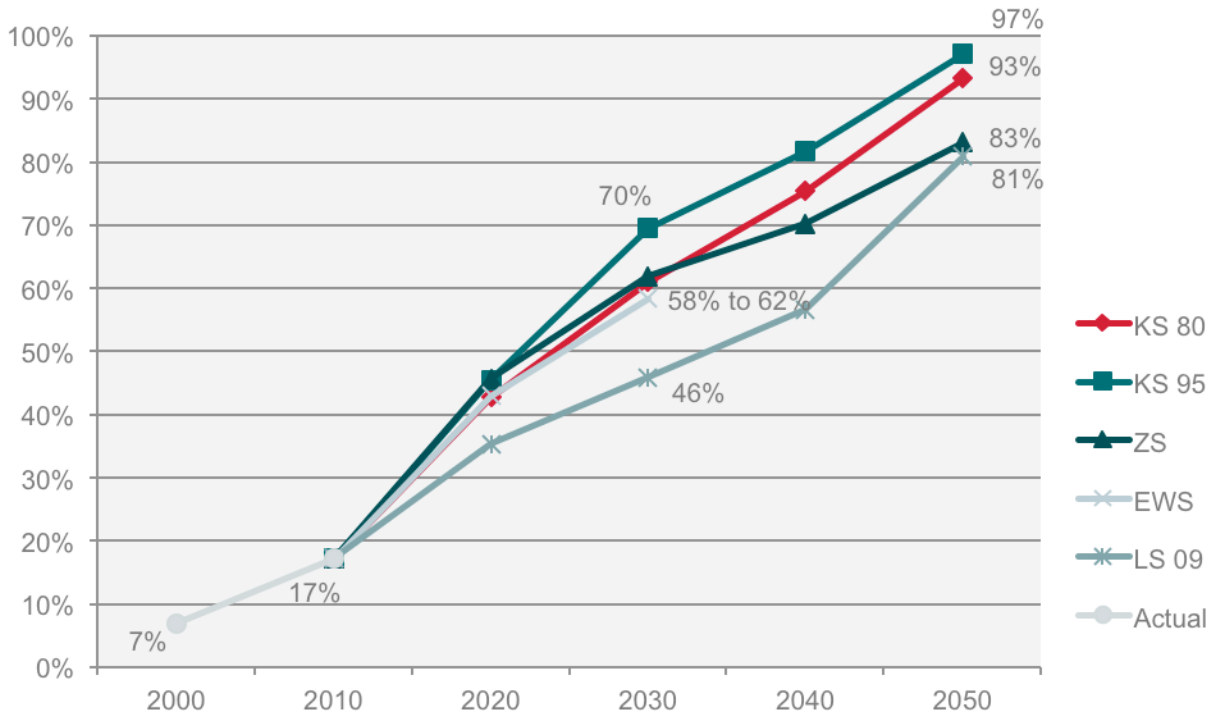
With regard to the share of renewables in primary energy supply, Figure 6-8 shows similar increases from 11% in 2010 to a share in the range of 32% to 39% in all five scenarios by 2030. After 2030 the share of renewables develops differently. While the ZS and the LS scenario anticipate a rather continues increase reaching a share of 56-57% in 2050, the KS 95 and KS 80 project a stronger growth until 2050, resulting in shares between 69% (KS 80) and 85% (KS 95).



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 6-8 Share of renewables in primary energy supply (without non-energetic use) (in %)

However, in regards to the share of renewables in net domestic electricity generation (Figure 6-9), it can be observed that all scenarios project shares of over 80% and up to 97% by 2050. The development pathways from the share of 17% in 2010 to the high shares of renewables in net domestic electricity generation in 2050 differ. By 2030 the share of renewables increases to 58% to 70% in most of the scenarios, with the oldest scenario (LS 09) being an exception with a share of only 46%.



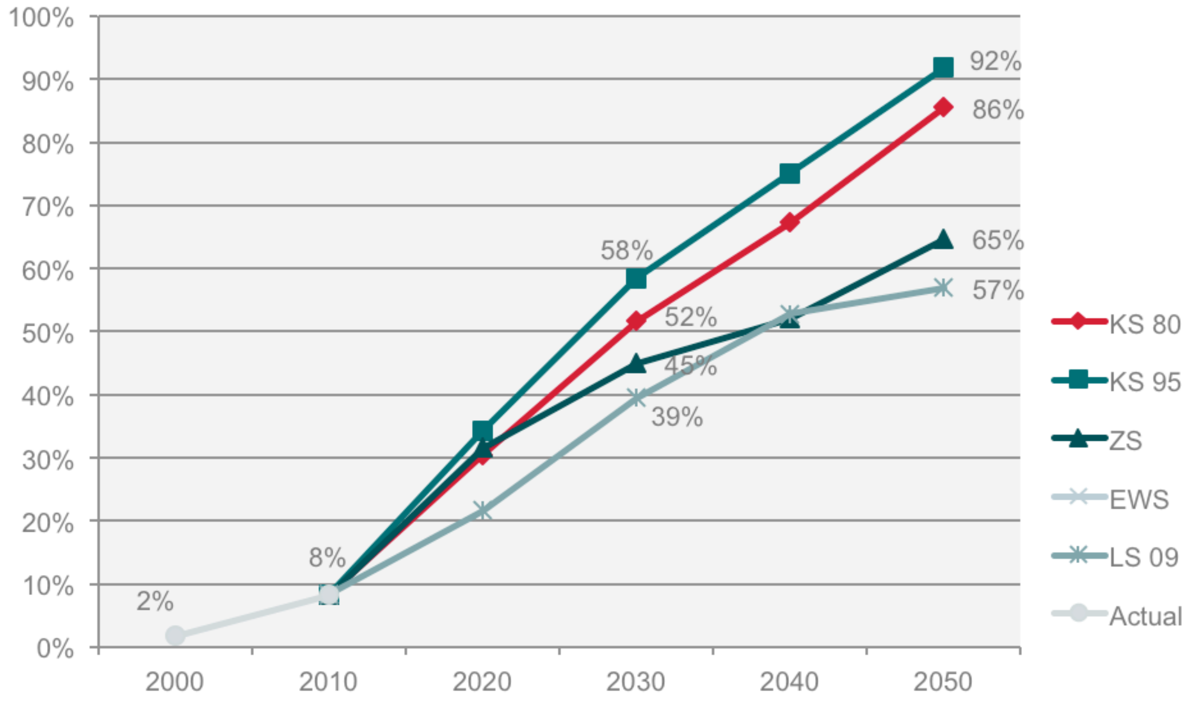
Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 6-9 Share of renewables in net domestic electricity generation (in %)

A closer look at the share of variable renewables in the domestic electricity generation (i.e. wind and solar PV) reveals that this type of electricity generation is expected to dominate domestic electricity supply in the future. The share of wind and PV increases considerably in all scenarios, from 8% in 2010 to about 40% to almost 60% in the scenarios in 2030. Until 2050, these shares increase further to about 60% to 90% (Figure 6-9).

The increasing share of intermittent renewables requires greater flexibility, which places high demands on the transmission infrastructures. To increase the flexibility and compensate the high share of variable renewables projected by the scenarios, various adjustments in the energy system will be needed in the long run (Hillebrandt et al. 2015). Options to make the energy system more flexible include advancing energy-storage options, expanding the transmission infrastructure and making it more flexible (e.g. smart grids), increasing flexible back-up options such as gas or hydro power plants or demand side options like demand reduction or demand-side management (DSM), which comprises shifting time or type of demand (e.g. power-to-heat).

Next to these technology options there are also market-related measures like increased market integration to reduce net volatility, coupling of balancing and intra-day markets, scarcity pricing to enable higher remuneration of flexible resources, dynamic pricing for demand management or cost-reflective grid charges (CEPS 2017). With the share of intermittent renewables projected to increase to 60% to 90% in 2050, none of these measures that support a more flexible energy system will be sufficient on its own. Rather, it is required to combine these different options and to increase the extent to which these measures are implemented considerably over time. For more details on the discussion of the challenges resulting from a high share of intermittent renewables please refer to Hillebrandt et al. (2015) or UBA (2013d).



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 6-10 Share of intermittent renewables (wind & PV) in net domestic electricity generation (in %)

The following Table 6-1 provides a summary of the key flexibility options assumed to be available by 2050 in the four selected German scenarios that run until then. The following four flexibility options are differentiated in the table:

- Energy storage
- Transmission infrastructure expansion
- Use of thermal power plants
- Load shifting and load management

While all scenario studies refer to all of these flexibility options, the details provided differ from one study to another. In general, information on flexibility options are most detailed for the scenarios KS 80 and KS 95. These two scenario with their very high share of intermittent renewables by 2050 (see Figure 6-10), also appear to use the various flexibility options most strongly.

While none of the studies provide quantitative details on the assumed expansion of the domestic and cross-border transmission infrastructure or on the electricity generation mix in the rest of Europe, increased cross-border trade is emphasized in all studies as an important element to enable the integration of high shares of electricity generation from fluctuating renewables. The advantage in this regard of the geographical location of Germany compared to Japan is discussed further in the joint conclusion of this report.

Tab. 6-1 Overview flexibility options assumed to be available by 2050

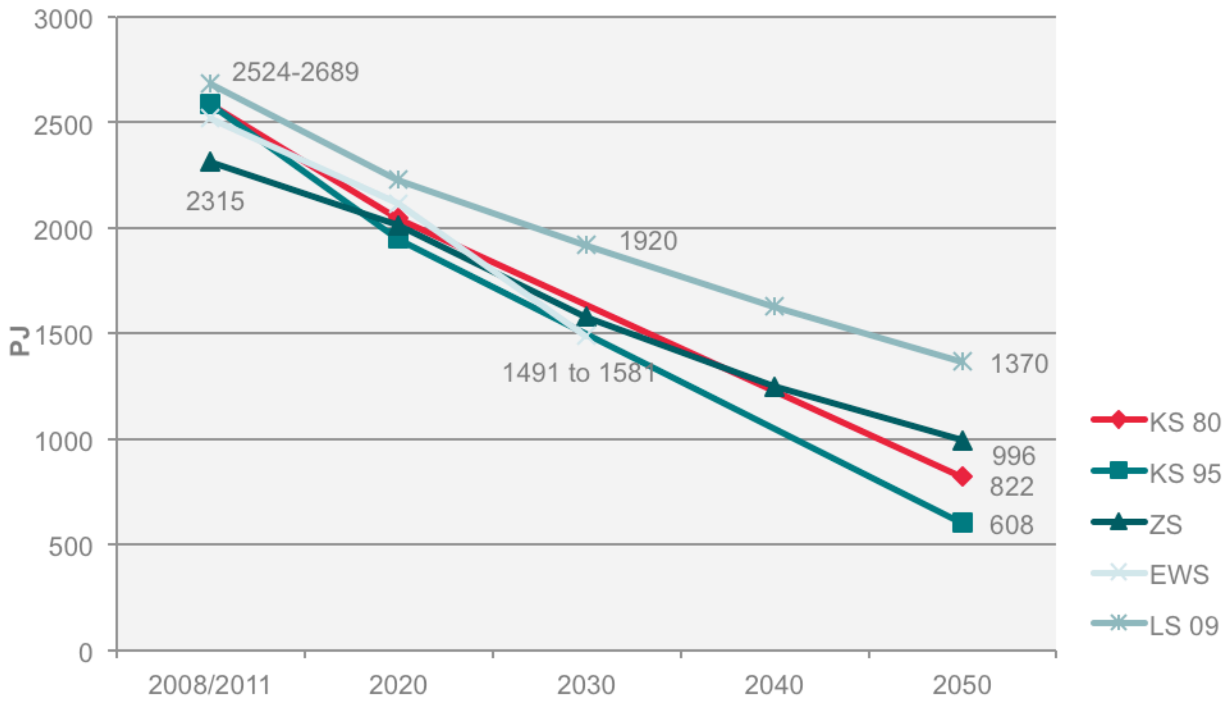
<table>
<tr><th></th><th>KS 80</th><th>KS 95</th><th>ZS</th><th>LS 09</th></tr>
<tr><td rowspan="2">Energy storage</td><td colspan="2">Expansion of pumped hydro storage (PHS) capacity (from current 9 GW to 16 GW) by 2040
Additional use of 6 GW of PHS capacity in Norway by 2050 (grid extensions assumed between Germany and Norway)</td><td rowspan="2">No expansion of PHS and no other types of storage plants assumed</td><td rowspan="2">Additional storage capacity is assumed to be built (with compressed air storage plants mentioned as an example), but not quantified</td></tr>
<tr><td></td><td>Hydrogen from electrolysis and the derived synthetic methane is used from 2040 on to generate electricity</td></tr>
<tr><td>Transmission infrastructure expansion</td><td colspan="4">Expansion of domestic transmission grid and of cross-border interconnections assumed, but not quantified</td></tr>
<tr><td>Use of thermal power plants</td><td>41 GW of gas plus 9 GW of coal power plants (gross) operating in 2050 (most of the plants are used as “back-up”, with very low full-load hours)</td><td>44 GW of gas plus 3 GW of coal power plants (gross) operating in 2050 (most of the plants are used as “back-up”, with very low full-load hours)</td><td>35 GW of gas and 21 GW of coal power plants (net) operating in 2050, operational flexibility of these plants assumed to increase</td><td>21 GW of gas and 8 GW of coal power plants (gross) operating in 2050.</td></tr>
<tr><td rowspan="2">Load shifting and load management</td><td colspan="2">Load management for electric cars, which consume 80 TWh (KS 80) or 106 TWh (KS 95) of electricity in 2050</td><td rowspan="2">Load shifting in industry and load management for electric cars enable a combined 5 TWh/a to be shifted by 2030 and 26 TWh/a to be shifted by 2050</td><td rowspan="2">Load management for electric cars, which consume 11 TWh of electricity in 2050
Power-to-gas plants as new and flexible electricity consumers from 2030 on, these plants use 75 TWh of electricity in 2050</td></tr>
<tr><td>Load shifting for several industrial processes (e.g. in paper and cement production), up to 1.9 GW can be shifted
Strong expansion of power-to-heat applications (13.5 GW by 2050)</td><td>Load shifting for several industrial processes (e.g. in paper and cement production), up to 3.8 GW can be shifted
Power-to-gas and power-to-liquid plants as flexible new electricity consumers from 2040 on, hydrogen productions requires 153 TWh/a by 2050
Very strong expansion of power-to-heat applications (35.3 GW by 2050)</td></tr>
</table>

6.2.2 Role of efficiency to achieve energy transitions

Besides increasing the share of renewables in the energy mix, energy efficiency measures will have to play a pivotal role in order to achieve the transition towards a sustainable energy system. Accordingly, all scenarios agree in the fact that considerable reductions of energy use are needed.

This can be seen, for example, in the projected energy demand for space heating in buildings (Figure 6-11). Already until 2030, significant reductions are expected in all scenarios. The demand reduction continuous until demand is at least halved by 2050. At the same time, differences in regard to the extent of feasible savings are considerable, especially when comparing the energy demand for space heating in the LS 09 scenario, which foresees a reduction of about 29% until 2030 and the KS 95 scenario which expects a higher reduction of about 40% by 2030.

The main reasons for differences are different assumptions about how strongly demand can be reduced through energetic renovations of the existing building stock. Many residential buildings in Germany are over 30 years old and their energy consumption for heating relative to the living space is much higher than in new buildings. In order to reach the projected demand reductions, these buildings need to become more energy efficient. However, energy efficient renovations of buildings can be expensive and owners hesitate to implement the required measures, resulting in a so far overall low renovation rate in Germany. (dena 2017).



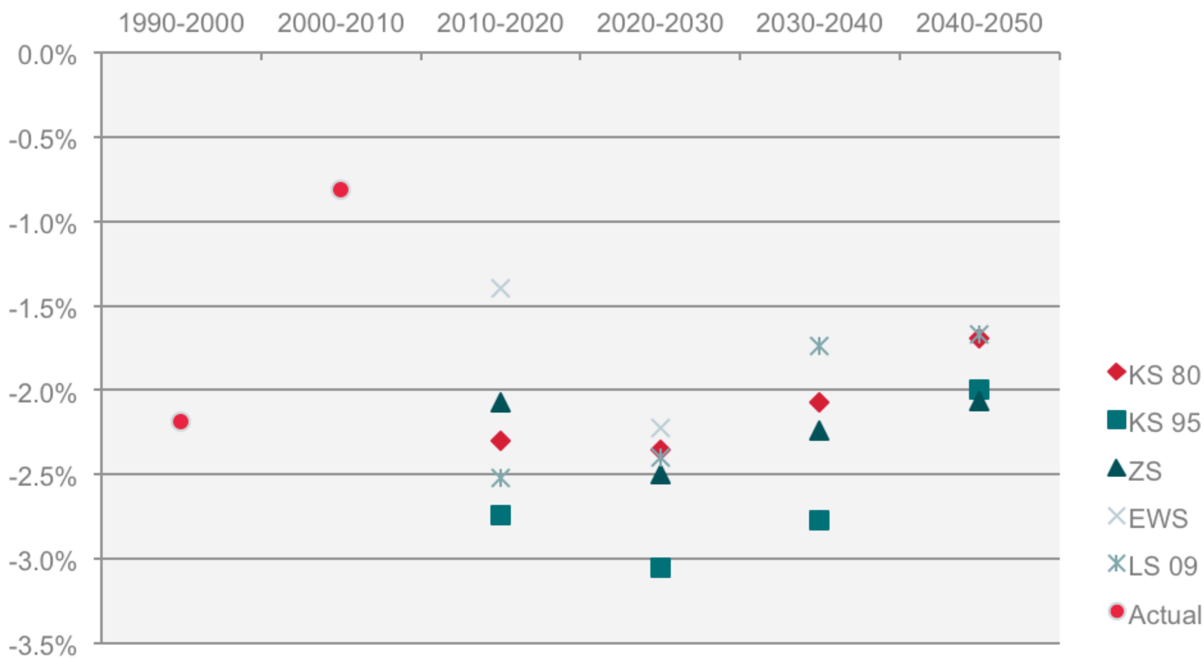
Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 6-11 Final energy demand for space heating in buildings (in PJ)

Taking a closer look at final energy demand, it can be observed in Figure 6-12 that in all scenarios final energy intensity is supposed to be reduced more strongly in the coming decades than it was reduced in the past decade (2010-2020). In most scenarios, the required annual reduction rate in this decade (2010-2020) and especially in the coming decade (2020 to 2030) is at or below the reduction rate experienced between 1990 and 2000 (an average annual reduction of 2.2%). Reduction rates are especially high in the ambitious KS 95 scenario, reaching 2.7% in this decade and even 3% in the next decade.

A main reason for the strong reductions between 1990 and 2000 were the effects of the German reunification, which led to the collapse of the emissions-intensive east German industry in the years following reunification. To reach these levels of average annual reduction in this and the following decades energy efficiency in all sectors needs to be increased significantly.

High potentials to increase the efficiency in Germany exist particularly in industrial processes, transport sector and the previously discussed building sector (Hillebrandt et al. 2015). The majority of the potential efficiency measures in these sectors are predicted to be cost-effective, both on macroeconomic and individual levels (Schlomann et al. 2016). Therefore, it is expected that the projected reductions of final energy intensity are still feasible, but the timely practical implementation might pose a problem. For a more detailed overview of current trends in energy efficiency measures in Germany please refer to Schlomann et al. (2015).



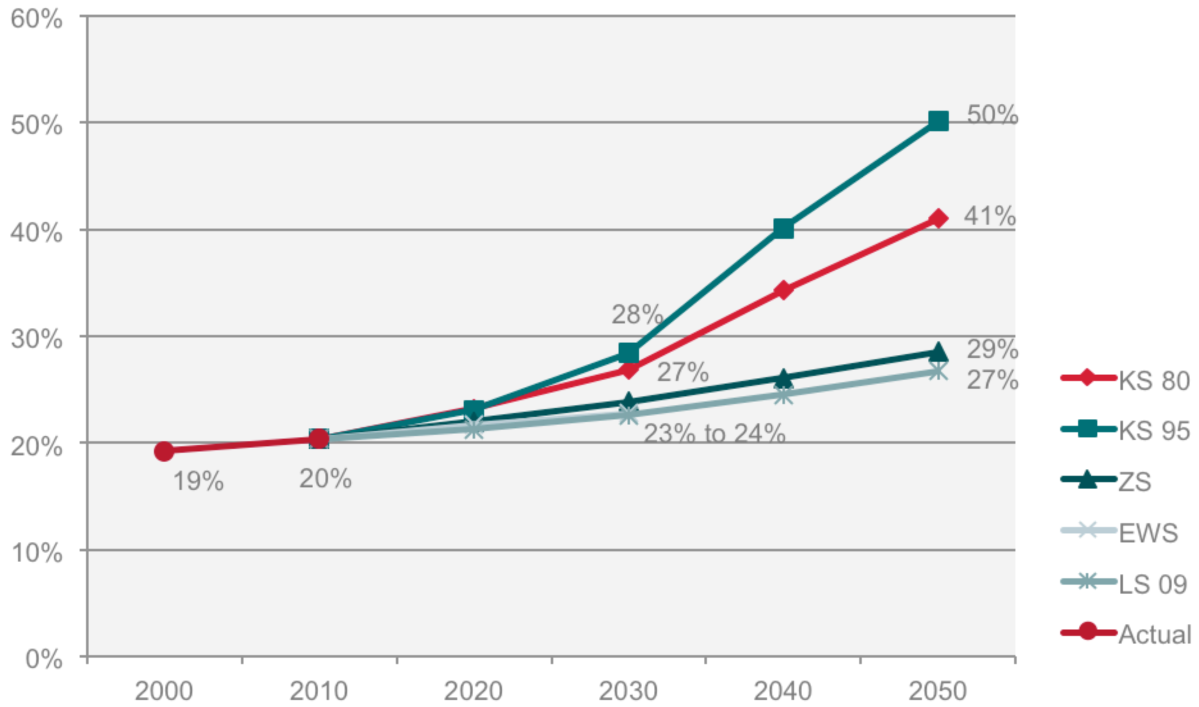
Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 6-12 Average annual change in final energy intensity (in %)

6.2.3 Role of electrification to achieve energy transitions

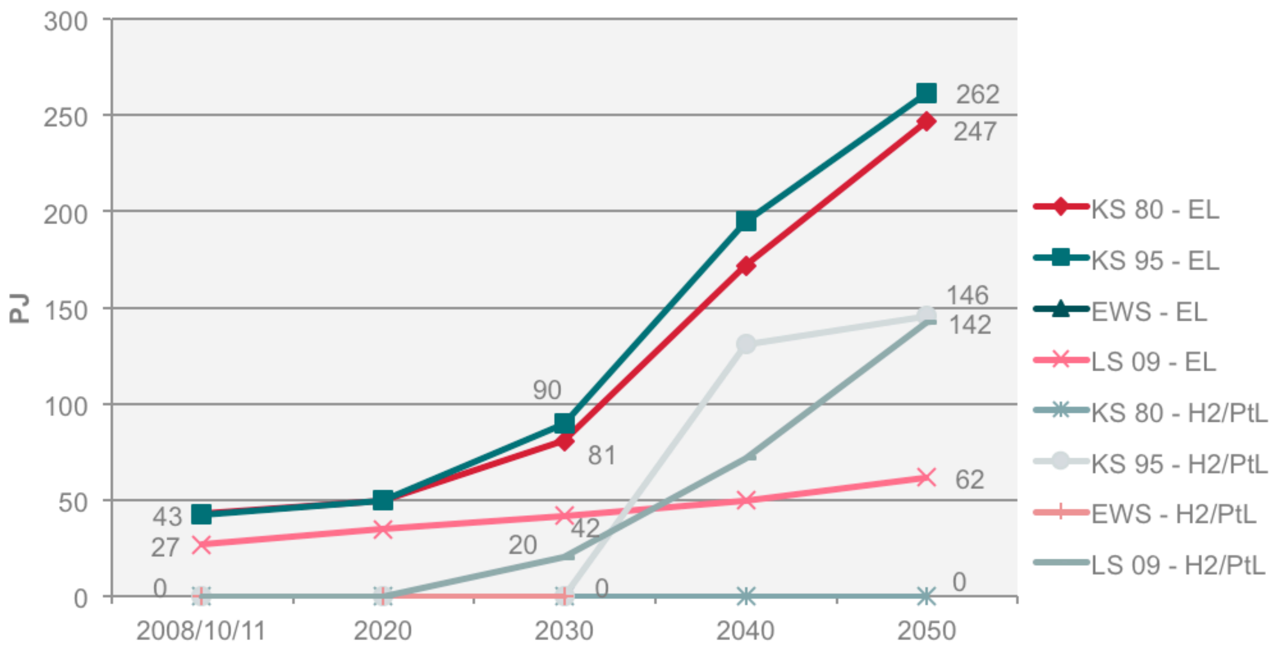
Another key strategy to achieve energy transitions is to expand the electrification of activities in the industry, transport and building sector. Electrification allows zero-carbon renewable electricity to be used for activities that so far rely on the use of fossil fuels. Accordingly, electrification is an important strategy to reduce greenhouse gas emissions in a low-carbon energy system. Furthermore, electrification also allows to increase the efficiency of processes as in many cases electrification allows applications with higher efficiency to be used, for example electric engines instead of less efficient combustion engines.

In regards to electrification as a transition strategy, all scenarios show a strong growth of electricity in the final energy demand, from about 20% in 2010 to 23% to 28% in 2030 (Figure 6-13). After 2030 the share of electricity in the total final energy demand continues to increase in all scenarios, but particularly the KS scenarios show a strong growth up to 41% in KS 80 and even 50% in KS 95. These observations suggest that electrification is a key strategy in these scenarios to achieve the energy transition in Germany.



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 6-13 Share of electricity in total final energy demand (in %)

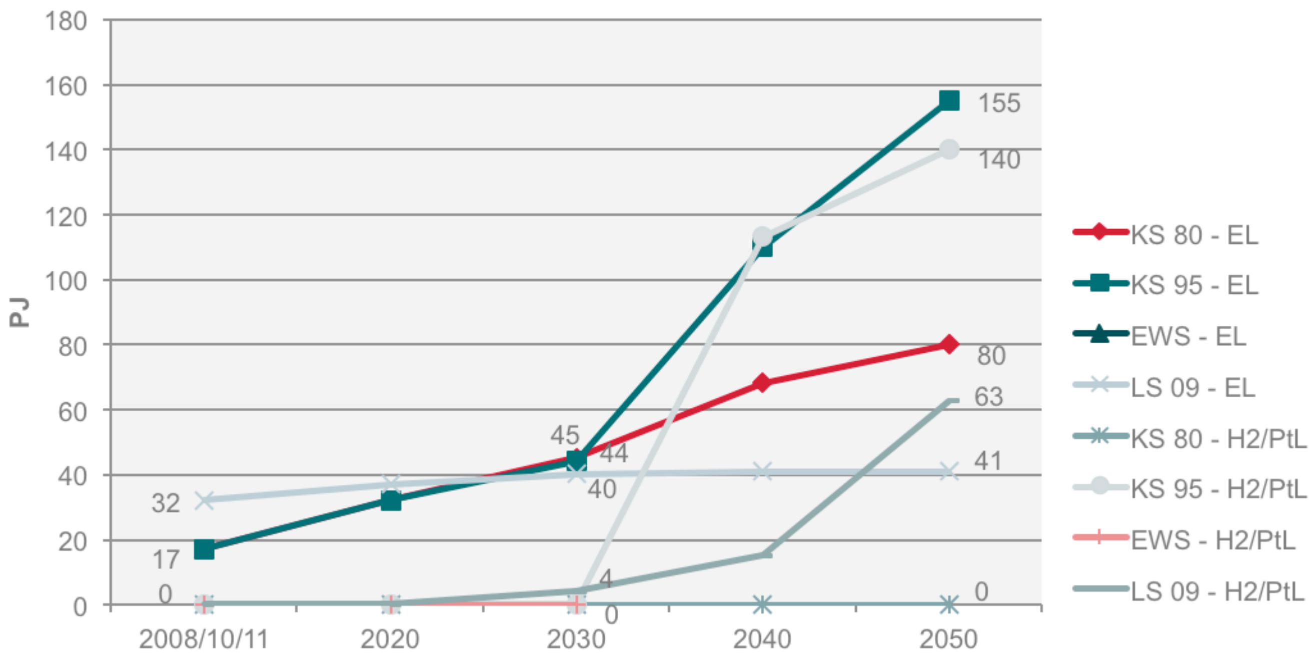


Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 6-14 Electricity and hydrogen/power-to-liquid use in the passenger transport sector (in PJ)

Taking a closer look at the role of electrification in the transport sector, all scenarios expect electricity to play a more prominent role in the future. With regards to the role of electricity in passenger transport (Figure 6-14) it is shown that the use of electricity increases slowly until 2030. After 2030, the LS 09 scenario foresees only a low but continuous increase, while KS 80 as well as KS 95 project a very steep increase between 2030 and 2050. The same can be observed for hydrogen/power-to-liquid, which is only considered in the two KS scenarios. Hydrogen/power-to-liquid are becoming relevant in these scenarios from 2030 onwards.

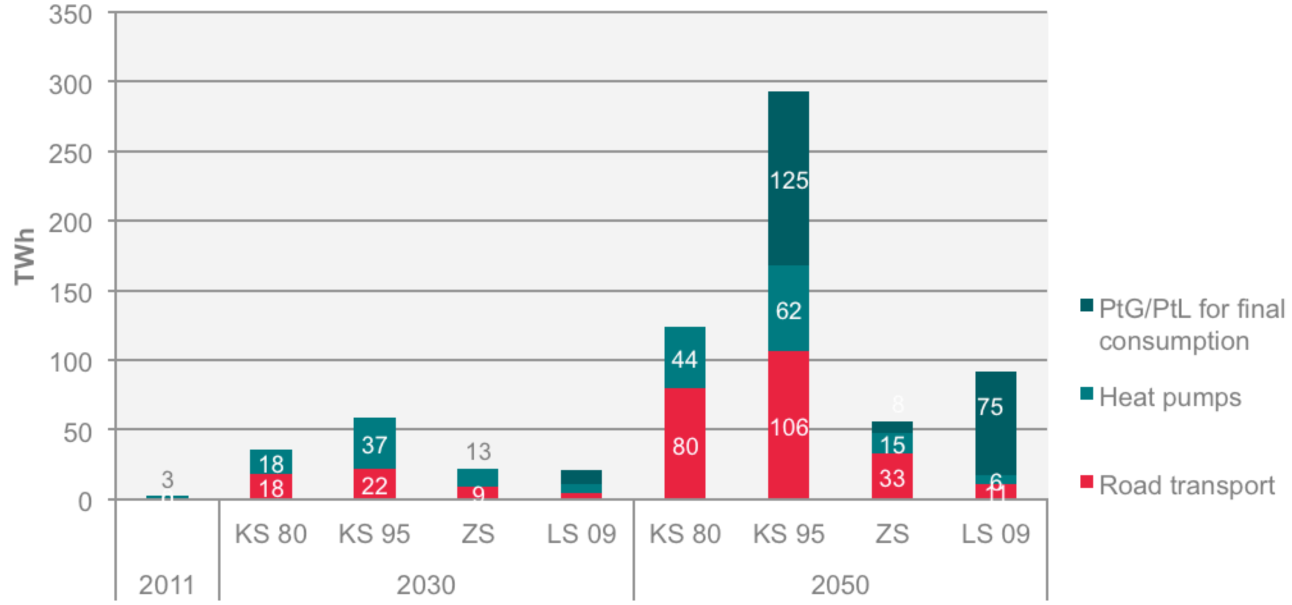
In the freight transport sector (Figure 6-15), growth of electricity use presents itself to be more modest than in passenger transport, but especially in KS 95, electricity use increases considerably as well, especially after 2030. The reasons for the slower increase in electricity use can be traced back to the fact that electrification of heavy transport vehicles is much more difficult than for passenger transport vehicles. In KS 95 however, the scenario assumes that trucks can be partly electrified by power cables on key highways, explaining the higher use of electricity compared to the other scenarios. After 2030, hydrogen/power-to-liquid use shows to be of relevance in KS 95 and LS 09. These are same scenarios which also foresee hydrogen/power-to-liquid to play an increasing role in the passenger transport sector.



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

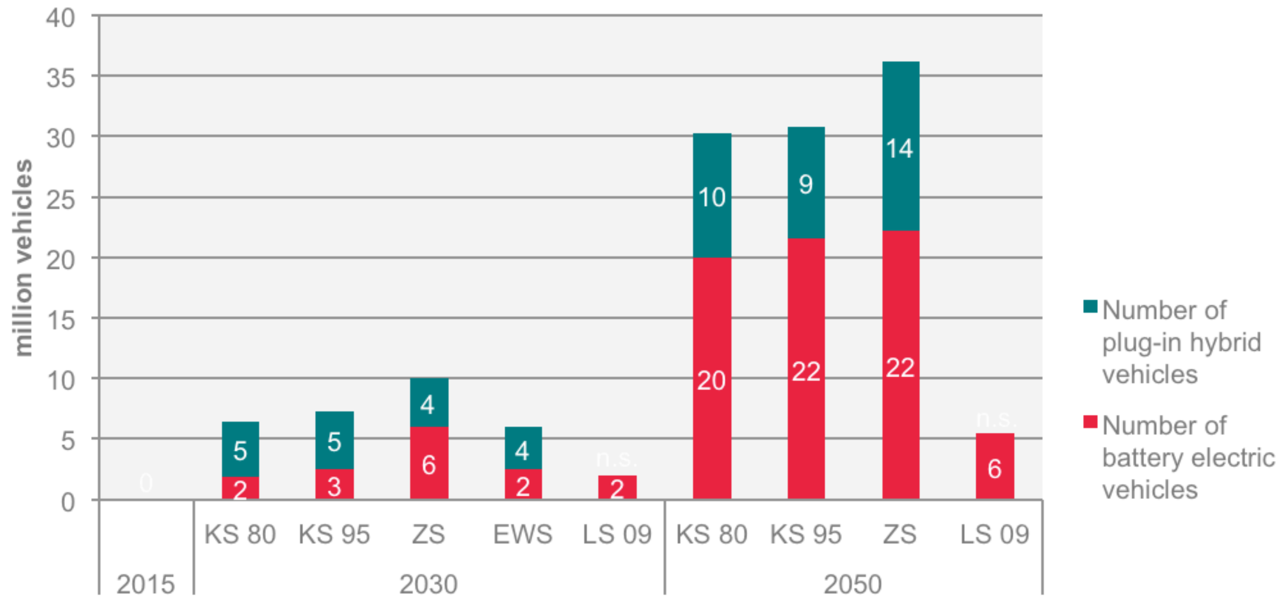
Fig. 6-15 **Electricity and hydrogen/power-to-liquid use in the freight transport sector (without international maritime traffic) (in PJ)**

Expanding electrification also implies that additional electricity will be required for "new" applications, which is illustrated in Figure 6-16. These new applications include heat pumps, plants to produce power-to-gas/power-to-liquid for final consumption purposes and electric road vehicles. It should be noted that the figure does not include power-to-heat applications, as no specific information on these was provided in the majority of the analysed scenario studies.



Sources: Own figure based onBMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 6-16 Electricity demand for "new" applications (in TWh)



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 6-17 Number of battery electric and plug-in hybrid passenger vehicles in use (in million)

Demand from these new applications already starts to become relevant in the scenarios by 2030, with an additional annual power demand of 20 to about 60 TWh for heat pumps and electric vehicles combined, in all but the LS 09 scenario. Between 2030 and 2050, the scenarios start to differ considerably in their assumptions on the future additional power demand from these new applications.

These differences do not only relate to the extent of electricity demand but also the types of applications differentiated in Figure 6-17. While road transport based on electricity has a high or the highest share in the three scenarios KS 80, KS 95 and ZS, it plays only a minor role in the LS 09 scenario. In LS 09 the electricity demand from the new applications will mainly come from power-to-gas/power-to-liquid applications. High demand from these applications is also projected by KS 95, which in total foresees a very high additional electricity demand from “new” applications.

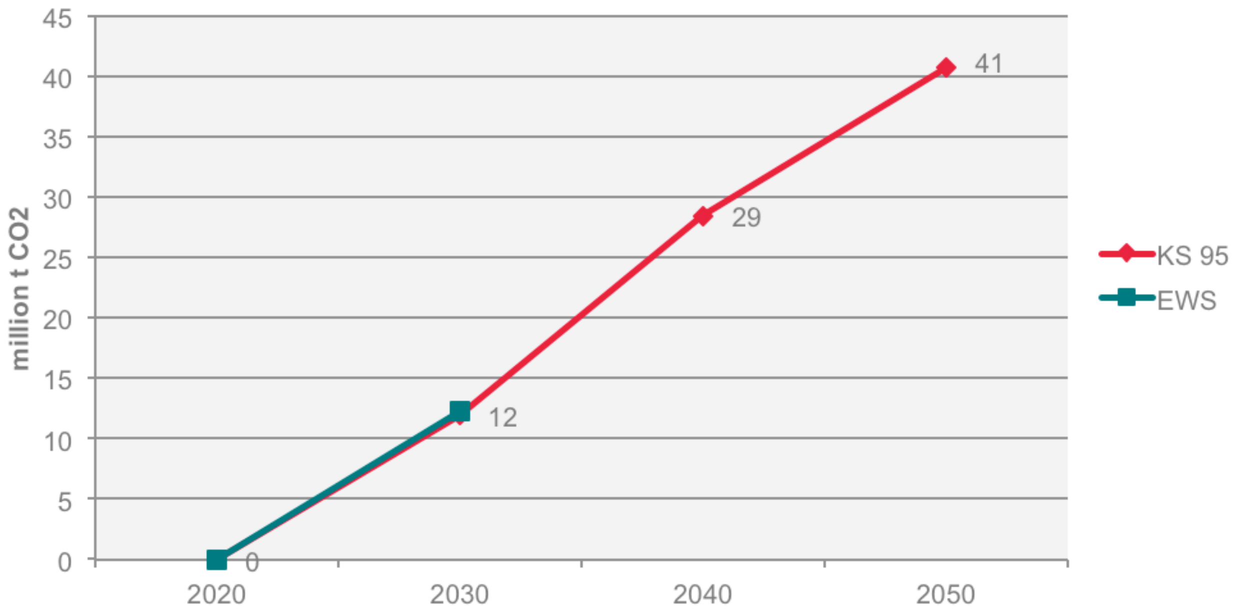
As shown, the electricity demand for electric road transport will increase already until 2030 in all scenarios. Accordingly, electric vehicles will play an increasing role in the transport sector, contributing to reducing the GHG emissions from this sector. In terms of the type of electric vehicles, it can be differentiated between battery-run and plug-in-hybrid vehicles. By 2030, most scenarios foresee 2 to 3 million electric battery vehicles to be in use (with even 6 million in the ZS scenario), plus 4 to 5 million additional plug-in hybrid electric vehicles. These numbers are expected to rise sharply so that until 2050, when 20 to 22 million full electric vehicles and an additional 9 to 14 million plug-in-hybrid vehicles are expected to be in use in all but one scenario. In the older LS 09 scenario, the projected amount of full electric vehicles is much lower, at only 6 million in 2050, while no information is provided about the amount of plug-in hybrid electric vehicles.

6.2.4 Role of carbon capture and storage (CCS) to achieve energy transitions

In order to achieve a global transition towards a low-carbon energy system, underground carbon-dioxide sequestration is often regarded as an important option. In this context, the term Carbon-Capture-and-Storage (CCS) is used to describe technologies that allow to capture CO_2 emissions from the energy or industry sector and store them underground, either on- or offshore (IEA 2017). While CCS can potentially reduce the amount of harmful greenhouse gas emissions released into the atmosphere, concerns exist in regard to the environmental safety, technological progress, social acceptance and financial viability (UBA 2013c).

While internationally, CCS power plants are often assumed to play an important role to achieve climate change mitigation objectives, in Germany it is generally assumed today that CCS power plants will not be part of a future sustainable electricity supply in Germany (UBA 2013c). However, even in Germany CCS might play a role in the future when applied to capture emissions from industrial processes that cannot be avoided in the foreseeable future.

Among the analysed scenarios, two assume that CCS will be used in Germany in the future to reduce emissions from the industrial sector. Both, EWS and KS expect CCS to start playing a role during the 2020s, with the amount of CO_2 sequestered annually being 12 Mt in both scenarios in the year 2030 (Figure 6-18).



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 6-18 CO_2 sequestered annually by means of CCS (in million t)

After 2030, KS 95, which provides data until 2050, shows a steady rate of increase of the annual volume of CO_2 sequestered to 41 Mt by the year 2050. By comparison, the total potential storage capacity in Germany is estimated to be about 6.3 to 12.8 billon tonnes of CO_2 (BGR 2017). The widespread use of CCS combined with the use of biomass assumed in KS 95 explain the negative emissions reported for the industrial sector in this scenario (see Figure 5-62).

6.2.5 Role of behavioural changes to achieve energy transitions

Apart from technological strategies to achieve the transition towards a sustainable energy system, behavioural changes that can reduce the use of energy directly or indirectly can also play a relevant role. However, in many energy scenarios, behavioural changes towards energy-sufficient lifestyles are not or only marginally assumed to take place in the future (Samadi et al. 2016).

In the analysed scenarios, the potentials of behavioural changes for the energy transition in Germany are also given only limited attention. Some behavioural changes are implied in the transport sector, where compared to the respective reference scenarios, either reductions in passenger-km (Figure 5-39) and/or increases in the share of local public transport and rail in land-based passenger transport (Figure 5-40) are assumed.

The scenario KS 80 and especially the scenario KS 95 assume some additional behavioural changes. These include reduced meat consumption compared to a reference scenario (although this change mainly affects non-energy-related GHG emissions, that are not focused on in the study at hand) and in the KS 95 scenario also an assumed reduction of the indoor temperature during the heating period, from 20 °C to 19 °C.

Behavioural changes can undoubtedly contribute to reducing energy demand and GHG emissions and can also reduce the investments required to achieve a certain reduction in GHG emissions. However, many scenarios do not explore the potential of behavioural changes or do so only marginally. This may be due to a limited understanding of how such changes can be initiated and perhaps also doubts about whether efforts to modify behaviours or lifestyles will be accepted by the public.

7 Analysis of macroeconomic implications of energy system transition

This chapter analyses the macroeconomic implications of the energy system transitions described by the various scenarios, focusing inter alia on the expected effects on investments, GDP, employment and foreign trade. It needs to be emphasized that the following overview describes the respective findings of the analysis performed by the selected scenario studies. It was not possible within the scope of this project to perform separate (and harmonized) modelling analysis of the potential macroeconomic implications. As the studies use different methodologies and sometimes report different parameters, comparisons between scenarios as well as interpretations of observed differences need to be made carefully.

7.1 Japan

7.1.1 Comparison of methodologies (especially models applied)

METI(2012) conducted analyses using four computable general equilibrium (CGE) models base on common energy (and electricity) demand which provided by METI. Different structure of power generation will change its cost and hence affect economic activity. Models are also required to comply with CO_2 emission reduction rate set by METI, and they calculate marginal CO_2 abatement cost (MAC), i.e. necessary carbon price. This carbon price will also affect economic activity. Models divided into two groups depending on employed assumption of power generation cost. Group B models assumes higher power generation cost than Group A models in thermal power and nuclear power.

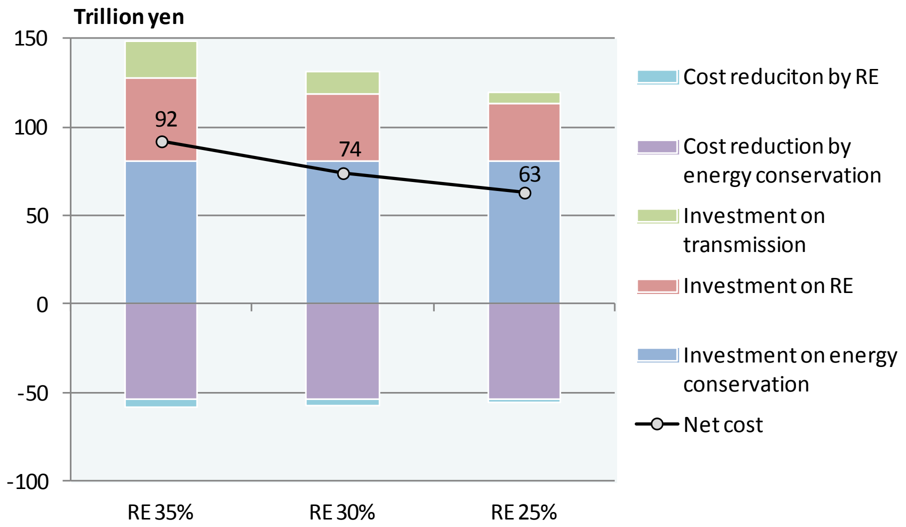
Organization/model	Assumption of power generation cost	Herein after call it
- Keio university - Research Institute of Innovative Technology for the Earth (RITE)	Adopt estimation of government committee	Group A
- Osaka university - National Institute of Environment Studies (NIES)	Adopt their own estimation	Group B

RITE(2015) also conducted economic impact analysis using CGE model (DEARS). Similar to METI(2012), different power generation mix will change electricity cost, hence affect economic activity. MAC (IEA WEO2014 new policy scenario equivalent and 450 scenario equivalent) is exogenously adopted to estimate other part including energy demand and CO_2 emission reduction. Which means that CO_2 emission reduction amount is calculated in the model depending on power generation mix and carbon price.

Meanwhile, IEEJ(2015) utilize econometric model for analysis. IEEJ utilize integrated econometric type model, combination of macro economy model and energy supply-demand model, to emphasize inter-linkage of both systems. Power generation mix will affect economic activity through power generation cost, fossil fuel import price, and so on. The model does not include carbon price.

7.1.2 Investments

No report is indicating investment amount for low carbon technologies such like energy efficiency and renewable energy. However in METI(2012), it calculate cumulated investment and cost reduction amount from 2011 to 2030 for the reference case, which is not a result of model analysis. It shows 81 trillion yen of investments in energy conservation, 32-47 trillion yen of investments in renewables and 7-21 trillion yen of investments in transmission, which will result in 54 trillion yen of energy conservation merit and 2-4 trillion yen of renewable merit. It indicates that approximately two third of investment cost will be compensated by its benefit to reduce energy consumption.



	RE 35%	RE 30%	RE 25%
Investment on energy conservation	81	81	81
Investment on RE	47	38	32
Investment on transmission	21	12	7
Cost reduction by energy conservation	-54	-54	-54
Cost reduciton by RE	-4	-3	-2
Net cost	92	74	63

Sources: METI, Basic data for draft of choice of energy mix, June 2012

Fig. 7-1 Accumulated investments on energy conservation and renewable energy (2011-2030)

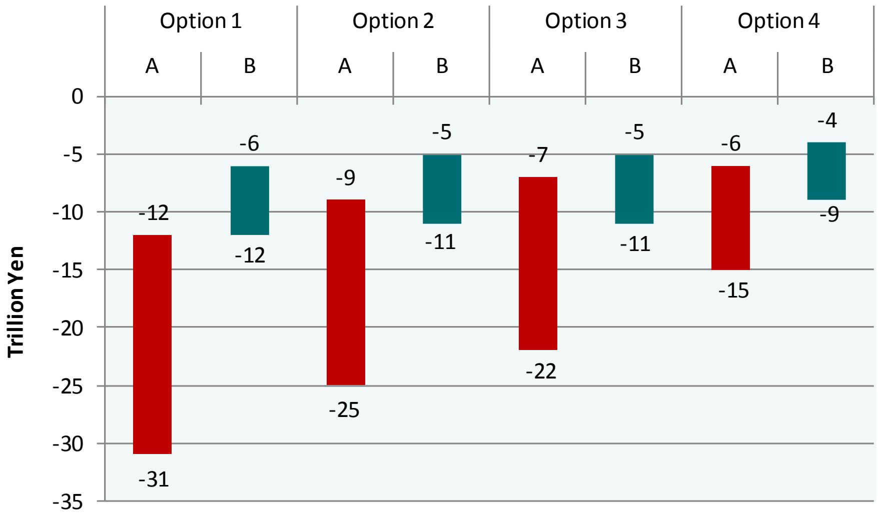
7.1.3 GDP, employment

7.1.3.1 Effect on GDP

METI(2012) estimates impact of different power generation mix to GDP. It is basically saying that less nuclear power together with higher share of renewable energy and fossil fired power generation will provide negative impact on GDP.

Since METI gathers four estimates which were developed by different organizations, calculated result differs widely. For instance in Option 1, where assuming high share of renewable energy (35%) and thermal power generation (50%) together with zero nuclear power, it estimates that the assumed power generation structure will reduce GDP by 31 to 12 trillion yen (5%-2% reduction) for the Group A analyses compared to the reference case which assume no additional energy conservation measure and the same power generation mix as in 2010. On the other hand, reduction of GDP become smaller, from 12 to 6 trillion yen (2%-1% reduction), in the Group B analyses ..

GDP loss become smaller as share of nuclear in power generation increase. This trend is more significant in the Group A analyses. This is because that the Group A models assume wider disparity of power generation cost between nuclear power and renewable power.



Option 1= Nuclear 0% + Renewable 35%+ Coal 24%+ LNG 17%+ Oil 6%+ Co-generation 15%
Option 2= Nuclear 15% + Renewable 30%+ Coal 23%+ LNG 11%+ Oil 4%+ Co-generation 15%
Option 3= Nuclear 20-25% + Renewable 25-30%+ Coal 21%+ LNG 8%+ Oil 4%+ Co-generation 15%
Option 4= Nuclear 35% + Renewable 25%+ Coal 16%+ LNG 3%+ Oil 4%+ Co-generation 15%

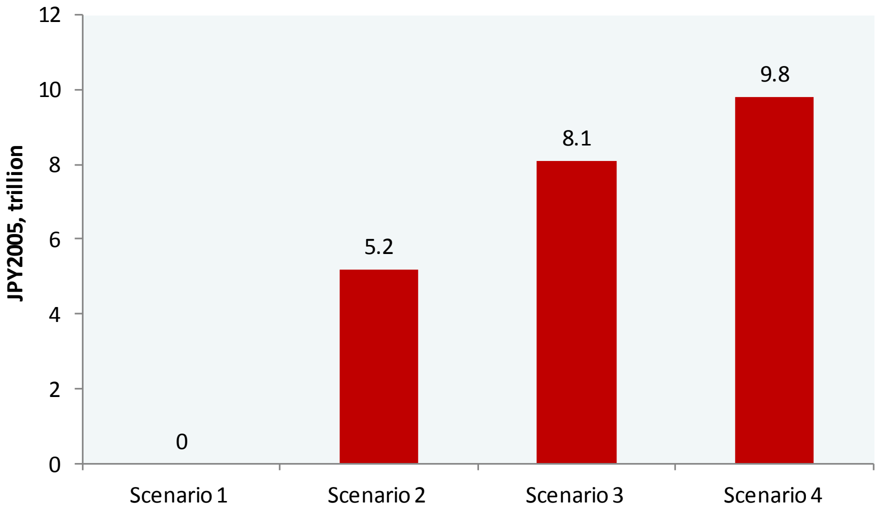
A = Group A analyses (Keio university and RITE)
B = Group B analyses (Osaka university and NIES)

Baseline of comparison is the reference case (no additional energy efficacy measures, power generation structure in 2010 will remain until 2030)

Sources: METI, Draft of choice of energy mix, June 2012

Fig. 7-2 Impact of power generation mix on real GDP in 2030

The IEEJ (2015) estimates differences of real GDP in the year 2030 caused by energy import spending and electricity rates. The results show that Scenario 4 that assume higher share of nuclear power and less renewable can gain an additional JPY 10 trillion compared to Scenario 1.



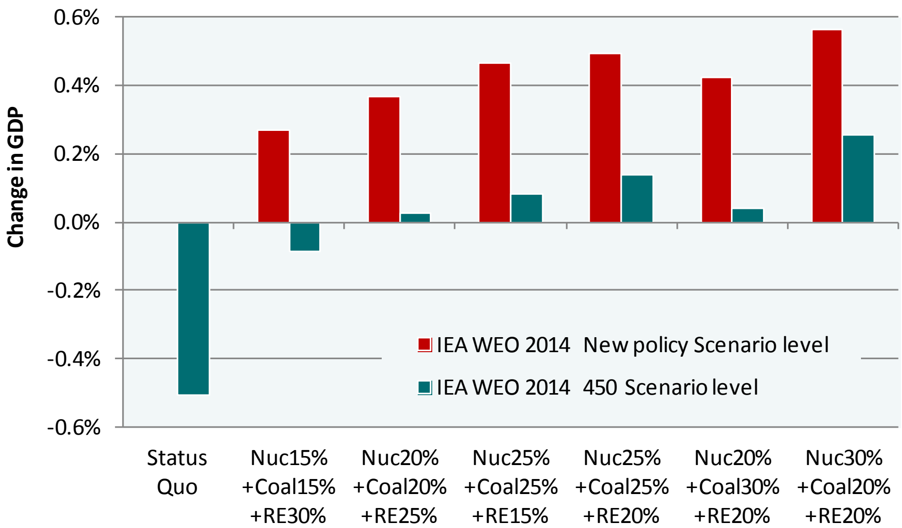
Scenario 1 = Nuclear 0% + Renewable 35%
Scenario 2 = Nuclear 15% + Renewable 30%
Scenario 3 = Nuclear 25% + Renewable 25%
Scenario 4 = Nuclear 30% + Renewable 20%
Baseline of comparison is the Scenario 1

Sources: IEEJ, Towards Choosing Energy Mix, 2015

Fig. 7-3 Difference of Real GDP in 2030

RITE (2015) estimates GDP and household consumption as follows. It shows GDP will become larger as the ratio of baseload power generation, i.e. nuclear power and coal power, increase. This is because it assumed power generation cost is cheaper in such baseload power generation compared to other middle to peak power generation, particularly renewable power such like solar PV and wind. In addition, when comparing the last two scenarios which represent different composition of baseload power generation, nuclear and coal. It appears that higher share of nuclear to coal will bring more economic benefit as it reduce CO2 emission mitigation cost.

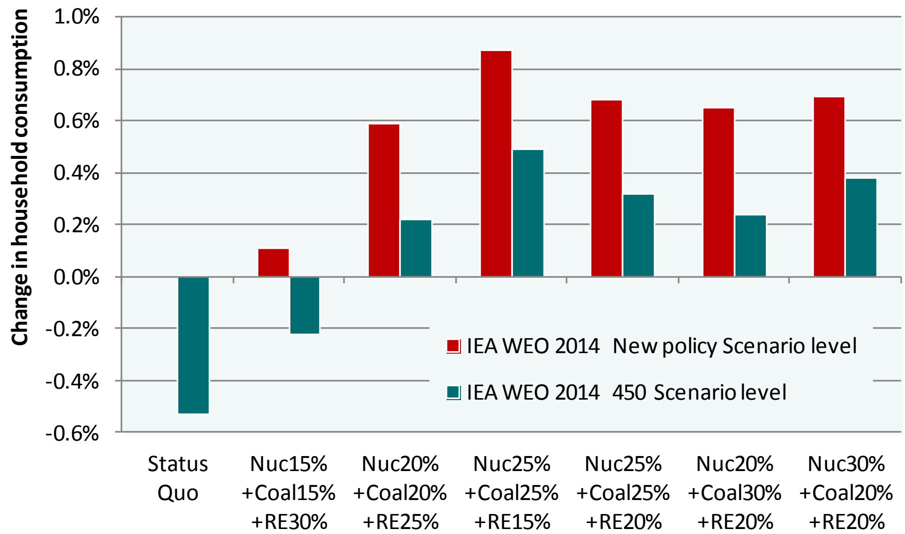
When comparing different level of CO2 emission restriction, the study resulted to present that stronger restriction, i.e. IEA WEO 2014 450 scenario, will further dampen GDP growth. The result can be explained by different level of assumed CO2 cost and hence applied CO2 emission mitigating technologies. It assumes CO2 cost of $37/ton-CO2 (2000 price) in 2030 for the IEA WEO 2014 new policy scenario and $61/ton-CO2 (2000 price) in 2030 for IEA WEO 450 scenario respectively. Higher CO2 cost allow more expensive mitigation technologies to penetrate the market, and it enable to reduce larger amount of CO2 emission, while on the other hand it increase total cost to reduce GDP.



Baseline of comparison is the Status quo + IEA WEO 2014 New policy scenario level CO2 emission restriction
Status quo = assume power generation structure in 2013 (Nuc 1%, Coal 32%, RE 13%) will remain until 2030

Sources: RITE, Analysis of energy mix and GHG emission projection, 2015

Fig. 7-4 Effect of power generation mix on GDP in 2030



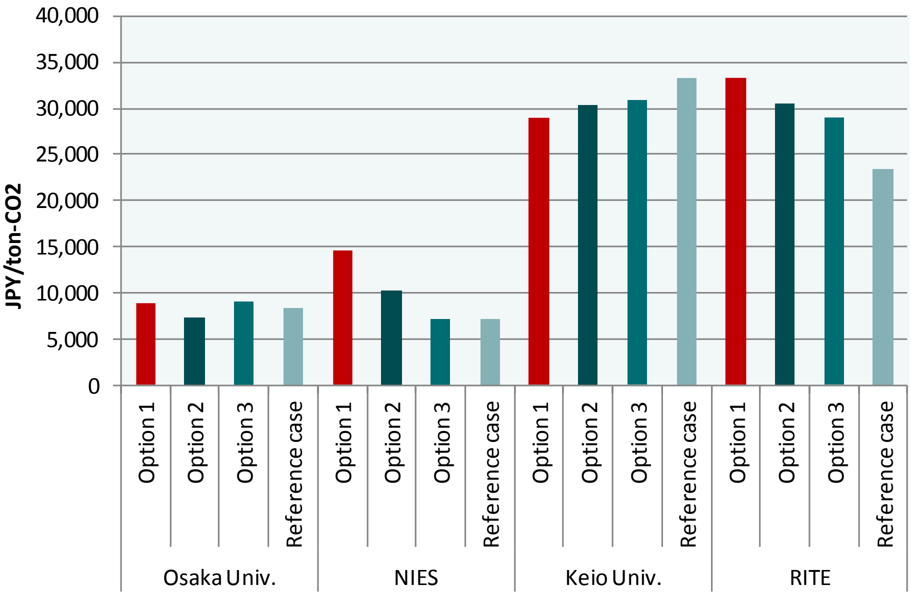
Baseline of comparison is the Status quo + IEA WEO 2014 New policy scenario level CO2 emission restriction
Status quo = assume power generation structure in 2013 (Nuc 1%, Coal 32%, RE 13%) will remain until 2030

Sources: RITE, Analysis of energy mix and GHG emission projection in Japan

Fig. 7-5 Effect of power generation mix on household consumption in 2030

7.1.3.1 Effect on marginal abatement cost

The marginal abatement cost of CO2 is also estimated in the METI(2012). The option 1, 2, 3, and 4 assume CO2 emission reduction of 16%, 20%, 23%, and 28% respectively in 2030 relative to 1990. Every models endogenously estimate marginal CO2 abatement cost, i.e. carbon price, to comply with such reduction amount of CO2 emission. CO2 emission can divide into that from power generation and others. Of which, power generation mix cannot be changed by carbon price since it is exogenously adopter assumption, while other energy demand will be affected. In general, calculate result demonstrate that carbon price become lower when assuming higher share of non-fossil power generation increase as it will ease necessary action in other sectors. According to the Group A models, Keio University and RITE, the estimated marginal CO2 abatement cost is around JPY 30,000/ton-CO2. While the Group B models, Osaka University and NIES, estimate it about JPY 10,000/ton-CO2.



Option 1= Nuclear 0% + Renewable 35%+ Coal 24%+ LNG 17%+ Oil 6%+ Co-generation 15%
Option 2= Nuclear 15% + Renewable 30%+ Coal 23%+ LNG 11%+ Oil 4%+ Co-generation 15%
Option 3= Nuclear 20-25% + Renewable 25-30%+ Coal 21%+ LNG 8%+ Oil 4%+ Co-generation 15%
Option 4= Nuclear 35% + Renewable 25%+ Coal 16%+ LNG 3%+ Oil 4%+ Co-generation 15%

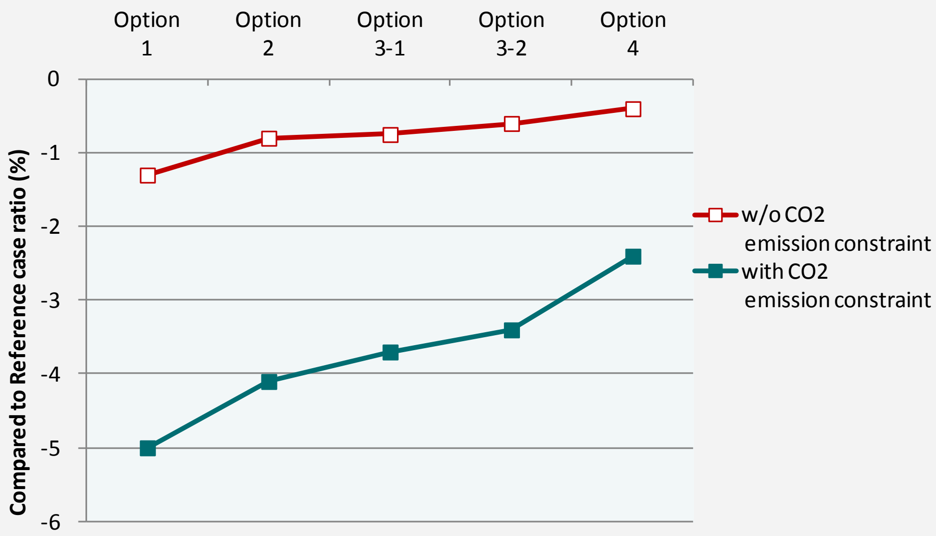
Sources: METI, Draft of choice of energy mix, June 2012

Fig. 7-6 Marginal abatement cost of CO_2 emission

Box 6: GDP impact of CO_2 restriction

In METI(2012), each scenario put restriction for CO2 mission amount, and models are endogenously calculating marginal CO2 abatement cost, i.e. carbon price, to comply with respective constraint. Calculated carbon price will affect type and amount of energy consumed in sectors other than power generation. RITE decomposed effect of different scenarios on GDP into power generation mix element and CO2 constraint element by estimate cases which do not apply restriction for CO2 emission. If there is no restriction for CO2 emission, power generation cost will become dominant element to differentiate impact for GDP. Meanwhile when assume strict constraint of CO2 emission, carbon price become necessary to fill in gap between the CO2 constraint and effect of power generation mix to reduce CO2 emission, and this carbon price push down economy.
When comparing cases “with” CO2 constraint and “without” CO2 constraint, larger negative effect on GDP is observed in “with” CO2 constraint cases. It demonstrate

that CO2 constraint element has greater effect on GDP than power generation mix element.



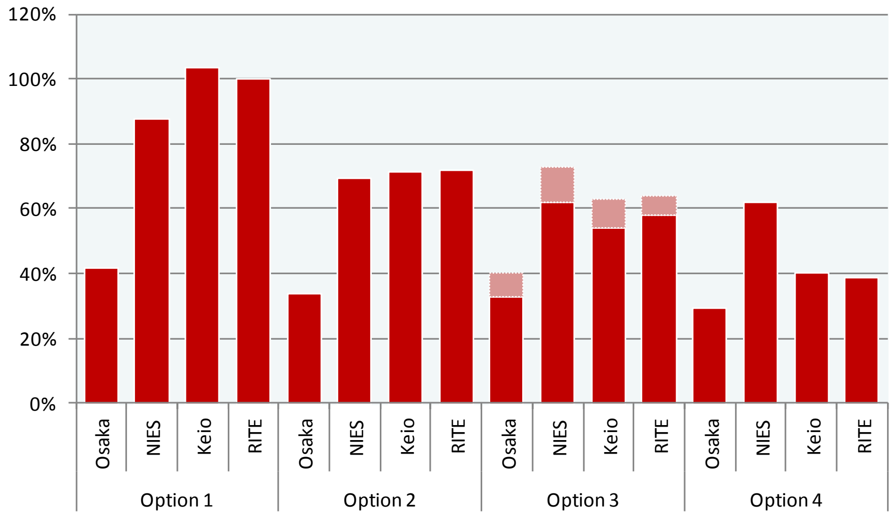
Option 1 = Nuclear 0% + Renewable 35%, CO2 emission reduction target -16% from 1990
Option 2 = Nuclear 15% + Renewable 30%, CO2 emission reduction target -20% from 1990
Option 3-1 = Nuclear 20% + Renewable 30%, CO2 emission reduction target -23% from 1990
Option 3-2 = Nuclear 25% + Renewable 25%, CO2 emission reduction target -23% from 1990
Option 4 = Nuclear 35% + Renewable 25%, CO2 emission reduction target -28% from 199

Sources: METI, Draft of choice of energy mix, June 2012

Fig. 7-7 Impact of CO2 emission constraint on real GDP (2030)

7.1.3.1 Effect on electricity price

METI(2012) estimates electricity rates in 2030 for the different power generation mix, mostly assessing different combination of nuclear power and renewable. Every analysis presents that larger share of nuclear power while smaller share of renewable power will decrease power generation cost and electricity price.



Option 1 = Nuclear 0% + Renewable 35%+ Coal 24%+ LNG 17%+ Oil 6%+ Co-generation 15%
Option 2 = Nuclear 15% + Renewable 30%+ Coal 23%+ LNG 11%+ Oil 4%+ Co-generation 15%
Option 3 = Nuclear 20-25% + Renewable 25-30%+ Coal 21%+ LNG 8%+ Oil 4%+ Co-generation 15%
Option4 = Nuclear 35% + Renewable 25%+ Coal 16%+ LNG 3%+ Oil 4%+ Co-generation 15%

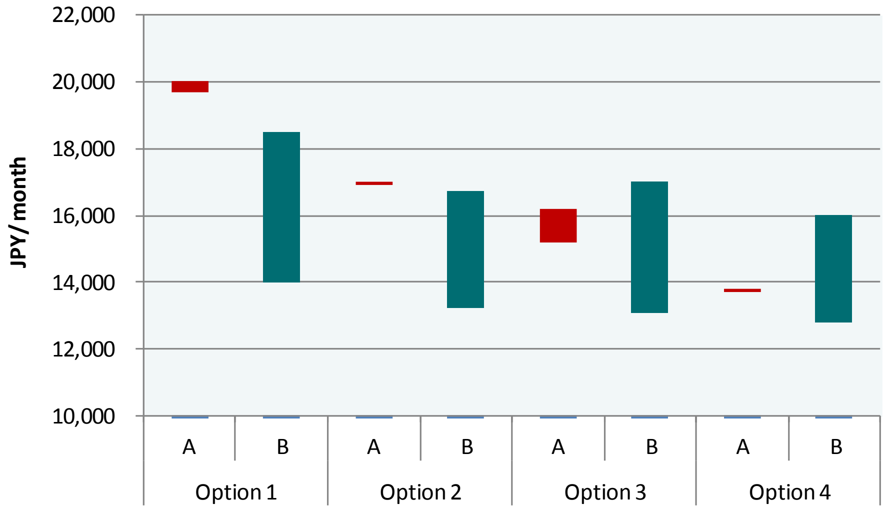
Baseline of comparison is the reference case (no additional energy efficacy measures, power generation structure in 2010 will remain until 2030)

Sources: METI, Draft of choice of energy mix, June 2012

Fig. 7-8 Change rates of electricity tariffs in 2030 compared

When comparing the options, it appears that lower share of nuclear power, in turn higher share of renewable energy, will increase electricity charge. For example in the extreme case Option 1 which assume 0% of nuclear and 35% of renewable energy, electricity charge is calculated to become from JPY 19,700/month to JPY 20,000/month in 2030 according to the Group A analyses. This is about JPY 6,000 or approximately 1.4 ford increase of monthly payment, which is not small for industry and household.

IEEJ(2015) estimate electricity “cost” rather than electricity “price”. It includes not only power generation cost but also include balancing cost for variable renewable power and surcharge of Feed-in Tariff for renewable power. The scenario 1, where assume zero nuclear together with highest renewable power, resulted in highest cost and scenario 4, where assume highest share of nuclear power together with low renewable power, resulted in lowest cost.



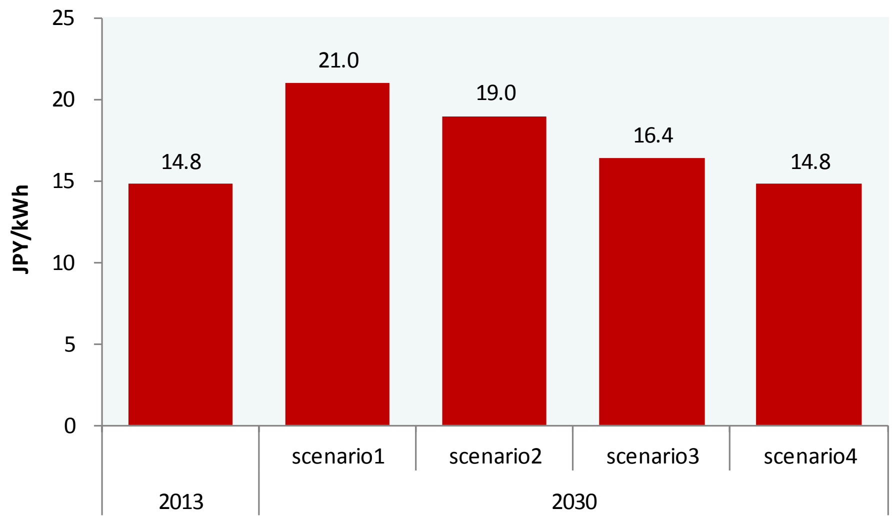
Option 1 = Nuclear 0% + Renewable 35%+ Coal 24%+ LNG 17%+ Oil 6%+ Co-generation 15%
Option 2 = Nuclear 15% + Renewable 30%+ Coal 23%+ LNG 11%+ Oil 4%+ Co-generation 15%
Option 3 = Nuclear 20-25% + Renewable 25-30%+ Coal 21%+ LNG 8%+ Oil 4%+ Co-generation 15%
Option 4 = Nuclear 35% + Renewable 25%+ Coal 16%+ LNG 3%+ Oil 4%+ Co-generation 15%

A = Group A analyses (Keio university and RITE)
B = Group B analyses (Osaka university and NIES)

Baseline of comparison is the reference case (no additional energy efficacy measures, power generation structure in 2010 will remain until 2030)

Sources: METI, Draft of choice of energy mix, June 2012

Fig. 7-9 Nominal electricity charge in 2030

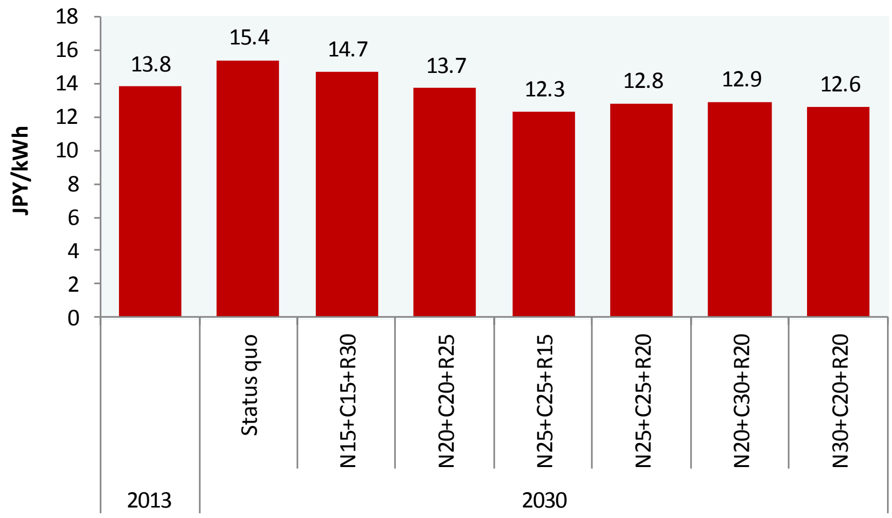


Scenario 1 = Nuclear 0% + Renewable 35%
Scenario 2 = Nuclear 15% + Renewable 30%
Scenario 3 = Nuclear 25% + Renewable 25%+Coal 23%+ LNG 22%+Oil 4%
Scenario 4 = Nuclear 30% + Renewable 20%+Coal 21%+ LNG 25%+Oil 4%

Sources: IEEJ, Towards Choosing Energy Mix, Jan 2015

Fig. 7-10 Power generation-related cost in IEEJ(2015)

Electricity cost estimated in RITE(2015) include balancing cost for variable renewable power and so on. The status quo scenario present highest cost which assumed almost zero nuclear power. Meanwhile, higher the contribution of base load power (nuclear and coal), lower the electricity cost.



Status quo = assume power generation structure in 2013 (N 1%, C 32%, R 13%) will remain until 2030
N=nuclear power, C=coal power, R=renewable power

Sources: RITE, Analysis of energy mix and GHG emission projection in Japan

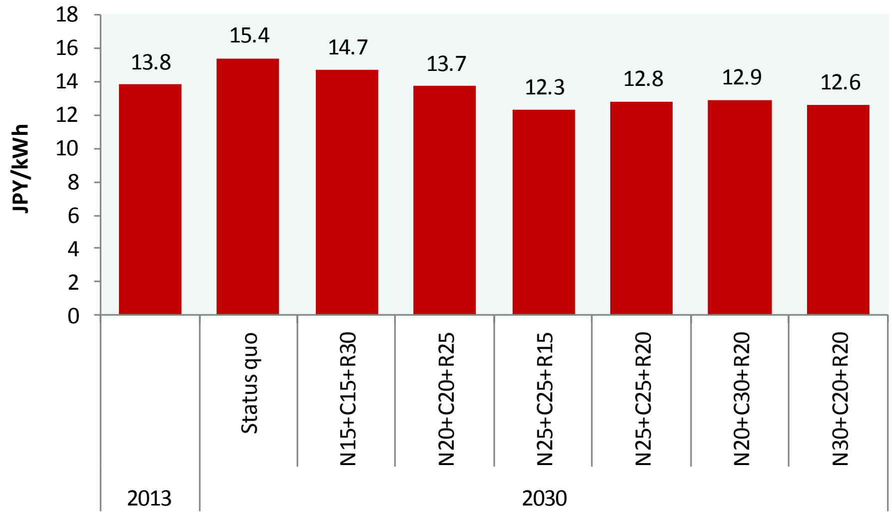
Fig. 7-11 Power generation-related cost in RITE(2015)

7.1.3.2 Effect on employment

The METI(20120) calculated impact of scenarios on employment by using CGE model. Of which, RITE does not present the result as their model assume full employment. Keio model is capable to evaluate under employment proactively. Keio model estimate largest negative effect for employment in Option 1 which assume zero nuclear. Meanwhile in Osaka model, Option 3 resulted in largest negative impact.

The IEEJ(2015) estimated that increased fossil fuel import spending and the consequent weaker international competitiveness will deteriorate the employment situation and harm the nation's macro economy. As shown in following figure, increasing use of low carbon energy, in particular nuclear power, hence reducing use of fossil fuel will decrease unemployment.

In addition, even those workers and households free from unemployment will be affected by lower wages. Coincident rises in electricity rates will exert the greatest pressure on household budgets in Scenario 1.

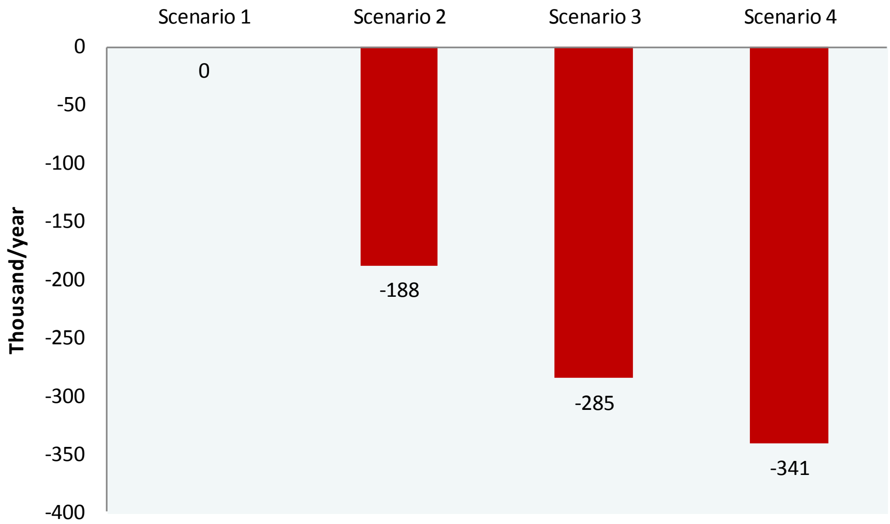


Option 1= Nuclear 0% + Renewable 35%+ Coal 24%+ LNG 17%+ Oil 6%+ Co-generation 15%
Option 2= Nuclear 15% + Renewable 30%+ Coal 23%+ LNG 11%+ Oil 4%+ Co-generation 15%
Option 3= Nuclear 20-25% + Renewable 25-30%+ Coal 21%+ LNG 8%+ Oil 4%+ Co-generation 15%

Baseline of comparison is the reference case (no additional energy efficacy measures, power generation structure in 2010 will remain until 2030)

Sources: METI, Draft of choice of energy mix, June 2012

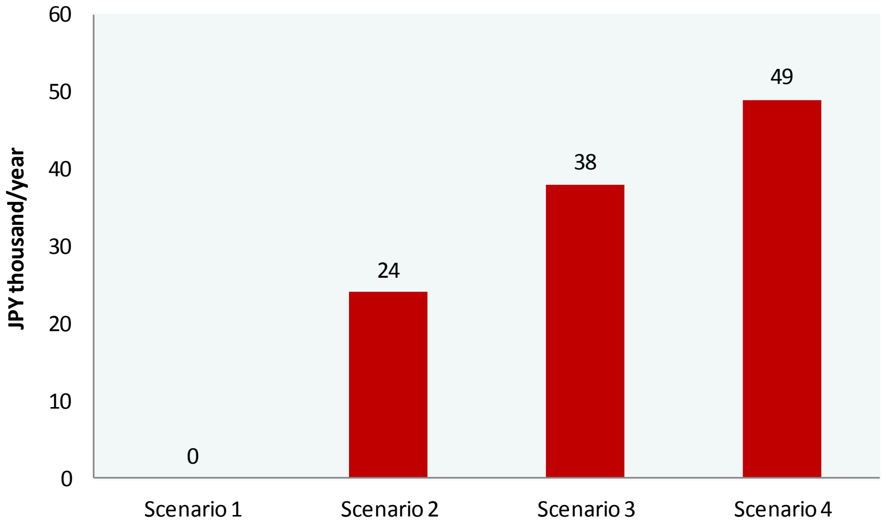
Fig. 7-12 Change rates of employment in 2030



Scenario 1 = Nuclear 0% + Renewable 35%
Scenario 2 = Nuclear 15% + Renewable 30%
Scenario 3 = Nuclear 25% + Renewable 25%
Scenario 4 = Nuclear 30% + Renewable 20%
Baseline of comparison is the Scenario 1

Sources: IEEJ, Towards Choosing Energy Mix, Jan 2015

Fig. 7-13 Effect to reduce unemployment by scenario in IEEJ(2015)



Scenario 1 = Nuclear 0% + Renewable 35% Scenario 2 = Nuclear 15% + Renewable 30%
Scenario 3 = Nuclear 25% + Renewable 25% Scenario 4 = Nuclear 30% + Renewable 20%
Baseline of comparison is the Scenario 1
Sources: IEEJ, Towards Choosing Energy Mix, Jan 2015

Fig. 7-14 Effect to increase nominal wages by scenario in IEEJ(2015)

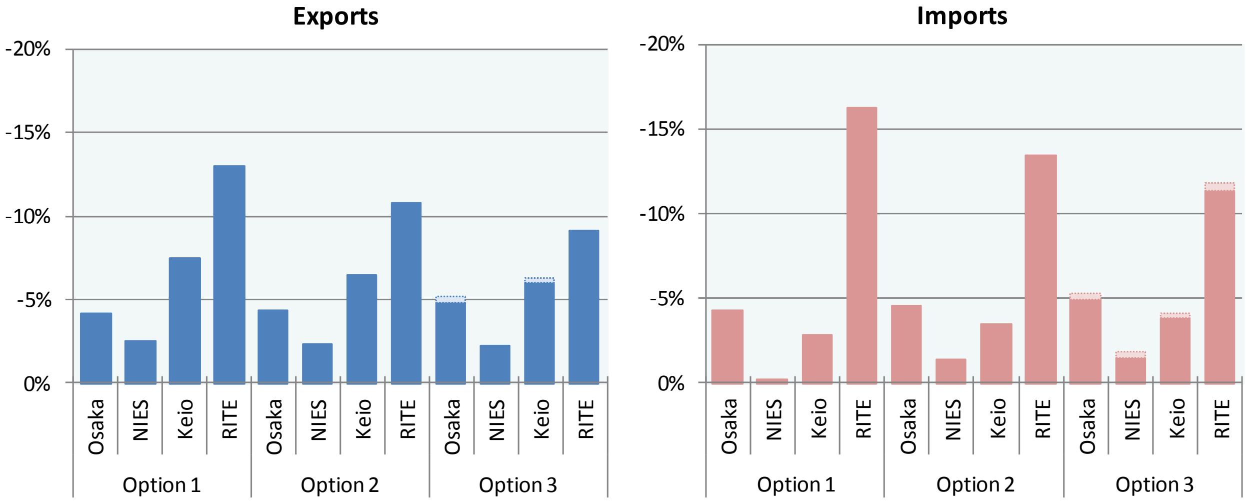
7.1.4 Foreign trade

The METI(20120) calculated impact of scenarios on export and import by using CGE model. In terms of export, power generation cost and carbon price will affect export competitiveness, and with this, negative impact tends to become largest in Option 1 which assume zero nuclear power (except Osaka model). Effect on Japan's export competitiveness is more clearly observed in the RITE model as it is a global model and cable to compare with other countries.

Meanwhile, import will also affected by economic activity and import requirement of fossil fuel in addition to power generation cost, carbon price, and consequent change of relative price of domestic product and import product. Except the RITE model, largest effect is presented in Option 3 as it estimate smallest fossil fuel import requirement. The RITE model assume lowest power generation cost and carbon price in Option 3, hence estimate smallest negative impact on GDP which result in smallest impact on import.

IEEJ(2015) has conducted analysis focusing on fossil energy import in view of energy security. According to the IEEJ(2015), fossil fuel import spending in Scenario 3 will be JPY 2.1 trillion less than in Scenario 1. The spending in 2030 will increase by JPY 6 trillion to JPY 34 trillion from 2013 in Scenario 1 due to change of import price and amount.

LNG imports will decrease in all scenarios where the dependence on thermal power generation declines. LNG imports in Scenario 1, however, will be 14 million ton more than before the Great East Japan Earthquake.

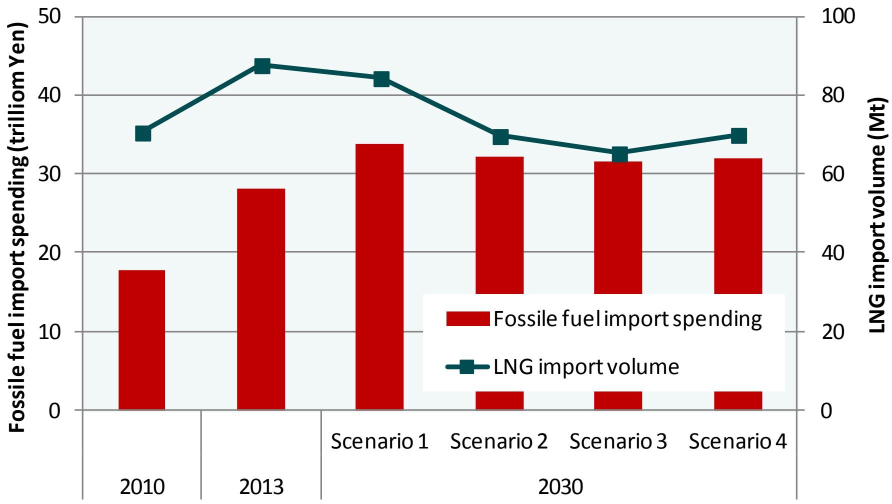


Option 1= Nuclear 0% + Renewable 35%+ Coal 24%+ LNG 17%+ Oil 6%+ Co-generation 15%
Option 2= Nuclear 15% + Renewable 30%+ Coal 23%+ LNG 11%+ Oil 4%+ Co-generation 15%
Option 3= Nuclear 20-25% + Renewable 25-30%+ Coal 21%+ LNG 8%+ Oil 4%+ Co-generation 15%

Baseline of comparison is the reference case (no additional energy efficacy measures, power generation structure in 2010 will remain until 2030)

Sources: METI, Draft of choice of energy mix, June 2012

Fig. 7-15 Change rates of exports and imports in 2030



Scenario 1 = Nuclear 0% + Renewable 35%
Scenario 2 = Nuclear 15% + Renewable 30%
Scenario 3 = Nuclear 25% + Renewable 25%+Coal 23%+ LNG 22%+Oil 4%
Scenario 4 = Nuclear 30% + Renewable 20%+Coal 21%+ LNG 25%+Oil 4%

Sources: IEEJ, Towards Choosing Energy Mix, Jan 2015

Fig. 7-16 Fossil fuel import spending and LNG import volume in IEEJ(2015)

7.2 Germany

7.2.1 Comparison of modelling approaches

In order to establish the economic impacts of climate protection scenarios in Germany, commonly, two different models are applied. These are Panta Rhei and ASTRA. **Panta Rhei** (GWS) is a national macro-econometric simulation and forecasting model that has specifically been developed for Germany. It is based on national accounts and input-output tables published by the German Federal Statistical Office. The economic core of the model is based on INFORGE[26] and includes 59 economic sectors. Model parameters are estimated using time-series data. Panta Rhei is open for exogenous information from bottom-up models, e.g. sectoral investment impulses. External costs of climate change can be accounted for in form of CO_2 emission certificate prices.

ASTRA (FhG-ISI) is a combination of sector models including transportation, environment and economy. It combines micro and macro aspects and uses a system dynamics approach to display various feedback reactions within and between the modelled sectors. Economic impulses from bottom-up models (transportation sector or energy system) are inserted in the macroeconomic module. In reverse, the macroeconomic model triggers adjustments in bottom-up models. In contrast to Panta Rhei, the model includes 27 EU states plus Norway and Switzerland. Exogenous inputs, time-series data for the calibration of the model as well as data for parameter estimation come from supra- and international data bases like Eurostat, the OECD or the UN. In 2012, a country specific version for Germany was developed. In its economic module, **ASTRA-D** covers 57 sectors.

FARM-EU has been used supplementary to ASTRA-D in order to analyse effects on international markets, especially energy trade. FARM-EU is a multi-regional, multi-sectoral general equilibrium model designed to address energy policy and climate change issues. It can be used for either ex-post or ex-ante analysis. In order to link ASTRA-D with FARM-EU the models have to be calibrated, i.e. exogenous parameters are chosen so that endogenous variables are harmonised.

Panta Rhei and ASTRA have been applied for similar topics in a variety of studies. The models differ however in some aspects. First, due to a regional focus, the models use data inputs from different institutions. Panta Rhei uses data from Germany's Federal Statistical Office (Destatis) while ASTRA uses international data from Eurostat. Second, as Panta Rhei was specifically developed for Germany, it offers a higher degree of sectoral disaggregation. Third, models adjust differently to exogenous shocks. For example, a drastic increase in the oil price leads to a relatively stronger impact in the Panta Rhei model. The ASTRA model includes substitutions and impacts on technological progress. These effects lead to an inherent adjustment of the economy and of consumer behaviour, mitigating the negative GDP effect of the price increase. Thus, the overall impact of higher oil prices is lower than in Panta Rhei. In addition, due to the EU wide focus, in the

[26] INFORGE (INterindustry FORcasting GErmany) is a multi-sectoral forecasting and simulation model for Germany, which is widely used. It constitutes the economic core of Panta Rhei.

ASTRA model, an increase in oil price leads to lower imports from other EU states, which also suffer from higher oil prices. This reduces the negative economic impact in Germany (Lehr et al. 2011).

Panta Rhei to larger extend considers contractive effects of investment, i.e. crowding out other investment by climate related investment. GDP growth is therefore generally lower than envisaged in ASTRA. The latter assumes higher productivity gains and a larger multiplier effect (BMUB 2015).

7.2.2 Investments

Investment into renewable energies and energy efficiency in addition to energy prices and net electricity imports are important outcomes from energy strategy modelling for the subsequent macroeconomic analysis.

In all studies, the macroeconomic differences between the reference and target scenario are modelled based on the additional investments in energy efficiency and renewable energies needed in the target scenario. Studies differ regarding the timeframe. Whereas BMUB (2015) and BMWi (2014) consider additional investments until the year 2050, in UBA (2013a), BMU (2011) and Ifeu et al. (2011) the time horizon is limited to the year 2030. Annual additional investments in 2020 vary substantially between 11.59 billion EUR in BMWi (2014) and 33.35 billion EUR in UBA (2013a). Whereas in BMUB (2012), BMUB (2015) and UBA (2013a) annual additional investments rise or stagnate over the years, in BMU (2011) they decrease over time and in BMWi (2014) they decrease from 2030 on.

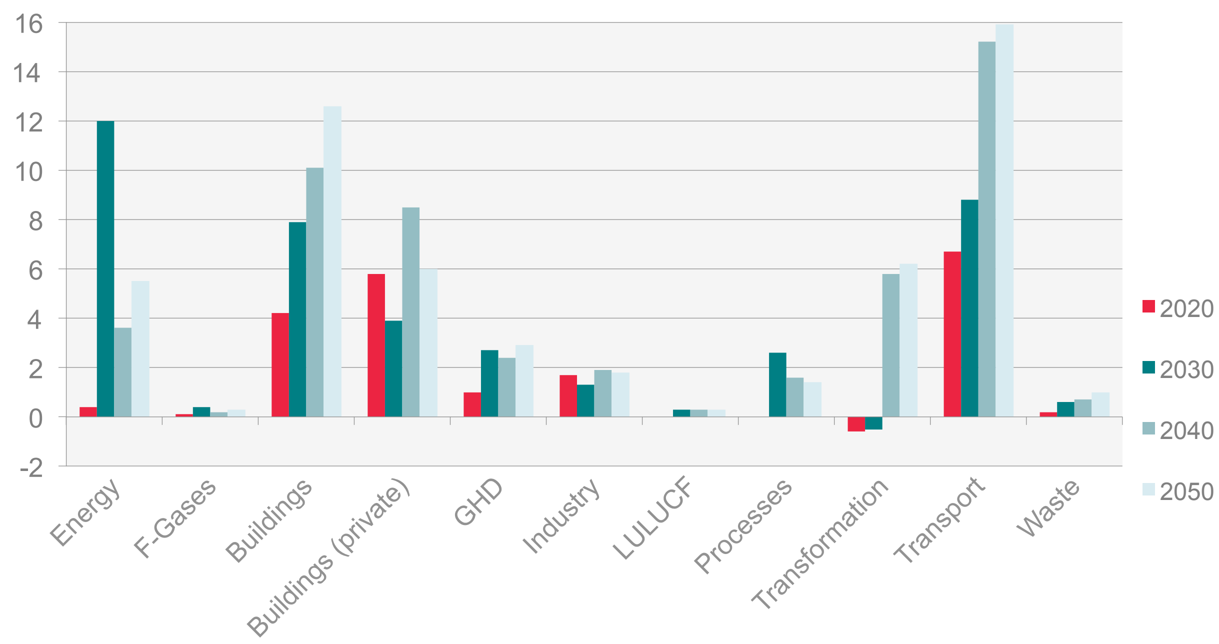
Tab. 7-1 Investments

		Additional investments in comparison to reference scenario (annually, in billion EUR constant prices of base year)			
Studies		2020	2030	2040	2050
KS80 BMUB 2015		13.7	36.1	41.8	47.9
ZS BMWi 2014		11.59	14.67	12.57	7.42
EWS UBA 2013a		33.35	39.25	NA	NA
BMUB 2012	BMU 2011	16.6	14	NA	NA
	Ifeu et al. 2011	18.1	18.1	NA	NA

Sources: Own calculation based on studies BMUB (2015), BMWi (2014), UBA (2013a) and BMUB (2012)

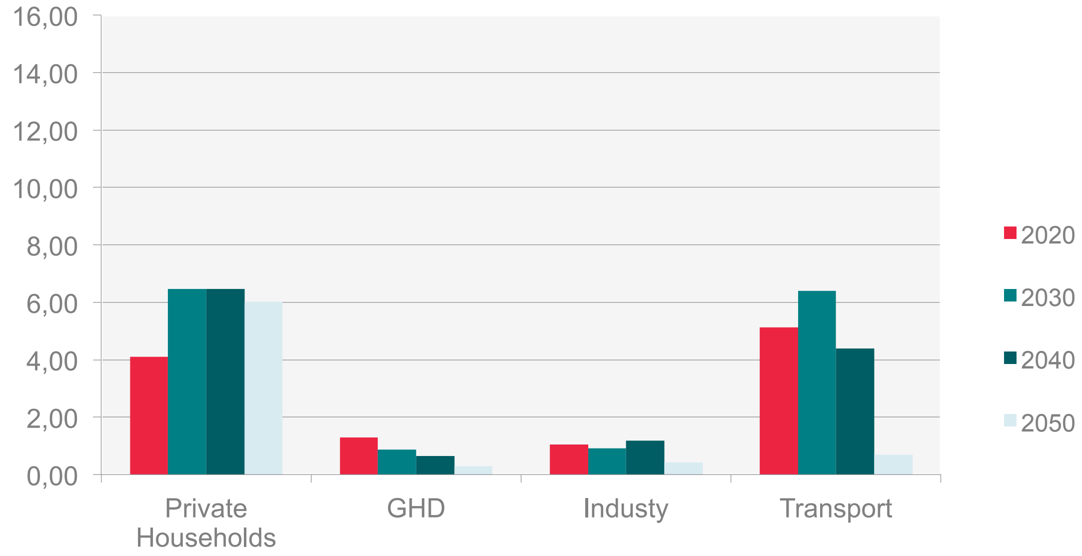
Size and timing of additional investment result from anticipated measures in renewable energies and energy efficiency defined to reach the mitigation targets and the development path each study has formulated. The numbers result from bottom-up sectoral models. For energy efficiency additional investment was considered only in case it was cost-efficient. Additional investment in heating and hot water supply to buildings was most important. Derived from mitigation measures, this original investment creates direct and indirect demand impulses in different economic sectors. The latter refer to effects initiated by sectoral investment in supplying industries. Of the two studies (BMUB 2015 and BMWi 2014) which modelled scenarios until 2050, the BMUB 2015 Scenario KS 80 estimates much larger investment. This difference may be due to modelling of investment within ASTRA or to the design of the reference scenario, as the numbers demonstrate the additional investment. Also the sectors included in the analysis differ. In addition to investment impulses from the sectoral models here also indirect investment effects and multiplier effects are considered.

Investment requirements from the sectors demanding additional investment analysed in BMUB (2015) and BMWi (2014) differ by volumes and structure as indicated in Table 7-2. BMUB (2015) analyses an amplified sectoral scope. Although the sectoral structure is not completely comparable, apart from the bigger volumes of total investment Figures 7-17 and 7-18 show, that BMUB 2015 assigns a higher priority for change and respectively investment to the transport sector than BMWi 2014.



Sources: Own figure based on BMUB (2015)

Fig. 7-17 **Sectoral structure of initial investment demand derived from sectoral models in BMUB 2015 (KS 80) in billion Euro**



Sources: Own figure based on BMWi (2014)

Fig. 7-18 Sectoral structure of initial investment demand derived from sectoral models in BMWi 2014 (ZS) in billion EUR

In BMUB (2015) initial investment demand derived from sectoral model was split into investment occurring in different branches and consumption. For example investment into buildings insulation material as well as modal shift in transportation was assigned to consumption, but this data was not published. Therefore published data on direct investment assigned to different branches in the macroeconomic modelling represents only part of the original investment captured by Figure 7-18.

BMUB (2015) is also the only study modelling direct and indirect sector specific demand impulses from additional investment (the share of initial in-vestment not assigned to consumption) . Overall, demand impulses do not change considerably between 2020 and 2030. From 2030 to 2040, demand impulses rise especially strong in the manufacturing sector including construction, increasing from 21.1 billion EUR in 2030 to 37.1 billion EUR in 2040.

The construction sector is not only important for direct investment in improvement of energy efficiency in buildings and the share of renewable investment flowing into this sector, but it is also an important input supplier for other sectors. About 10% of the additional investment resulting from the sec-tor model “industry” is flowing into the construction sector. The power station sector model shows that, depending on the type of power station, about nearly 50% of that investment is flowing into the construction sector. Thus, the input of the construction sector to the sector of power stations production is substantial. The sectors vehicles and machinery are the sectors of second and third largest investment (including direct and indirect effects). The machinery sector is important in producing inputs for to many other sectors.

Tab. 7-2 Direct and indirect demand in sectors initiated by additional investments (in billion EUR)

Study: KS80 BMUB (2015)	2020	2030	2040	2050
Agriculture and forestry (including fishery)	0.2	0.3	0.3	0.3
Manufacturing (including construction)	20.6	21.1	37.1	34.2
Construction only	*9.3*	*8.8*	*10.8*	*9.8*
Services	2.8	2.4	1.6	0.6
Others	0.1	0.1	0.1	0.2
Total	23.7	23.9	39.1	35.3

Tab. 7-3 Direct and indirect demand in sectors from additional consumption in BMUB (2015) KS 80 (in billion EUR)

Study: KS 80 BMUB (2015) KS80	2020	2030	2040	2050
Agriculture and forestry	0.5	0.9	1.4	1.9
Energy and raw materials	-1.4	-2.7	-3.1	-2.7
Energy and water supply	-4.6	-9.9	-10.6	-8.3
Metals & Recycling	0	-0.1	-0.2	-0.3
Food and textiles	-0.4	-1.8	-3.9	-5.9
Chemistry and plastics	0	-0.3	-0.7	-1
Machines	0.5	0.7	0.6	0.2
Computers	0.6	0.8	0.6	-0.1
Electronics	0.4	0.6	0.6	0.3
Vehicles	1.9	2.7	13.9	12.3
Other products	0.3	0.5	0.3	0.4
Structural and civil engineering	5.7	0.4	5.8	6.2
Trade	7.2	14.6	13	23.6
Transport	2.3	4.7	5.8	7.1
Communication	0.8	2.9	6	12.5
Banks and insurances	1.8	2.7	0.9	3.3
Real estate	8.1	12	20.1	25.4
Research and education	0.3	0.7	0.8	1.4
Services to business	0.2	0.5	0.6	1.2
Others	2.7	6.9	8.3	15
Total	26.9	36.8	60.2	92.5

Model results of BMUB (2015) also show direct and indirect demand effects from additional consumption (Tab. 7.3). The sector with the biggest changes in consumption expenditures is the real estate sector which includes not only commercial renting but also renting to private households. Landlords are allowed to reallocate per annum 11% of the costs for insulation to the tenants. Additional flat rents are accumulating over time.

For estimation of the impact on GDP and employment the assumptions on the way of how this additional investment is financed is crucial. Investment can be financed through state subsidies, borrowing, retained earnings, decrease of savings, passing through to final customers by price increases and foreign direct investment. Financing schemes are often different between renewable energies (mainly borrowing and subsidisation) and energy efficiency (often decreased savings, retained earnings and borrowing). They all have different economic impacts. The analysed studies often do not describe in detail, which financing scheme they have assumed.

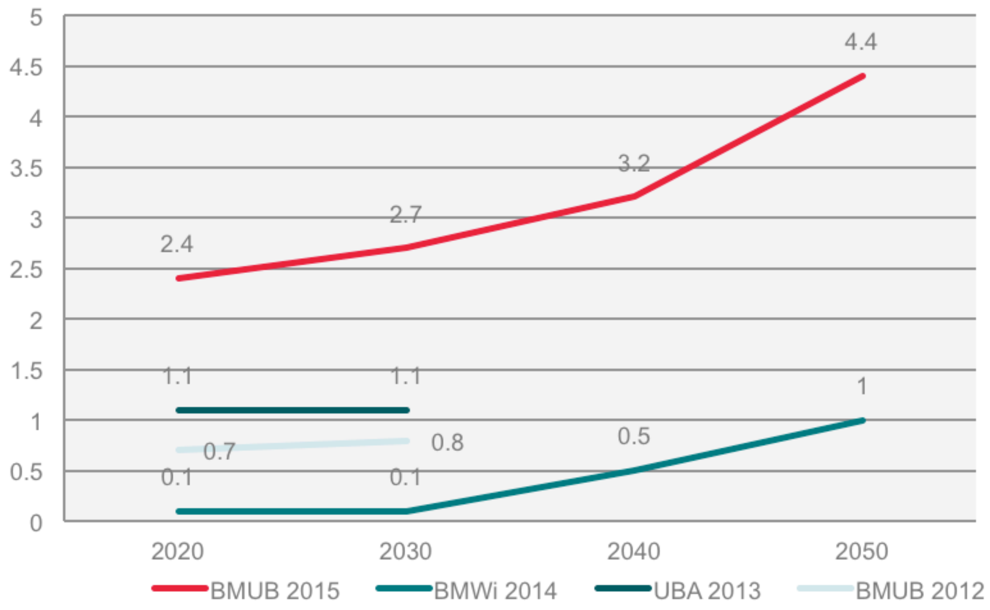
7.2.3 GDP, employment, value added

Investment in energy efficiency and in renewable energy can generate positive impact on GDP growth as it leads to increased demand directly in branches producing the required technologies, i.e. raise their output and create new jobs in these sectors as well as in sectors which provide necessary services. At the same time, investments in conventional fossil fuel energy production are expected to decrease. Increased electricity prices increase electricity and heat costs for final consumers, which can be reduced over time by energy efficiency. Most energy efficiency investments reduce costs during lifetime or depreciation period of measures. Overall GDP growth takes place when positive impacts from energy efficiency and renewable energies over-compensate the negative effects.

Tab. 7-4 Effects on GDP

		Absolute change (billion EUR)				Percentage change			
		2020	2030	2040	2050	2020	2030	2040	2050
KS80 BMUB 2015		66	81.2	102.7	149.7	2.4	2.7	3.2	4.4
ZS BMWi 2014		1.7	2.6	17.5	37.1	0.1	0.1	0.5	1
EWS UBA 2013a		29.9	29.8	NA	NA	1.1	1.1	NA	NA
BMUB 2012	BMU 2011	10.1	21.5	NA	NA	NA	NA	NA	NA
	Ifeu et al. 2011	17.8	23.6	NA	NA	0.7	0.8	NA	NA

Sources: Own calculation based on studies BMUB (2015), BMWi (2014), UBA (2013a) and BMUB (2012)



Sources: Own calculation based on studies BMUB (2015), BMWi (2014), UBA (2013a) and BMUB (2012)

Fig. 7-19 Effects on GDP (percentage change)

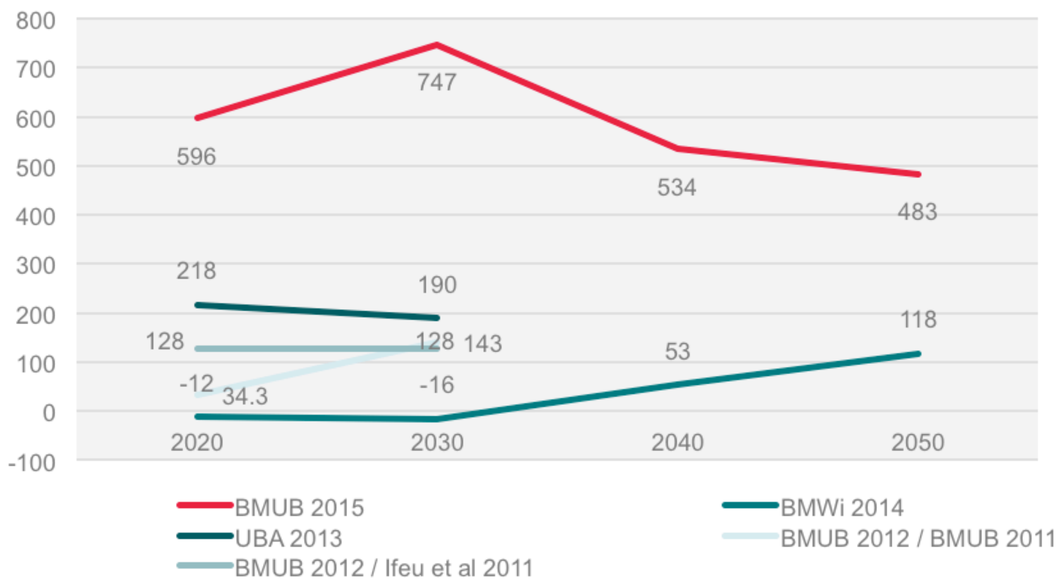
In all four studies in comparison with the reference scenarios investments into renewable energies and energy efficiency lead to a rise in GDP. The highest growth results in the BMUB (2015) study with 4.4 percent by 2050 translating into a positive deviation in real GDP of 149.7 billion EUR. The lowest rate of GDP growth can be observed in the BMWi (2014) study with only 1 percent by 2050, equivalent to an additional GDP of 37.1 billion EUR.

While BMWi (2014) based on Pantha Rhei was considering crowding out effects, BMUB (2015) KS 80, based on ASTRA-D and FARM EU, considered crowding out effects to less extent (<10%) and also did not include changing market interest rates. An additional condition for higher GDP growth resulting from the ASTRA model used in BMUB (2015) is the assumed financing of additional climate investment not only by targeted state subsidies and price increases but to a large extent by retained profits, i.e. own means of companies. That implies a postponement of current profits to the future and respectively postponement of current consumption to consumption in the future. Accelerating and multiplying effects enlarge thereby the basis of future profits.

The nuclear phase-out was mirrored through the investment which did not occur in conventional electricity generation. However, additional costs like for example compensation payment, cost nuclear storages and removal of nuclear waste were not considered. Effects of energy efficiency and renewable energy investment on employment can be measured by two indicators:

- The gross employment effect and
- The net employment effect

Investment in EE and RE create a *direct* positive employment effect in companies which produce respective technologies and which provide services for the technologies' installation, operation and maintenance. For their part, these companies order products, material and services from other branches and thereby create *indirect* employment in intermediate sectors and subcomponent suppliers. New direct and indirect jobs create income and *induce* additional demand for goods and services and, consequently, additional employment in other branches. The sum of both direct and indirect employment constitutes the positive gross employment effect.



Sources: Own calculation based on studies BMUB (2015), BMWi (2014), UBA (2013a) and BMUB (2012)

Fig. 7-20 Effects on net employment (absolute change in 1,000)

However, for a macroeconomic analysis also negative employment effects need to be considered, which mainly result from a decline in fossil fuel consumption and respective generation. Higher electricity prices due to renewable energies may also have a negative effect on indirect employment as private budgets are more constrained while energy saving effects did not accumulate to neutralise this effect. The net employment effect demonstrates the overall balance of positive and negative effects and is most important to measure realistic employment effects.

In all climate scenarios examined, additional investments trigger positive net employment effects over the whole observation period. Sectoral disaggregation of employment effects differs among the studies. In cases where sector data is available, the modelled employment effects differ as well. While BMUB 2015 shows the highest impact on net employment in absolute numbers in the service sector over the whole period until 2050, in other studies, effects in the service sector are the highest only in some periods. In others, positive net employment effects are highest in manufacturing, mainly in construction.

According to BMUB (2015) estimates, in 2030, nearly 750,000 additional jobs are created (net) due to additional energy saving and renewable energy investments. By 2050, this number declines to around 500.000. The study claims increase of average labour productivity due to sectoral shifts as important factor why employment effects are lower than GDP effects. Behavioural changes will influence employment as well. A decrease of employees in the manufacturing industry was observed for the food industry due to change in consumption behaviour. Less meat will be consumed. For the trade sector, a decrease of the number of employees was observed due to decrease in demand for petrol stations and vehicle maintenance and repair, as private vehicle miles travelled will decrease.

Tab. 7-5 Changes in number of employees in BMUB (2015) KS 80 compared to reference (in %) by sector

	2020	2030	2040	2050
Manufacturing	1.2	0.6	0.4	-0.9
Trade	1.6	2.6	1.3	1.2
Construction	4.5	2.9	3.7	3.1
Real estate and consultancy	1.6	1.3	1.3	0.8
Public services	0.9	1.5	1.2	1.4
Transport	2.3	5.7	4.1	5
Energy	4.8	3.3	7.1	10.8
Others	1	2.1	1.1	1.6

Other studies show net employment effects between 35,000 and 218,000 in 2030 and 118,000 in 2050.

The BMWi (2014) study is the only one showing negative impacts on net employment in the first half of the time horizon. Employment is lower by around 12,000 in 2020 and 16,000 in 2030 in comparison with the study's reference scenario. According to the study, this is mainly due to job losses in the service sector and trade sector as the overall cost-of -living index is higher than in the reference scenario. In the second half of the time horizon, effects on employment are positive across all sectors. The reason is, that starting from 2030 on accumulated energy savings become more and more important and the price level decreases compared to the reference scenario. Overall, there is additional employment of 53,000 was estimated by the year 2040, rising to 118,000 in 2050. However, total employment increases at lower rate than GDP due to wage increases.

Tab. 7-6 Effects on net employment estimated by different studies

	KS80 BMUB 2015		ZS BMWi 2014		EWS UBA 2013a	BMUB 2012	
						BMU 2011	Ifeu et al. 2011
	2020/ 2030	2040/ 2050	2020/ 2030	2040/ 2050	2020/ 2030	2020/ 2030	2020/ 2030
Percentage change	1.5/ 1.9	1.4/ 1.3	0/ 0	0.1/ 0.3	0.6/ 0.5	NA/ NA	0.3/ 0.3
Absolute change (1,000)	596/ 747*	534/ 483*	-12/ -16	53/ 118	218/ 190	34.3/ 143	128/ 128
Agriculture and forestry (including fishery)	NA/ NA	NA/ NA	NA/ NA	NA/ NA	NA/ NA	0/ 0	0.6/ 0.5
Manufacturing (including construction)	201/ 115*	111/ 26*	13/ 16	23/ 29	111/ 120	94/ 108	46/ 27
▪ *Construction*	*124/ 82**	*92/ 66**	*13/ 18*	*20/ 21*	*87/ 102*	*NA/ NA*	*35/ 18*
Services	386/ 416*	376/ 314*	-30/ -30	24/ 73	82/ 50	8/ 24	67/ 85
Other	10/ 216*	48/ 144*	NA/ NA	NA/ NA	NA/ NA	NA/ NA	NA/ NA
Total	596/ 747*	534/ 483*	-17/ -14	47/ 102	193/ 171	102/ 132	113/ 113

Sector effects do not add up to total effects in BMWi (2014), UBA (2013a) and BMUB (2012) as detailed data were published only for selected sectors.

Sources: Own calculation based on studies BMUB (2015), BMWi (2014), UBA (2013a) and BMUB (2012

An additional reason for the substantial positive net employment effects is that mitigation measures do not lead to significant increases in imports as the major part of technologies and services for implementation of the measures are assumed to be produced within Germany. Investment triggers an increase of the production potential leading to increased output and employment. Average labour productivity is increasing due to sectoral shifts. Increase of labour productivity, however, is the main reason why the relative increase in net employment is generally lower than the relative growth in GDP.

7.2.4 Foreign trade

All measures to improve energy efficiency and increase the use of renewable energies in the examined studies lead to reductions in fossil fuel combustion and increased demand for low carbon technologies. In the case of Germany, which depends to a large extent on fossil fuel imports on the one hand while on the other hand many of the low carbon technologies are produced by the German industry the energy transformation process is expected to have a positive impact on the foreign trade balance. Less costly fossil fuel will be imported. Other imports will not change substantially and eventually exports may increase due to productivity gains.[27] However, for a country like Germany with a considerable present net export surplus, this may not be seen as an exclusively positive effect. Not all publications on the studies depicted this impact.

Tab. 7-7 Effects on foreign trade

		Change in imports (billion EUR)				Change in exports (billion EUR)			
		2020	2030	2040	2050	2020	2030	2040	2050
KS80 BMUB 2015		NA	NA	NA	NA	NA	NA	NA	NA
ZS BMWi 2014		0.2	-2.5	-4.2	-5.3	-0.5	0.3	4.6	11.7
EWS UBA 2013a		6.9	1.9	NA	NA	-0.3	0.4	NA	NA
BMUB 2012	BMU 2011	7	9.2	NA	NA	11.9	23.8	NA	NA
	Ifeu et al. 2011	3.9	3.8	NA	NA	0.5	0.6	NA	NA

Sources: Own calculation based on studies BMUB (2015), BMWi (2014), UBA (2013a) and BMUB (2012)

Studies implicate that the change in imports is positive in 2020 but will decrease over time. Only the BMWi 2014 study estimates a reduction in imports from 2030 onwards. Regarding the change in exports, the pattern is reversed. First, the effect is relatively small, some studies show even negative effects in 2020, but will rise over time. Main reasons are seen in lower production costs due to productivity gains. In general, the studies do not allow for a straight forward conclusion on future developments of Germany's foreign trade balance over time. In BMUB (2015) KS80 net imports are declining as well due to lower fossil fuel imports.

The concrete development of chances for the German business on international markets depends on many factors. One of them is the expected international demand for low carbon technologies another is long-term competitiveness of German technologies.

Other studies show that firms may benefit from the first mover effect, i.e. a sustained competitive advantage on international markets due to realization of economies of scale and/or the realization of experience effects. These advantages will gain particular importance if the global initiatives for climate change mitigation will gain momentum. A sector where German companies won significant importance is the production of wind turbines. By contrast, in photovoltaic manufacturing German companies have not been able to sustain their interim market position (Kemfert et al. 2015).

27 BMWi (2014) states that lower productions costs may enable an increase of exports compared to the reference scenario after 2030.

7.2.5 Public Finance

The energy transition has manifold impacts on public finance. Main contributions stem from:

- Increasing or decreasing income from VAT and income tax. On the one hand growing employment may lead to tax increases on the other hand reduced fossil fuel consumption may lead to a decrease of tax revenue.
- Decreasing budget spending on health. Cleaner environment due to less fossil fuel combustion has a positive impact on health for the local population.

However, according to IEA (2014) there is still little experience with estimating the full budget impacts.

Tab. 7-8 Effects on public finance

		Change in net lending/net borrowing (billion EUR)				Change in product taxes (billion EUR)			
		2020	2030	2040	2050	2020	2030	2040	2050
KS80 BMUB 2015		NA	NA	NA	NA	NA	NA	NA	NA
ZS BMWi 2014		NA	NA	NA	NA	NA	NA	NA	NA
EWS UBA 2013a		7.1	8.3	NA	NA	2.9	0.2	NA	NA
BMUB 2012	BMU 2011	0.7	-1.7	NA	NA	NA	NA	NA	NA
	Ifeu et al. 2011	-2.9	-1.8	NA	NA	-2.4	-4.1	NA	NA

Sources: UBA (2013a) and BMUB (2012)

In the analysed studies and scenarios results on public finance are not coherent. Studies do not offer a uniform trend regarding the change in net lending/net borrowing or the change in commodity tax revenues. Whereas UBA (2013a) implies a positive effect on net lending/net borrowing, in Ifeu et al. (2011) the effect is strictly negative. This is similar regarding the deviation in product taxes. In UBA (2013a) the effect is positive, decreasing from 2.9 billion EUR in 2020 to 0.2 billion EUR in 2030. In Ifeu et al. (2011) there is a negative effect in the amount of -2.4 billion EUR in 2020 and -4.1 billion EUR in 2030.

7.2.6 Co-benefits

Besides the mentioned effects on the economy, investments in energy efficiency and renewable energies may lead to further (positive) impacts.

- They increase energy security through two channels. On the one hand, a lower dependency on energy supply by fossil fuel abundant countries, decrease the costs of imports. On the other hand, cost savings can be realised by being more isolated from cost volatility on international energy markets. Investments in renewable energies and energy efficiency are a main contributor to lower GHG emissions. The benefit of lower costs of climate change is partly accounted for in models by the price of CO_2. However, not all sectors and all GHG gases are currently covered by the EU ETS. Also, low certificate prices do not fully reflect the costs of emissions.

- Additionally, the transition to a cleaner and more efficient energy sector lowers the level of air pollution and by that leads to positive effects on health costs.

Furthermore, a successful implementation of the German "Energiewende" can be seen as a **positive example** for the transition into a climate friendly economy and might inspire other countries to go in the same direction.

8 Advantages and disadvantages of scenarios and their specific transition strategies

This chapter assesses the advantages and disadvantages of the selected scenarios and of specific transition strategies focused on in these scenarios in regard to the following five categories:

- Costs and macroeconomic implications
- Environmental sustainability
- Energy security
- Risk minimization and social acceptance
- Robustness of scenarios to uncertain future developments

This chapter is more normative than the previous chapters, meaning it includes to a stronger extent judgements by the respective country teams (IEEJ authors for the Japanese scenarios and WI and DIW Econ authors for the German scenarios). As in the previous three chapters, a separate analysis is performed for Japan and for Germany, before in the next chapter (Chapter 9) a joint conclusion is derived, by inter alia comparing the developments described by the analysed Japanese and German scenarios.

8.1 Japan

8.1.1 Costs and macroeconomic implications

The METI(2012), the IEEJ(2015), and the RITE(2015) evaluate economic impact of different power generation mix. Every four models in METI(2012) employing computable general equilibrium (CGE) model estimate that lower share of nuclear will result in higher electricity price, hence put larger burden on economy. The same trend is presented in both IEEJ(2015) using econometric model and RITE(2015) using CGE model plus linear programming (LP) model.

In case of Japan, larger use of renewable power is clearly increase electricity cost. IEEJ(2015) and RITE(2015) indicate that higher contribution of renewable energy will result in higher electricity cost including balancing cost necessary for variable renewable power. Further, Result of the Keoi model in METI(2012) illustrate that purchase cost of renewable energy (payment for Feed-in Tariff) will significantly rise in a future and this will become economic burden for people.

8.1.2 Environmental sustainability

Around 90% of GHG in Japan derived on CO_2 from energy. Energy Policy and GHG measurement are the two sides of the same coin. When innovating energy mix, it should be considered for reducing GHG emission.

IEEJ(2015) shows energy-related carbon dioxide emissions will be the lowest in scenarios where renewables and nuclear, which are zero-emission power sources, will account for a larger part of electricity generation. It's essential to have a well-balanced use of both renewables and nuclear rather than choosing just one since each of these types of energy has both advantages and disadvantages.

According to the RITE(2015) analysis, the increase in share of coal and nuclear power can expect the decrease in the electricity and energy supply costs since the costs of LNG and renewable energy are higher than those of coal and nuclear power in Japan. While cost of coal fired power is slightly lower than that of nuclear when the costs related to accident risks and decommissions are added. However, if climate damage risks of USD 40/ton-CO2 is considered in 2030, the cost of nuclear is still lower than that of coal fired power. Therefore, taking into account climate challenge, nuclear power is an important option in Japan even after the Fukushima Daiichi nuclear power accident. While energy efficiency is a crucial measure for emissions reduction, according to the analysis by the RITE DNE21+ model taking into account end-use technologies in detail, the energy saving potential by 2030 is limited in Japan. Even under the carbon price levels compatible with the 450 scenario (USD 100/ton-CO2 in 2030), GHG emissions in 2030 is 15% below 2005 level. This indicates that Japan's national determined contribution (NDC, 26% reduction from 2013, 25.4% reduction from 2005) is highly ambitious requiring larger reduction compared with the scenario compatible with 450 scenario.

RITE has also analysed the INDC of major countries based on a set of indicators including mitigation costs. This analysis indicates that Japan's 26% target entails extremely high mitigation costs. While Switzerland and the EU also would bear high mitigation costs for achieving their respective INDCs, some major countries such as China, India and Russia would bear almost no costs for achieving their INDCs. Under such situation, carbon leakage from high cost nations to low cost nations could happen, which would make global mitigation efforts less effective.

8.1.3 Energy security

Supply security is one of the first priorities of energy policy in Japan where fossil fuel resources are scarce and there is no physical connection to another country. Given the supply disruption risks originate from dependence on energy imports, the first measure is to reduce this dependence. It's not realistic for Japan to substantially increase fossil fuel production other than methane hydrate which is now under development. Therefore, it's important to increase the use of renewable energy which has been used increasingly over recent years and has posted a remarkable cost reduction. Nuclear power generation that features far less frequent fuel (uranium) imports than fossil fuel and can be stored is also an effective option. This is because the most of subjected scenarios are assuming higher share of renewable energy and restart of nuclear power plant.

Despite such efforts to increase energy self-sufficiency, Japan will still need to import fossil fuels to some extent for the foreseeable future. Therefore, Japan is required to limit the impact of any energy supply disruptions by diversifying its energy sources, its energy exporters and the import routes, or prepare measures that would offset any disrupted supply. Holding reserves would be an effective safety net in the event of emergency.

8.1.4 Risk minimization and social acceptance

METI states that changes of world structure and innovations may be faster and larger than we imagine. Giving current situation in energy demand and supply, there are not few uncertain factors such as geopolitical risks in middle-east, international affairs, revolution in energy system, international framework of GHG emission reduction, electricity price rise and its impacts on economy and employment.

When choosing energy, while it is important to forecast a fixed future, it is also needed to fully recognize such uncertainties. In addition, it's also important to forecast the future with a width and review flexibly along with the progress of policies and situation changes as well as minimizing to set strong restricted target. From this view point, Japan needs to deepen the study regarding figures in energy mix in the future.

IEEJ assesses, while coal is cheaper than other fuels, it involves climate change risks caused by CO_2 emissions and related political risks. Oil has geopolitical risk because it is largely reserved in the Middle East. Regarding natural gas, although the shale revolution has been making progress, the still relatively high price does have an impact on the economy. While nuclear has advantages in supply stability and lower cost (in Japan) over other fuels, it is difficult to completely eliminate the possibility of severe accidents and it also has final depository issues. Even though the introduction of renewable energy has increased and power system stabilization has been improved, Japan-specific issues such as narrow and mountainous land still remain. In addition, renewable energy cannot be an exceptional from NIMBY (Not In My Back Yard) issue. As such, each energy source has its own risks, hence there is no single perfect form of energy in today's world.

Thus, when considering both the advantages and disadvantages of each type of fuel, the best course we can take at present is to create a better energy mix. On the other hand, flexible review along with technological development and social change will also be needed.

Social acceptance through dialogs with public and municipalities is an important factor when selecting an energy source. In the open electricity and gas market in which consumers have the right to select a utility company, suppliers have to take "acceptance" into consideration. However, since the government has responsibility for energy supply security, if it intends to pursue a certain target of energy mix, and if public acceptance is an issue, the government may be requested to take action in order to gain public acceptance and hence help achieve the energy mix goal.

8.1.5 Robustness of scenarios to uncertain future developments

In the METI, IEEJ and RITE scenarios, the largest uncertainty lies in nuclear restarts. Future scenarios will be fundamentally changed depending on how many reactors can be restarted in the future or if their operational life can be extended or if they can build new reactors.

In addition, on the supply side, cost and technological development of balancing measures for variable renewable energy (VRE, typically solar PV and wind power) is another uncertain factor. If cost of VRE drop to competitive level against fossil power, and if we can implement the perfect solution to accept large amount of VRE without distorting electricity supply, VRE will become the best answer from every aspect of 3E. However under current circumstances where sufficient capability of absorption mechanism of highly volatile electricity output from VRE has not been developed and installed, introduction of VRE require careful assessment.

Energy conservation is also an uncertain area. The household and building sectors, which we need to strongly address, are difficult areas in which to impose compulsory regulation in order to replace inefficient appliances and buildings. Efficiency improvement in this sector depends on not only technology but also on the awareness of each and every consumer. In this sense, education and advertising will also become important measures to change people's behaviour.

Lastly, uncertainty also lies in front of automobile technology. For instance, there is no clear perspective for how fast internal combustion engine car will be replaced by electric vehicle (EV) and which become predominant EV and fuel cell vehicle (FCV). Every analyses in METI(2012), IEEJ(2015), and RITE(2015) seems assuming conventional internal combustion engine car, include hybrid car, will stay at dominant position until 2030. Various causes affect development of automobile technology such like fuel supply infrastructure, choice of consumer, energy policy, and industrial policy, hence contain high uncertainty in its future.

8.2 Germany

8.2.1 Costs and macroeconomic implications

Studies model the impact of additional sector investments in energy efficiency and renewable energies on macroeconomic variables. By that they account for direct and indirect effects. BMUB (2015) offers the most detailed analysis on macroeconomic effects including sector specific developments for demand impulses, effects on employment and gross value added. However, the study does not offer insights into macroeconomic effects on foreign trade and public finance. An analysis of these effects can be found in BMWi (2014), UBA (2013a) and BMUB (2012) where impacts on net imports and exports, net lending/net borrowing as well as product taxes are explored. Unfortunately, in contrast to BMUB (2015), studies only offer sectoral effects on employment. Effects on gross value added and demand impulses are not provided.

All studies analyse only the impact of additional sector investments on macroeconomic variables. Feedback reactions from the economic sector on the energy sector are not modelled and are therefore unaccounted.

All studies also take into consideration CO_2 prices, increasing until 2050 substantially, reflecting increasing abatement costs. In BMUB (2015) they achieve a level of 130 EUR/t in 2050, which is the highest level of all scenarios, followed by 76 EUR/t in BMWi (2014). As the share of fossil fuel based electricity is declining and the cost for renewable electricity is declining as well, overall consumer prices for electricity will decline as well. In BMWi (2014) this development takes place from 2025 on and Figure 8-1 shows that in 2050 still the level of prices will remain above 2011 level. Incentives for energy efficiency therefore, will not disappear.

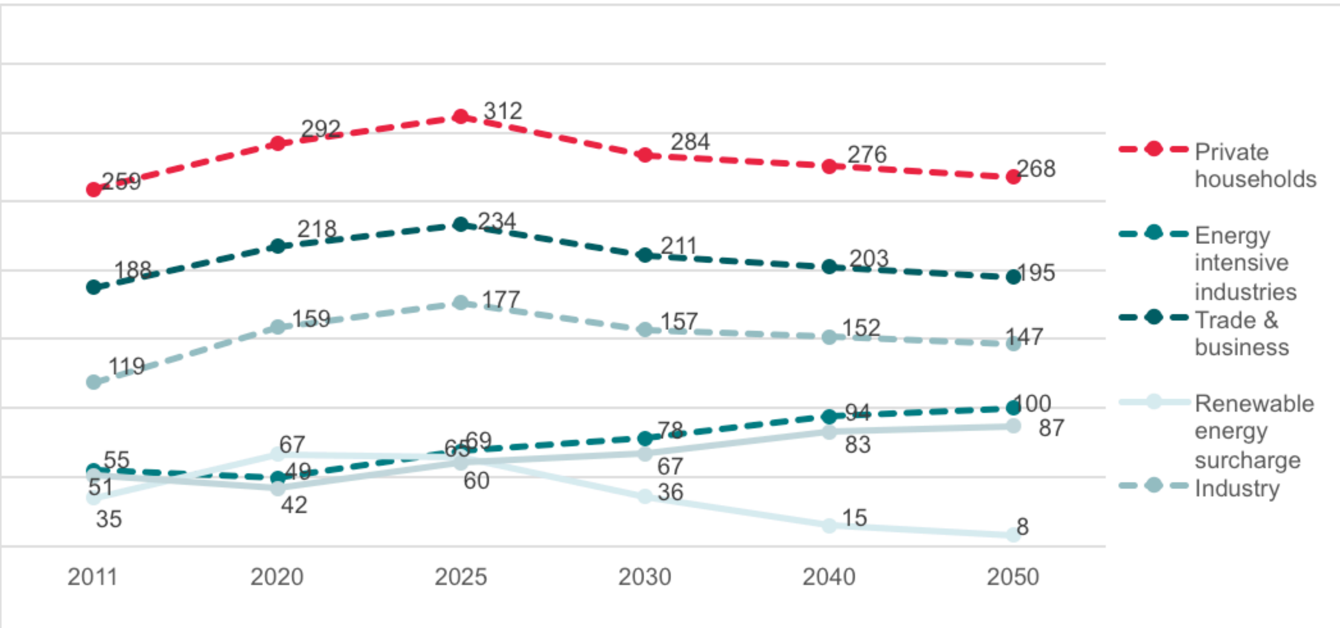


Fig. 8-1 **Consumer prices in reference forecast and trend scenario 2011 – 2050 for BMWi (2014) ZS, in EUR 2011/MWh**

Unfortunately, such consumer price data as indicated in Figure 8-1 are not available for BMUB 2015. Prices may be higher in BMUB 2015 as the study assumes higher oil and natural gas price increases than in BMWi 2014. That would make more energy efficiency measures economically profitable.

Highest investment costs are assumed in UBA 2013a, followed by BMUB 2015, but overall GDP effect is lower in UBA 2013a than in BMUB 2015. This may be due to the models used. As mentioned, the ASTRA model used in BMUB 2015 tends to achieve higher GDP growth. In addition, energy efficiency improvement achieved in UBA 2013a is less ambitious than in BMUB2015, which may contribute to lower GDP effects as well. BMUB2015 turned out to be most costly but also most ambitious concerning the use of renewable energies, energy efficiency improvement and electrification of transport. Highest GDP effect of this investment is plausible as investment impulses are strong and indirect investment effects are also included. Employment effects are the highest as well. Productivity gains due to structural shifts, however, will slow down the employment development after 2030 notwithstanding an additional raise in investment during this period.

Reference scenarios differ considerably across studies and complicate the comparability of macroeconomic implications. Especially, the results of the two studies analysed in BMUB (2012) have to be interpreted with caution and are not comparable with results from other studies. In BMU (2011), the chosen reference scenario assumes the absence of the development of renewable energies after 1995. In Ifeu et al. (2011), the reference scenario and its assumption are not clearly presented. Additionally, the target scenario in BMU (2011) only focuses on renewable energies, whereas in Ifeu et al. (2011) only investments in energy efficiency are considered.

Although the overall employment effects are positive, the two studies with their scenarios which cover the full long-term period until 2050 come to contradicting results concerning long term trends of employment spurred by the modelled climate investment. That might be due to different models used. As could be expected, strong employment effects are shown in the scenarios for the manufacturing and the construction sector. However, BMUB 2015 indicates highest additional employment in absolute numbers for the service sector, which may be due to the indirect effects also spurred by high indirect investment. Mainly for the sector of real estate and consulting, the sector with the biggest changes in consumption expenditures, followed by the construction sector (Tab. 7-5).

8.2.2 Environmental sustainability

A key objectives of the energy transition in Germany is climate protection. Accordingly, all analysed energy transition scenarios aim to meaningfully reduce CO_2 and other GHG emissions (see the comparison of GHG emissions in section 5.2.2.3). The most ambitious scenario, KS 95, does not only foresee the lowest emissions in 2050 by far, but it also plans to reduce emissions much more aggressively in the short to medium term (until 2030). This of course is important to reach ambitious climate change mitigation objectives, as it is the cumulative emissions that are relevant, more so than the emissions at one point in the future.

Apart from GHG emissions, local pollutants like particulates, sulphur dioxide, nitrous oxides or carbon monoxide are also relevant when discussing environmental sustainability in regards to the future energy system in Germany. These pollutants are responsible for a high number of premature deaths in Germany and Europe. Nitrogen dioxide, for example, is estimated to have caused almost 70,000 premature deaths in Europe in 2013 (EC 2017).

Coal-fired power plants and road transport are important sources of local pollutants. Road transport, for instance, is responsible for about 40% of the nitrous oxide emissions in Europe (EC 2017). Accordingly, the reduction of coal combustion in the energy sector and the reduction of oil and diesel use in the transport sector are energy transition strategies that can contribute considerably to a reduction of local pollutants.

While none of the analysed scenarios quantify air pollution and its health effects, it can be assumed that the KS 95 scenario is associated with a particularly strong reduction of local pollutants, as it aims for a fast reduction of coal in electricity generation (Figure 8-5) and strongly increases the use of electricity and hydrogen/power-to-liquid in the freight and passenger transport (Figure 6-13 and 6-14), reducing strongly the use of diesel and oil in the transport sector by 2050 (Figure 5-50).

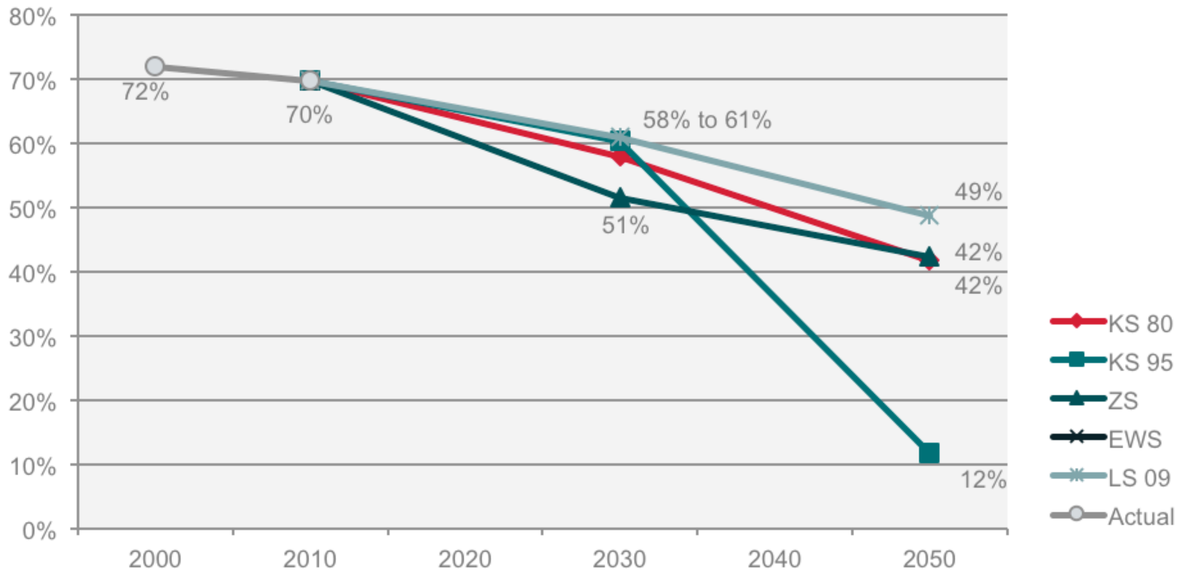
Emission and pollutant reductions are not the only dimension of environmental sustainability that can be differently affected by the transition pathways described by the scenarios. Water and resource requirements as well as protection of these resources are likewise essential to environmental sustainability. However, these resource uses are not quantified in the analysed scenarios. In general, it can be expected that a decline in thermal electricity generation will also reduce water consumption. The ambitious KS 95 scenario, which reduces thermal energy generation already significantly by 2030, likely exhibits lower water demand for power generation compared to the other scenarios. In regards to none-energetic resource use, far-reaching transition strategies could be less favourable, as for example the expansion of renewable energy technologies or the renovation and insulation of buildings require additional resources.

8.2.3 Energy security

Guaranteeing energy security is an important political objective of many governments around the world, as energy security is linked to various critical economic, environmental, social and technical aspects. Yet, due to its multi-dimensional nature, energy security is not a clearly defined term and various concepts and indicators exist to describe or measure energy security (Ang et al. 2015; Ren and Sovacool 2014; Winzer 2012).

In Germany, energy security is not explicitly defined in any legislation (Breitschopf and Schlotz 2014). However, energy security is imbedded in the energy strategy for Germany, which mentions three primary objectives: security of energy supply, economic efficiency and environmental sustainability. These objectives combine both, national security and sustainability aspects of the energy supply. Accordingly, measures to the ensure energy supply are seen as cross-cutting tasks at the interface between security and defence, foreign, environmental and economic policy (Reitz 2016).

Important aspects to be discussed in relation to energy security in Germany include import dependency, diversity of supply and stability of supply. Import dependency includes both imports of energy commodities and the import of electricity. Figure 8-2 gives an overview of the different import dependences in the analysed scenarios in regards to net primary energy imports. It is shown that the imports are expected to decline significantly from the import rate of 70% in 2010. Until 2030, import dependency in the scenarios can be reduced to about 50% to 60%. Until 2050, three scenarios foresee a share of primary energy imports of 42% to 49%, while in the highly ambitious KS 95 scenario, the share drops to a very low level of 12% as dependence on fossil fuels is reduced drastically.



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

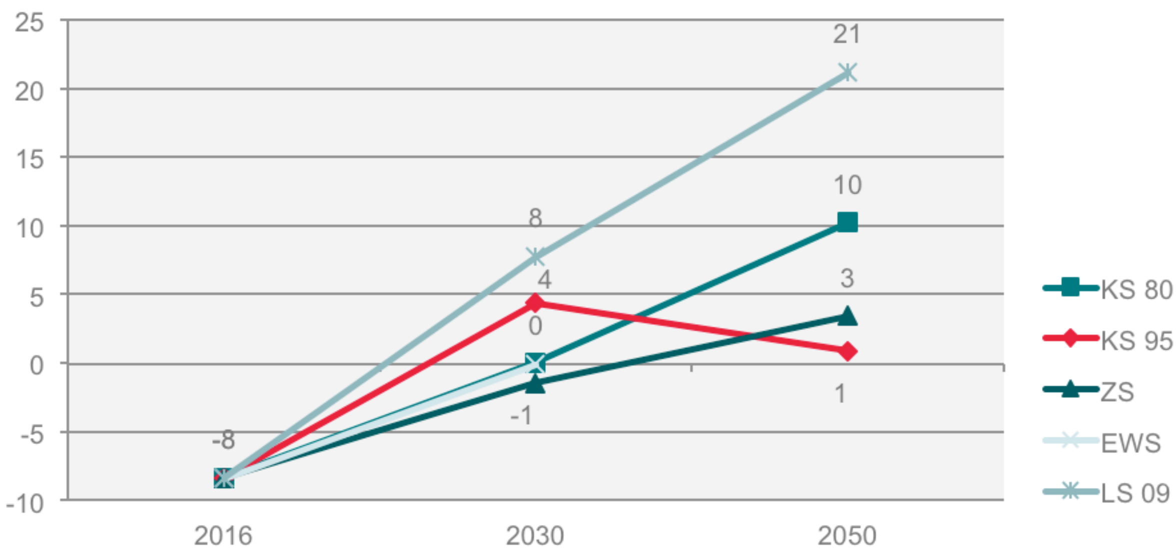
Fig. 8-2 **Net primary energy imports (without non-energetic use) (in % of total primary energy use)**

Risks in relation to energy imports do not only exist in regards to the import volume of an energy carrier but also to in regards to the countries which supply the energy sources. In order to avoid interruptions of supply, price increases and political extortion, it is critical to ensure the stability of supply conditions and diversification in terms of number of suppliers and geographic location of suppliers. The scenarios do not provide information on the supply countries of the projected primary energy imports, but it is apparent that oil is one the most critical energy carriers in terms of import dependency as supply is and foreseeably will depend on a limited number of suppliers of which several can be regarded as politically unstable. Furthermore, oil resources worldwide are strongly geographically concentrated.

Next to oil, Germanys as well as Europe's dependency on natural gas imports could pose challenges to the security of energy supply. Germany currently relies on only a few suppliers for natural gas, which makes it difficult to compensate the supply in case one or more key countries withhold their supplies. The biggest supplier of natural gas to Germany is Russia, supplying about one third of the natural gas demand (BMWi 2017b). In order to reduce the vulnerability resulting from the dependency on one major supplier, Germany and Europe strive to reduce their reliance on Russian gas.

Compared to oil and natural gas, the risks stemming from the import dependency of hard coal are limited. The flexibility of the supply is high, given a high availability of relatively cheap hard coal on the world market and a large number of suppliers from different world regions (Hake and Rath-Nagel 2015).

In regards to the import of electricity, the diversification of suppliers is also of relevance, but as Figure 8-3 shows, the foreseen power imports in the scenarios only make up a small portion of the overall electricity use, at least until 2030.



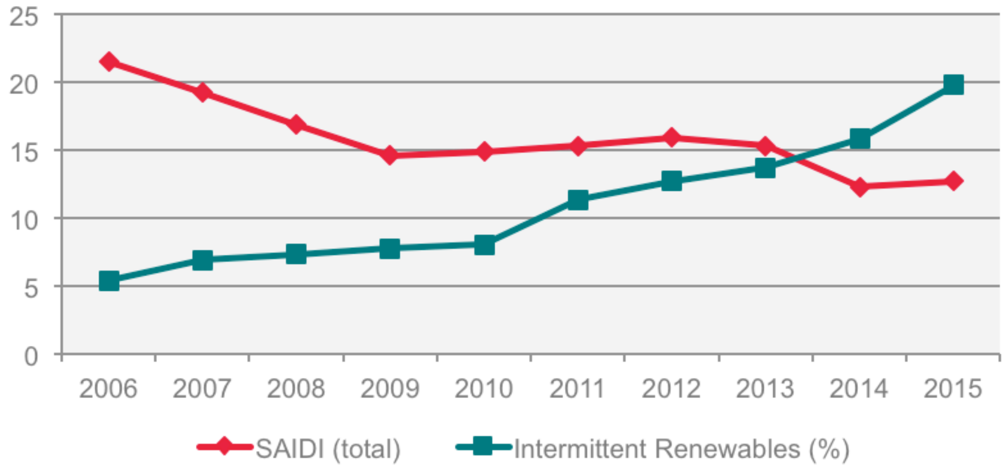
Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 8-3 Share of imports in net electricity generation (%)

The share of net electricity imports are foreseen to be a maximum of 8% in 2030 in the LS 09 scenario. The other scenarios expect lower or no net electricity imports or even electricity exports on a low level (ZS scenario). By 2050 the scenarios differ more strongly with the share of imports in net electricity generation varying between 1 to 21%. A high share of imports such as foreseen in the LS 09 scenario of course entails higher supply risk compared to the other scenarios due to the previously discussed risks in connection to higher energy imports such as geopolitical uncertainties and dependence on a limited number of suppliers.

Apart from the diversification of suppliers and supply regions to avoid or mitigate geopolitical risks, the resilience of the required energy infrastructure against accidents, sabotage or natural disasters is also important. This includes contingency planning for technical risks such as failure of infrastructure components like transmission lines, power plants or transformers, and human risk sources like for example demand fluctuations, underinvestment, sabotage and terrorism (Winzer 2012).

In terms of natural disasters, one potential risk could be a large-scale volcanic eruption like the one of Tambora, on the island of Sumbawa, in 1815. Risks from such eruptions – or possibly also from the use of nuclear bombs in some part of the world – on the security of electricity supply in future energy systems have so far not been widely discussed, but the possibility exists that a large-scale outburst of volcanic aerosols reduces solar radiation over month or even years. This could directly reduce the power output of solar power plants but indirectly also effect electricity generation from wind, biomass and hydropower. In terms of energy security, the implications of such a scenario for a stable future electricity supply in different scenarios (including potential contingency measures) should be analysed in the future.



Sources: Own figure based on Bundesnetzagentur 2016 and AGEE-Stat 2017

Fig. 8-4 **SAIDI Index in relation to share of intermittent renewables in gross electricity consumption (%)**

Another important aspect that also needs to be discussed in terms of energy security is the increasing share of intermittent renewable resources in the energy mix foreseen by all scenarios. While a high share of fluctuating renewables in electricity supply is often portrayed as a risk, several studies have shown that with an adequate system design the security of supply can be ensured also with high shares of solar and wind energy (Lehmann and Nowakowski 2014; UBA 2013d; IEA 2016a). Although, past developments are not necessarily an indicator for future developments, at least so far, no negative correlation could be observed for Germany with an actual share of renewable sources of about 32% of the power generation in 2016 (AGEE-Stat 2017). This is shown in Figure 8-4, which shows an increase of the security of supply, represented by the System Average Interruption Duration Index (SAIDI - indicating the average interruption duration per customer in one calendar year), an increase of the between 2006 and 2015, even though the share of intermittent renewables (wind and PV) in gross electricity consumption increased strongly in this period, from 5% in 2006 to 20% in 2015.[28]

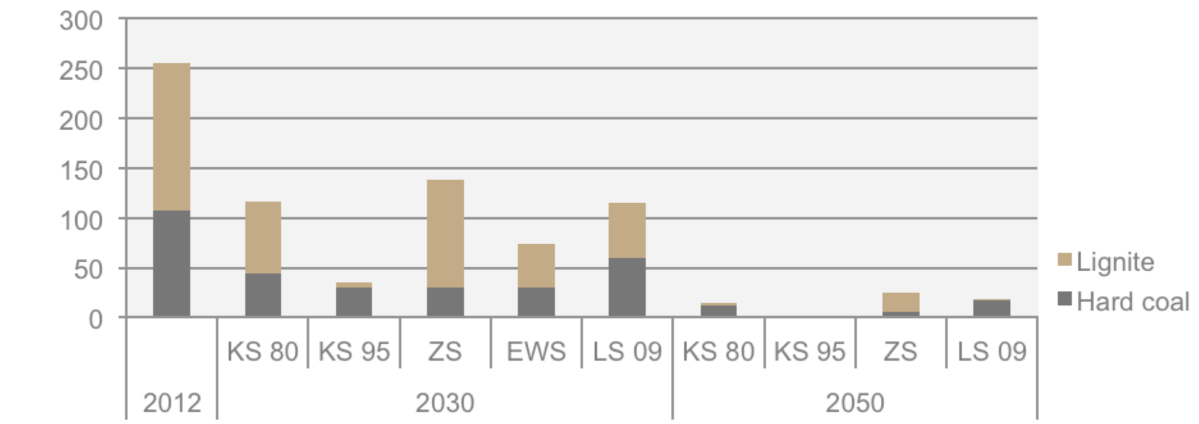
8.2.4 Risk minimisation and social acceptance

Energy transitions require long-term and far-reaching changes not only in terms of energy infrastructures and technologies but probably also in regards to lifestyles, living environments and institutions. Social acceptance and the minimisation of risks for human health and the environment therefore play an essential role in order for energy transition strategies to be successful.

Social acceptance in the context of the German energy transition has so far been primarily related to topics such as climate and environmental sustainability, costs of energy and affordability, participation and level of acceptance regarding impairments of the natural or social environment. Energy transition strategies address and effect these topics to different degrees resulting in different levels of acceptance. Particularly, the acceptance levels of different energy carriers and technologies vary. While the overall acceptance of renewable energies is very high in Germany , with 93% of the population being in favour of the expansion of renewable energies, the acceptance of nuclear power and coal as power sources is very low (AEE 2015). Yet, also the acceptance of renewable energy technologies varies in regards to the type of technology but also in regards to the overall acceptance compared with the acceptance of installations in the direct neighbourhood (for more details please refer to AAE 2015 and Wunderlich and Vohrer 2012).

Comparing the analysed scenarios in regards to the likely public acceptance of their respective power generation mixes, it can be seen that concerning nuclear energy, the scenarios do not differ substantially as they all anticipate the phase out of nuclear power plants until 2022. However, in regards to coal-fired power generation, which has become increasingly contentious in Germany in recent years, it is shown in Figure 8-5 that the scenarios differ in the amounts of electricity generated from lignite and hard coal particularly until 2030. KS 95 and to a smaller extent also the EWS scenario foresee a faster decrease of coal use in the power generation sector compared to the other scenarios. Based on the low acceptance of coal as energy carrier (AAE 2015), it can be expected that scenarios with a faster reduction of coal in the energy mix will (all else being equal) have a higher level of public acceptance.

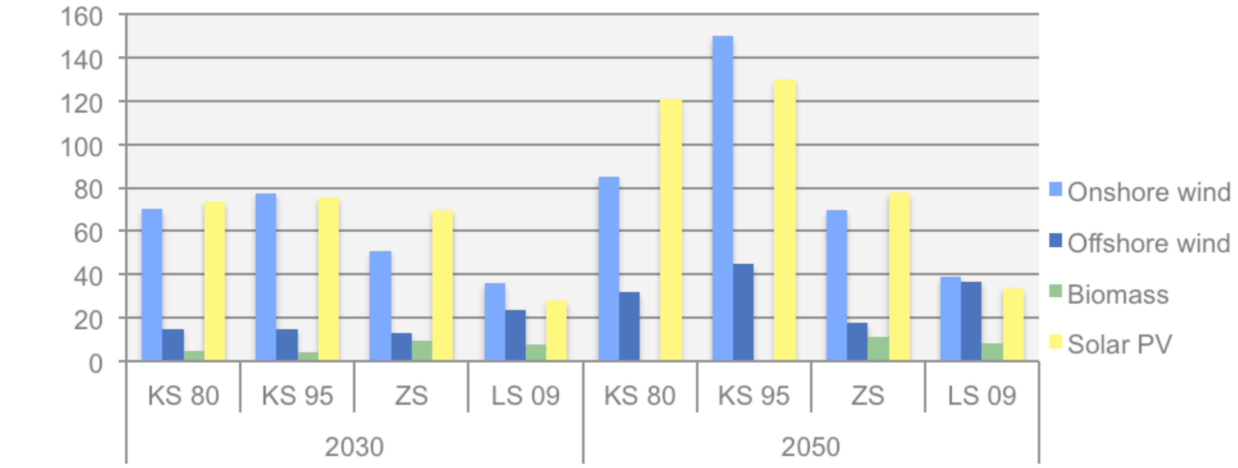
[28] It should be emphasized that of course from these developments between 2006 and 2015 it cannot be concluded that much higher shares of intermittent renewables such as those envisioned by the analysed German scenarios for 2050 (about 60% to 90%) would likewise have no tangible effects on the security of electricity supply. However, it is nonetheless interesting that so far no effects on the SAIDI can be discerned, despite a relatively steep increase in electricity generation from intermittent renewables within only ten years.



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 8-5 Net electricity generation from lignite and hard coal (in TWh)

In regards to renewables energy technologies, wind energy has lower acceptance levels than solar energy, especially if people are asked about their approval of renewable technologies implemented in their direct living environment (AAE 2015). Scenarios with high amounts of onshore wind generation could therefore face lower acceptance levels compared to scenarios that foresee a higher increase of solar capacities. Figure 8-6 shows that from the analysed scenarios, the KS 80 and KS 95 scenarios foresee high capacities for onshore wind already by 2030. This could result in a lower public acceptance or even resistance to this development path.



Sources: Own figure based on BMUB (2012, 2015); BMU (2009); BMWi (2014); UBA (2013b)

Fig. 8-6 Net power plant capacity wind, solar and biomass (in GW)

Apart from individual technologies, the energy system infrastructure can also be a concern in regards to social and political acceptance. Especially the question of the extent and the placement of new power grid construction in Germany is subject to an intensive political debate. However, the scenarios do not provide sufficient quantitative information that would allow to compare them in regard to this aspect. In any case, as all scenarios envision cross-border trade to become more relevant in the future, realising the required expansions of domestic and cross-border transmission grids may continue to be a challenge in Germany, given these social acceptance issues.[29]

8.2.5 Robustness of scenarios to uncertain future developments

Energy transitions strategies need to be robust against uncertain future technological, physical, economic or social developments. In regards to the technical dimension for example, a robust strategy does not rely strongly on a certain technology or on technologies which are not yet mature, but it pursues different technical options so as to avoid technological lock-ins (Droste-Franke et al. 2015). Furthermore, robustness also relates to aspects such as safety against natural fluctuations or safety of the supply, generation and transmission infrastructures which are widely connected to the aspects discussed in regards to energy security in section 8.2.3. Robustness in a social sense means that the energy transition strategies need to be acceptable in a wide range of values and diverse interest (Droste-Franke et al. 2015). The robustness of the scenarios, therefore, is strongly linked to social acceptance issues discussed in the previous section 8.2.4.

Taking a closer look at the technical robustness of the energy transition, the foreseen use of technologies that are not yet sufficiently mature could make development pathways more prone to complications and failure. Particularly, energy transitions strategies that rely considerably on hydrogen and CCS use, like KS 95, LS 09 and EWS, entail a certain implementation risk. However, it should be stressed that no fundamental technical restrictions exist for the introduction of these technologies from 2025/2030 onwards.

Furthermore, scenarios that rely on an extensive use of hydrogen or CCS as well as scenarios that anticipate a fast transition towards electric mobility and/or a high short-term building renovation rate require higher investments and can at least temporarily involve higher costs compared to scenarios that do not or only to a limited extent apply these strategies. This could lead to acceptance problems which could even lead to a failure of these transition strategies. However, it should be stressed that high investments and far-reaching changes are inevitable if ambitious climate change mitigation objectives are to be reached. Behavioural or lifestyle changes hold the potential to reduce the amount of investments required.

Another aspect that influences the robustness of a scenario is the level of foreseen energy imports. As discussed in section 8.2.3, strategies that rely on high electricity imports, such as in the LS 09 scenario, could entail a certain risk to fall victim to geopolitical conflicts.

[29] The stronger use of underground cabling at suitable segments may be part of the solution to overcome this issue. However, underground cabling is considerably more expensive and technologically more complex than landlines.

9 Comparison of findings for Japan and Germany (Joint Conclusion)

In this section the findings from the meta-analysis of Japanese and German energy transition scenarios are compared and discussed jointly. First, the national energy transition targets and possible reasons behind the observed differences in the target setting are discussed (Section 9.1). This discussion is followed by a detailed comparison of the differences and similarities in the analysed scenarios for both countries (Section 9.2). Based on the results from this comparison and the findings from the country analysis, recommendations for further cooperation between the two countries in regards to policy development, business opportunities and further research are derived.

9.1 Discussion and comparison of energy transition targets in Japan and Germany

The main energy policy objectives of the Japanese and German governments are similar in the sense that both countries' governments emphasize the importance of three core pillars: energy security, economic efficiency (or "competitiveness") and environmental sustainability (or "GHG emission reductions"). However, there are noticeable differences between the objectives of both governments in respect to the following four issues:

- The future role of nuclear power
- Prioritisation of the GHG emission reduction objective
- Level of ambition of the GHG emission reduction objective
- Timeframe

In the following discussion of these aspects, the varying preconditions in terms of geography (Japan being an island state while Germany is located in the centre of Europe), and the historic developments of the energy sector in both countries need to be kept in mind to better understand the differences in priority setting in Japan and Germany.

The future role of nuclear power

On top of the three common policy objectives mentioned above, a fourth key policy goal of the German energy transition is phasing out the use of nuclear power until 2022. The phase-out plan reflects the sceptical opinion of a majority of the German population towards the use of nuclear power and aims at reducing and eventually abandoning the risk of large-scale nuclear accidents, as well as reducing other potential problems, such as those related to proliferation and the safe long-term storage of radioactive waste. Another reason why Germany decided in 2011 to speed up the phase out of nuclear power was the considerable success already achieved by then in increasing the share of renewables in electricity generation.

In Japan, the role of nuclear power itself is not a policy goal, but the technology is seen as one of the tools to achieve the three pillars of Japanese energy policy, namely energy security, economic efficiency and environmental sustainability. Taking the pros and cons of different energy sources available into consideration, the Japanese government decided to continue the use nuclear power after the accident in the Fukushima Daiichi plant, although the share of nuclear power in the future energy mix is expected to be reduced compared to the pre-accident era. The benefits that support the continuous use of nuclear energy are that it can simultaneously address the three pillars of energy policy mentioned above, improve self-sufficiency of energy supply, reduce electricity cost, and reduce GHG emissions. The restart of the existing nuclear facilities that satisfy the new safety criteria, is seen by the Japanese government as an immediate remedy to tackle these three challenges.

Prioritisation of objectives

- **From a German perspective**

  The Japanese government states[30] that its "first and foremost" objectives are energy security and a low cost energy supply on the premise of safety. Environmental sustainability, while being a central element, seems to be a subordinate objective. In Germany, on the other hand, there is no prioritization between the four policy goals and the GHG emission reduction goal is often mentioned first in many government publications.

  This difference between the prioritisation of GHG emission reduction objectives appears to be a reflection of the public discourse on energy issues in the two countries. In Germany, climate change mitigation has long been an important issue, driven especially by the relatively influential environmental NGOs and the Green party. In Japan, on the other hand, the country's high dependence on energy imports and its historic experiences with supply insecurities may explain why energy security and low-cost energy have a higher relevance compared with the objective of environmental sustainability. Unlike Germany, the Japanese government has formulated *quantified* targets for energy security (the country's self-sufficiency rate is supposed to increase to "close to 25%" by 2030) and economic efficiency (electricity costs are supposed to be lower by 2030 compared to 2013).

- **From a Japanese perspective**

  History of modern energy policy in Japan started after the oil crises in the 1970s, which made Japan aware of its vulnerable state in regard to energy security and the related issue of energy costs. More than three decades later, Japan's energy security was again challenged by the impacts resulting from the Great East Japan Earthquake in 2011. This time, increasing import re-

[30] METI, Strategic Energy Plan, April 2014 Provisional Translation

quirements of oil and natural gas, in combination with high global crude oil prices of around USD100/bbl, put a huge burden on Japan's economy. Yet, it is needless to say that environmental sustainability is an important pillar of the energy policy in Japan. However, this historical background, lack of fossil fuel resources, and the geographically isolated location have led Japan to traditionally emphasize energy supply security and economic efficiency in its energy policy development.

In Germany, on the other hand, there seems to be a stronger emphasize on climate protection rather than on the security of supply and economic issues. The scenarios in Germany indicate that the country is willing to invest in stronger interlinkages with neighbouring countries when it comes to its future electricity supply[31] and would also accept a surcharge on electricity prices during a transitional stage, which is a different approach from that of Japan. One of the advantages of Germany is that the country is surrounded almost exclusively by EU member countries, and hence importing and exporting electricity as well as fossil fuels from and to these countries does not appear to be associated with any security risk. In terms of electricity cost increases, it seems that the German government expects the German population and industry to be more patient, or willing to bear these costs, than in Japan.

Level of ambition of the GHG emission reduction objectives

A comparison between the GHG emission reduction targets of Japan and Germany for the year 2030 (Table 9-1) indicates that the German government's reduction target is set higher in terms of the reduction percentage. This can be observed for the emission reductions aimed for relative to any of the base years used by the two countries (2013 in the case of Japan, 1990 in the case of Germany). The same holds true for the per capita GHG emissions. These are currently slightly (7%) higher for Germany, but if both countries' reduction targets are met by 2030, per capita GHG emissions in Germany would be lower by 20% compared to those of Japan (see Table 9-1 and Figure 9-1).[32, 33]

[31] Such stronger interlinkages are not only seen as beneficial for integrating high shares of renewables in electricity generation in Germany and other European countries, but is also seen as an opportunity to increase the economic efficiency and to achieve a higher level of security of energy supply. Therefore, the EU has for many years worked on achieving an "Internal Energy Market" (EC 2014).

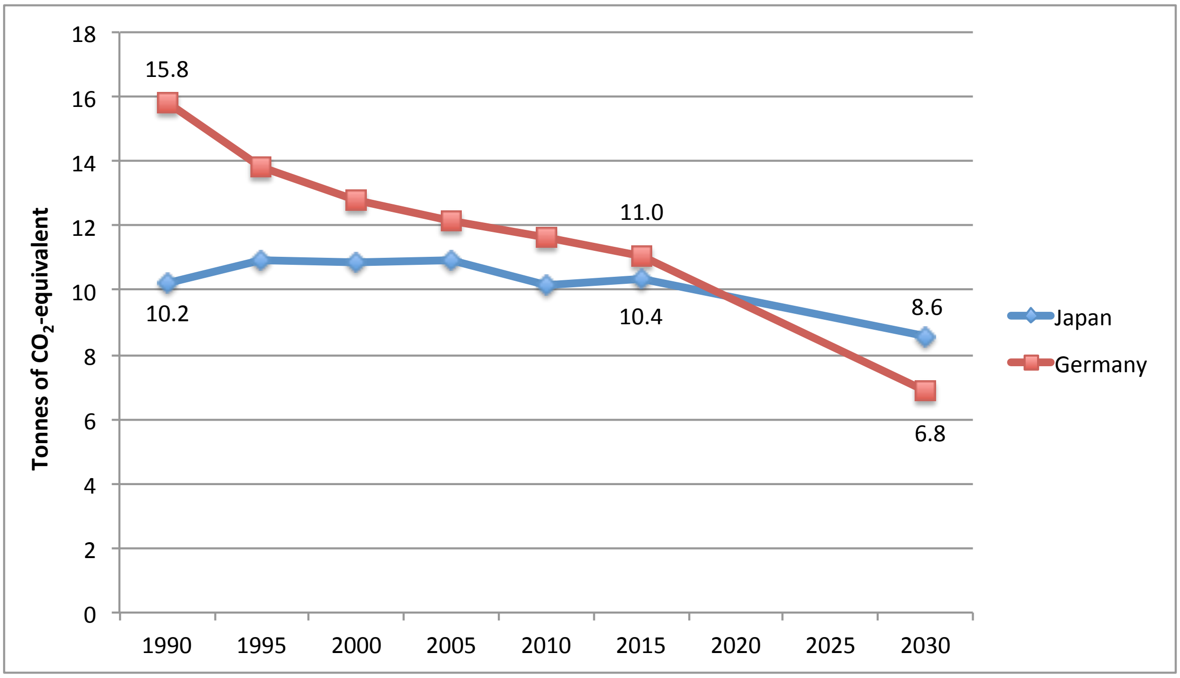
[32] This calculation is based on a population development in both countries as described by the „Medium variant" of the United Nations' 2017 revision of its World Population Prospects (UN 2017).

[33] It needs to be noted that so far no commonly agreed indicator exists to compare emissions reduction efforts. Other studies exist that apply different indicators. A study by RITE (2015), for example, sees the emissions reduction ambitions of Japan on the same level as the EU.

Tab. 9-1 Comparison of the 2030 GHG emission reduction targets and of current and pursued future per capita GHG emissions in Japan and Germany

	Japan	Germany
GHG emission reduction target by 2030		
relative to 1990	-18%	-55%
relative to 2013	-26%	-40%
Per capita GHG emissions (in t of CO_2-equivalent)		
2015	10.4	11.0
2030 (targeted)	8.6	6.8

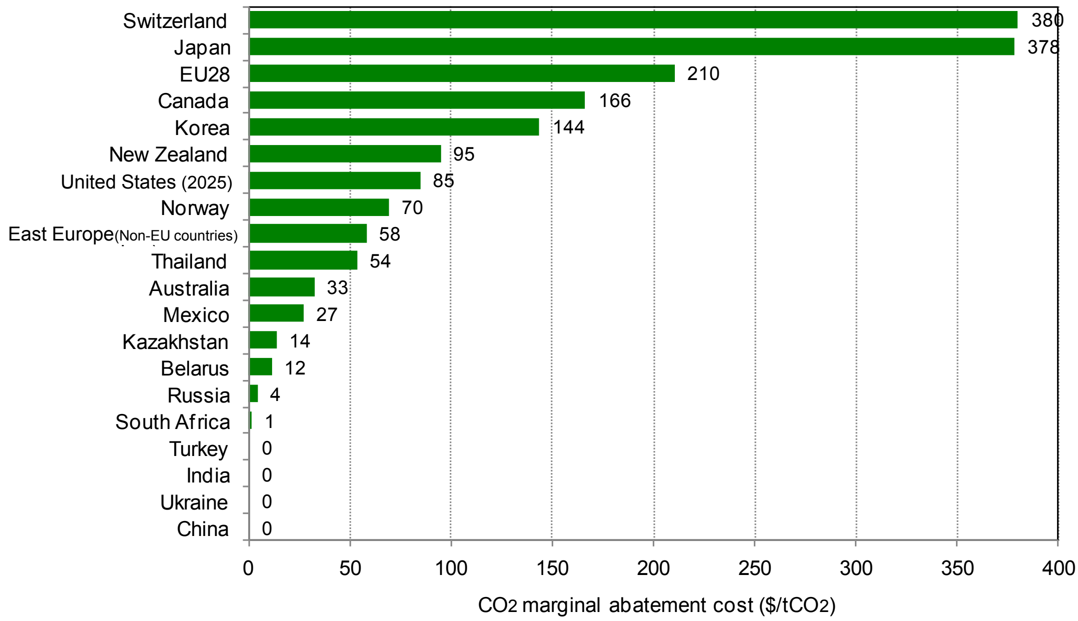
Sources for GHG emissions and population: OECD (2017), UN (2017).



Sources: Own figure based on data from OECD (2017), UN (2017).

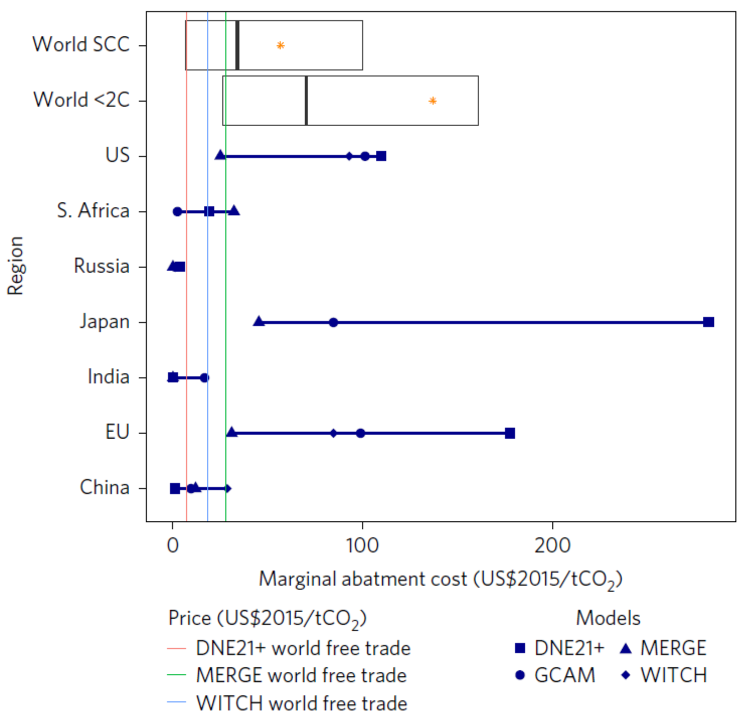
Fig. 9-1 Per capita GHG emissions in Japan and Germany from 1990 to 2015 (historic values) and in 2030 (assuming government targets are met)

However, when comparing these numbers, it should be noted that besides the reduction target itself, other indicators can be applied to asses the level of ambition, for example marginal CO_2 abatement cost. Different studies have shown, for example, that Japan has considerably higher marginal CO_2 abatement cost compared to other countries and regions, including the European Union (Akimoto et al. 2016; Aldy et al. 2016) (see Figures 9-2 and 9-3).



Sources: Akimoto et al. (2016)

Fig. 9-2 Marginal CO2 abatement costs in 2030 according to DNE21+ model when NDCs are realized



Sources: Aldy et al. (2016)

Fig. 9-3 Average 2025-2030 marginal abatement costs for four integrated assessment models

Timeframe

Finally, another difference between the energy targets of both countries is their timeframe. Germany has not only set a GHG emission reduction target for the year 2050, although it is currently a target *range* (-80% to -95% compared to 1990 levels), but it has also set several quantified energy savings/energy efficiency and renewable energy targets for that year as well as for interim years. Japan, on the other hand, has so far focussed on the fiscal year 2030 when formulating specific energy targets. While the Japanese government has stated in the past that it intends to reduce emissions by 80% by the middle of the century under a fair and effective international climate change mitigation framework, so far no more specific targets (e.g. on the energy sources expected to dominate by then) have been formulated for 2050. Due to various uncertainties related to climate science projections as well as economic, technological and societal conditions and the overall international situation, 80% in 2050 is regarded as a vision rather than a target in Japan. Nonetheless, analysis of the developments beyond 2030 are helpful to better understand which path dependencies can occur and how undesirable technological lock-in effects and stranded investments can be avoided.

The differences in the energy transition objectives of Japan and Germany also have an influence on the energy scenarios that are developed in both countries. This is especially true for government-commissioned studies, which can be expected to be guided by the government targets. And indeed, key differences between the German and Japanese energy scenarios analysed in this study include the diverging relevance of nuclear power, a stronger emphasis on GHG reduction in the German scenarios and a typically longer timeframe of those scenarios.

9.2 Discussion and comparison of differences and similarities in the analysed scenarios

9.2.1 Comparison of methodologies used to derive energy scenarios

All but one of the analysed scenarios for Germany (all but the EWS scenario) use a back-casting approach, in which certain targets are set (especially a long-term GHG or CO_2 reduction target) and future energy system developments are then modelled and adjusted until in line with these targets. The back-casting approach combined with the use of engineering-driven bottom-up models enables scenario developers to adjust assumptions about future technology deployments, thereby allowing them to describe technologically feasible future energy system developments, even if certain changes (e.g. in regard to technology diffusion or energy efficiency improvements) deviate substantially – and possibly already in the short to medium term – from historical developments. This advantage of being able to describe changes from past developments is at the same time one of the main limitations of the back-casting approach, as this approach cannot assure that the realties of the current world are always reflected in a satisfactory way. Hence, such approaches are criticized for having difficulties describing realistic scenarios.

Most of the analysed Japanese scenarios, on the other hand, are centred on econometric models. The METI(2012) and the IEEJ(2016) studies are further composed of various supplement models centred in the econometric model. [34] Econometric models are used to simulate the likely future behaviour of market actors, based on extrapolation of past experience. Changes in future energy system developments in these models can be achieved by assuming policy changes, which affect the energy system indirectly, for example by changing the competitiveness of fuels when a CO_2 tax is introduced or modified. As econometric models are calibrated using historic data and are therefore based on past market structures and on past behaviour of market actors, it is often argued that with these models it is more difficult to model deeper system transformations, in which behaviours and market structures change significantly from past trends. On the other hand it can be argued that estimating future economic and energy structures based on past developments allows more realistic scenarios in case no major change are assumed in regards to people's behaviour principles (response to price and income). In this regard, 80% goal in 2050 is regarded as a "destination" or "vision", unlike the 26% target in 2030, which is backed by specific policies and technologies.[35]

Although uncertainties remain in regards to the question of how well the differences in the types of models used can explain some of the differences in the scenarios, these methodical differences are likely to be among the main reasons for the identified differences in the speed of the described technological transformation and GHG emission reductions between the Japanese and German energy scenarios.

9.2.2 Comparison of methodologies used to assess macroeconomic implications

Except for the KS 80 scenario of the BMUB 2015 study, which has used the ASTRA-D model, all other German scenarios modelled the macroeconomic implications of the energy transformation strategies by using the Panta Rhei model, a macro-econometric model. ASTRA-D links total factor productivity to investments, therefore functional chains react strongly on investments in new technologies. In Panta Rhei, on the other hand, the capital costs have a restraining impact on GDP. The results of the scenarios ZS, EWS and LS09 show lower GDP growth resulting from additional investments in the energy system. The model differences may explain part of the differences in GDP and employment effects in the respective scenarios. However, all climate change mitigations scenarios (regardless of which of the two models is used for determining the macroeconomic effects) show positive results for both, GDP growth and employment compared to their respective reference scenarios.

The amount of additional investment in each scenario (compared to the respective reference scenarios) is very important for the size of the macroeconomic ef-

[34] The econometric models are supplemented by various additional models. In case of the IEEJ model, it contains a macroeconomic model, a bottom-up technology model, a power generation mix model, a linear programming global trade model, a global inter industry economic (CGE) model, and a climate change model.

[35] The existing Japanese target of an 80% GHG emission reduction by 2050 is a conditional target, pursued only under the premise that other major emitters also undertake emission reductions in accordance with their respective capacities.

fects. This becomes obvious when comparing the macroeconomic implications of the EWS scenario and the ZS scenario until 2030. For both scenarios the Panta Rhei model is used, but the amount of additional investments differs substantially between the scenarios.

The macroeconomic impacts of the analysed Japanese scenarios are also modelled using two different approaches. METI (2012) employed an econometric model to analyse the energy supply-demand balance along a future timeline and also includes a bottom-up technology assessment model. The calculated energy supply-demand results were entered to a computable general equilibrium (CGE) model to assess the impacts on the economy. This approach analyses desirable power generation mixes in view of the "3 Es" by employing two types of models complementing each other.

RITE employed two kinds of models: a global energy systems model (DNE21+) which minimizes the energy system costs and a global CGE type model (DEARS). The DNE21+ model can evaluate detailed technology options for both the energy supply and end-use sectors. However, it is difficult to evaluate the whole economy such as GDP impacts with this model. Yet, the DEARS model is able to evaluate impacts on the whole economy as well as on disaggregated economic sectors while energy end-use technologies cannot be explicitly evaluated. Both models are global models and can evaluate energy and CO_2 emission reduction measures with global consistency including energy and carbon leakages.

Unlike the analysed German studies, the analysed Japanese studies do not focus on inputs but on the economic impacts, hence no detailed analysis has been made regarding the required investments. [36] This makes a comparison of the role of investments in Japan and Germany based on the analysed scenario studies difficult.

While differences in the models and the model structures are likely a main reason for the differences in the macroeconomic implications of the respective energy system developments as described by the analysed Japanese and German studies, other reasons may be:

- Assumptions on overall economic growth differ between the scenarios (Table 9-2). The available average annual GDP growth rate assumptions until 2030 used for the Japanese scenarios range from 0.9% to 1.7% and for the German scenarios from 0.8 to 1.1%. For comparison: From 2000 until 2016, the average annual GDP growth rate in constant prices in Japan was 0.8% and in Germany it was 1.2%[37], with growth rates in both countries showing a declining trend over past decades.

[36] METI (2012) calculates the necessary low carbon investments.

[37] Own calculations based on: http://data.worldbank.org/indicator/NY.GDP.MKTP.KN?locations=JP-DE

Tab. 9-2 Average annual growth rates (AAGR) of GDP (in constant prices) assumed in Japanese and German scenario studies until 2030

Japanese studies				German studies [33]		
		Period	AAGR (in %)		Period	AAGR (in %)
METI(2012)	Medium GDP growth scenario	2010-2030	0.9%	BMUB (KS 80/95)	2010-2030	0.9%
RITE(2015)	Status quo	2013-2030	1.7%	BMWi 2014 (ZS)	2011-2030	1.1%
IEEJ(2015)	Scenario 1	2013-2030	1.5%	UBA 2013 (EWS)	2010-2030	0.8%
IEEJ(2016)		2014-2030	1.0%			

Sources: Own calculations based on data in individual studies

- Assumptions on market prices for oil and natural gas differ between the Japanese and German scenarios. While until 2030 Japanese studies assume higher price increases for natural gas for the period 2020-2040, the assumed price increase is almost in the same range as in the German studies. For oil, however, the German studies assume a substantially higher level of market price increases compared to the Japanese studies. Higher oil and natural gas market prices have complex macroeconomic implications. In a first step they reduce economic growth, but in a next step substitutional processes are likely to be initiated. Economic efficiency of investments in renewable energies and energy efficiency would increase.
- Different cost assumptions for electricity generation technologies (resulting in different LCOEs) are also contributing to differences in the macroeconomic effects of the scenarios. Higher LCOEs for renewable energies in Japanese studies (see Figure 9-2) lead to higher electricity prices as more renewable energy technologies are deployed, and therefore to a less optimistic development of GDP and employment.

Tab. 9-3 Comparison of assumed increases of market prices for energy in German and Japanese studies (in %)[38]

	Japan (average of studies)		Germany (average of studies)	
	current - 2030	2020-2040	2010-2030	2020 - 2040
Oil	69.4	66.7	34.3	36.8
Natural Gas	24.5	31.8	24.5	29.9
Coal	20.7	48.3	9.5	

ForJapan, "current–2030" is average of METI(2012) and IEEJ(2016), "2020-2040" is IEEJ(2016)
Current year is 2010 in METI(2012) and 2015 in IEEJ(2016)

Sources: Own calculation based on data in individual studies

[38] Based on data indicated in Figures 5-6 and 5-7, and for Germany in Table 5-9.

9.2.3 Comparison of current and expected future costs of electricity generation in Japan and Germany

Differences in current and expected future electricity generation costs between various technologies do not directly determine the future deployment of these technologies in most of the analysed Japanese and German scenarios, as the future deployment of renewables is typically set exogenously in these scenarios. This is done based on government expansion targets (in case of some of the analysed Germany studies) or as a way to differentiate between several scenarios of a study (in case of some of the analysed Japanese studies). However, it is likely that both, government targets to expand renewables and scenario developers' decisions to set a range of different future electricity generation mixes are influenced to a great extent by current and future estimates of electricity generation costs for the various technologies.

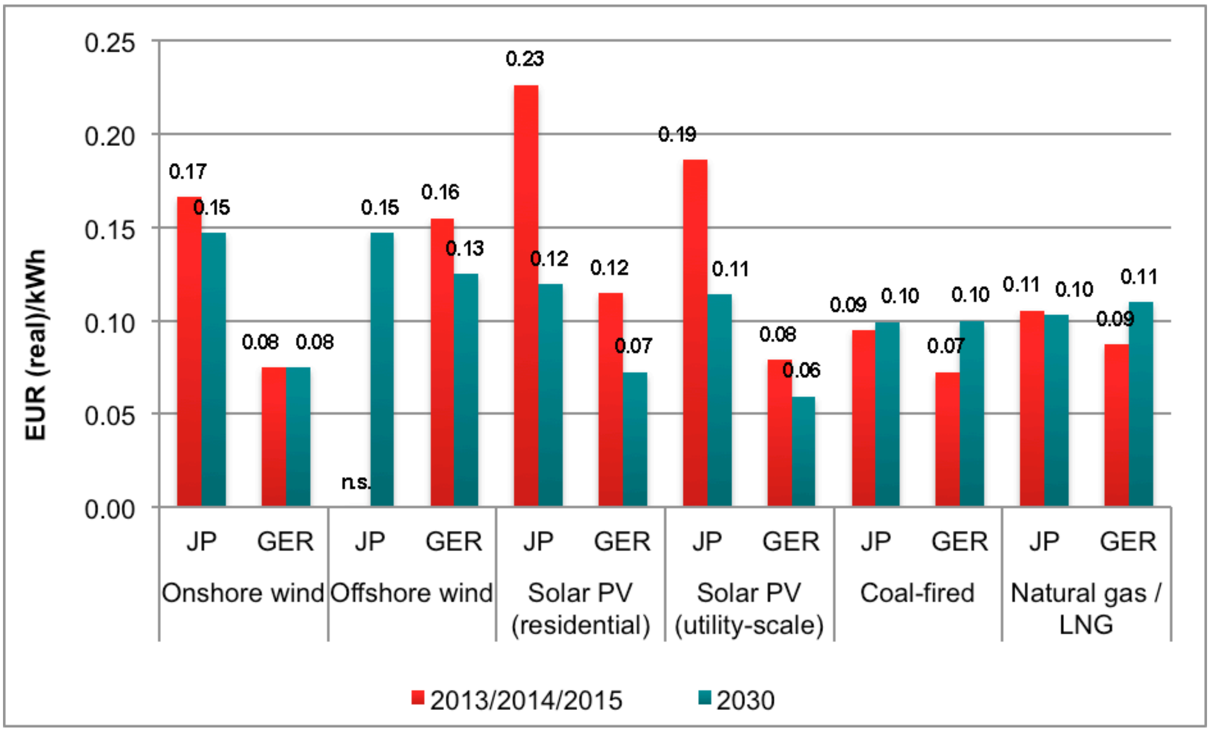
Therefore, this section compares current and expected future costs of electricity generation between Japan and Germany. Interestingly, many of the analysed scenario studies for both Japan and Germany do not include or disclose assumptions about the levelized costs of electricity (LCOE) or technology investment costs. Regarding the German studies, only BMWi (2014) (for the ZS scenario) provides investment cost assumptions, while BMU (2009) (for the LS 09 scenario) lists LCOE assumptions. As the latter study is relatively old and its LCOE assumptions are apparently no longer up-to-date and no longer representative for more typical assumptions by researchers today, this study's cost data will not be used here. Instead, current and expected future LCOE assumptions for Germany are taken from a separate study by Fraunhofer ISE (2013a), a source frequently cited in Germany for such data.[39] For Japan, the current and expected future LCOE assumptions presented and discussed below are taken from analysis of the "Power Generation Cost Analysis Working Group". The working group has submitted power generation cost outlooks in both 2011 and 2015. METI's scenario, which was developed in 2012, utilizes the working group's cost outlook data formulated in 2011. On the other hand, IEEJ's scenario developed in 2016 employed the cost outlook data formulated in 2015. RITE's scenario, on the other hand, adopted its own assessment results of power generation cost. Although, the data resources are different among the scenarios, the order of power generation costs is the same, i.e. nuclear and thermal (coal and natural gas) power generation are assumed to be relatively cheap, while solar PV and onshore wind power generation are seen as less economically competitive energy sources even in 2030.

Based mainly[40] on these two studies (METI 2015, Fraunhofer ISE 2013a), Figure 9-2 compares LCOE estimates for Japan and Germany for several types of new

[39] Although not explicitly mentioned in the BMUB (2015) study, the investment cost assumptions from Fraunhofer ISE (2013a) were also used for the macroeconomic analysis of the KS 80 scenario, as we were told by a co-author of the BMUB (2015) study.

[40] As Fraunhofer ISE (2013a) does not provide data for utility-scale solar PV power plants in Germany, for this technology Agora Energiewende (2015) was used instead.

plants built recently and for new plants to be built in 2030.[41] It should be stressed that LCOE estimates depend not only on investment cost assumptions, but also on a number of additional assumptions, including cost of capital, fuel costs, CO_2 costs and plants' full load hours. None of these assumptions are harmonized between the two studies, so it should be kept in mind that differences in values between the data for Germany and Japan can principally have a number of different reasons. Assumptions on full load hours of PV and wind are similar among both studies, which is in line with other analysis (Fraunhofer ISE 2014, IEA Wind 2015, IEA Wind 2016) and which suggests generally similar average quality of solar irradiation and wind in both countries. Assumptions on future CO_2 prices are also similar among both studies. On the other hand, coal prices are assumed to be somewhat higher in the German study, while LNG prices in Japan are – understandably – expected to be higher than natural gas prices in Germany.



Data sources: METI (2015), Fraunhofer ISE (2013a), Agora Energiewende (2015).
Note: A conversion rate of 1 Yen = 0.0077 Euro has been used to convert the Japanese cost data from Yen to Euro.

Fig. 9-4 Comparison of LCOE estimates for Japan and Germany for several types of new plants built recently (in 2013, 2014 or 2015) and for new plants to be built in 2030

Furthermore, there are considerable differences in the assumed full load hours of conventional power plants. These are assumed to be higher in Japan, especially in

[41] For Germany, no cost estimates for new nuclear plants are available, so this comparison does not include nuclear power. For Japan, METI (2015) provides an LCOE estimate for nuclear power of about 0.08 EUR/kWh, in line with other institutions'' estimates for nuclear power.

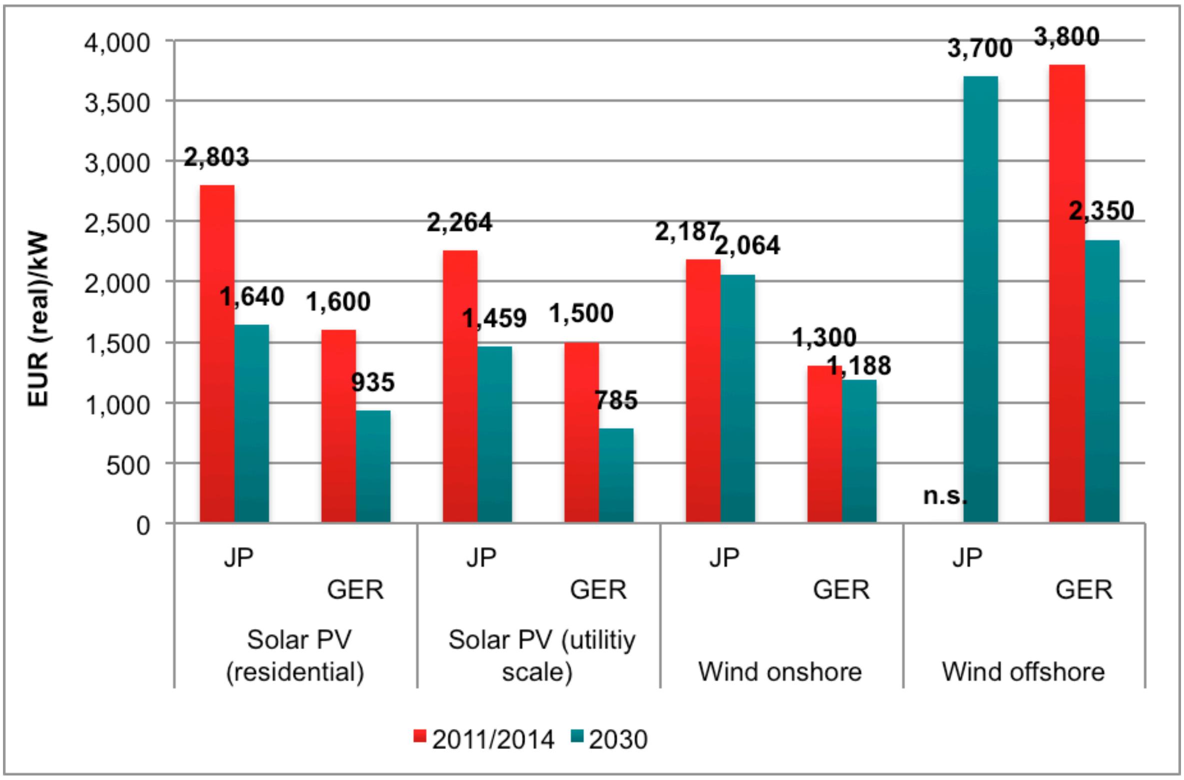
the case of LNG/natural gas power plants (about 6.100hrs/year for 40 years for Japan, but only 3.500hrs/year (2020) to 2.100 (2050) for Germany). The discount rate used is similar among both studies for renewable energy technologies other than offshore wind (3% for Japan, 2% to 4% for Germany), but lower for Japan for fossil fuel plants and offshore wind plants (3% for Japan, 7% to 8% for Germany).[42]

The figure shows that the LCOE estimates for both hard coal-fired power plants and natural gas power plants are quite similar between Germany and Japan, especially for the year 2030, although they are based on significantly different assumptions, as mentioned above. Apparently, in the case of natural gas/LNG, the two effects of higher fuel costs in Japan on the one hand, but also higher full load hours in that country balance each other out and lead to very similar projected LCOE in both countries in 2030. However, for wind (especially onshore wind) and PV technologies, cost differences for both, recent years as well as for the future differ considerably between Germany and Japan. The LCOE of onshore wind and solar PV (both residential and utility-scale) power plants are currently roughly twice as high in Japan compared to Germany and this relative difference is expected to remain largely unchanged by the year 2030, according to this comparison of the two studies. For offshore wind, no recent cost data is available from the Japanese study, but for 2030, the expected offshore wind LCOE is also higher in Japan than in Germany, although the difference for this technology is less pronounced than in the case of onshore wind and solar PV.

The following figure looks at total investment costs of wind and solar PV technologies, for which the most striking LCOE differences were found. In the figure, investment cost estimates for Japan are from the same study from which the LCOE data was taken from (METI 2015). For the investment cost estimates for Germany, one of the scenario studies analysed for this scenario was used (BMWi 2014), as it provides investment cost estimates until 2050. The comparison of the investment cost estimates shows a very similar picture to the comparison of LCOE cost estimates: Investment cost estimates for recent years for solar PV and onshore wind are much higher in Japan than in Germany43 and they are expected to remain much higher (by about 75% to 85%) by 2030. For offshore wind, investment costs are expected to be 55% higher in Japan by 2030 than for Germany. A recent study by IRENA (2016) similarly finds much lower current and future (2025) globally weighted investment costs for solar PV and wind technologies, compared to the cost assumptions in METI (2015).

[42] However, despite these differences in several assumptions relevant for the LCOE calculation, the investment cost assumptions remain crucial and a closer look at differences in investment cost assumptions between Japan and Germany (see Figure 9-5 below) suggests that these differences in investment cost estimates are mainly responsible for the considerable differences in the LCOE between Germany and Japan of several renewable energy technologies.

[43] The differences for the recent years provided by the two studies is smaller than for 2030 (investment costs in Japan for recent years are 50% to 75% higher than in Germany). However, it should be noted that recent costs for Germany refer to the year 2011, while recent costs for Japan refer to the year 2014, so as the costs for these technologies fell over time, the cost difference between Germany and Japan for „recent" years is somewhat underestimated by comparing the 2011 data from the German study and the 2014 data from the Japanese study.

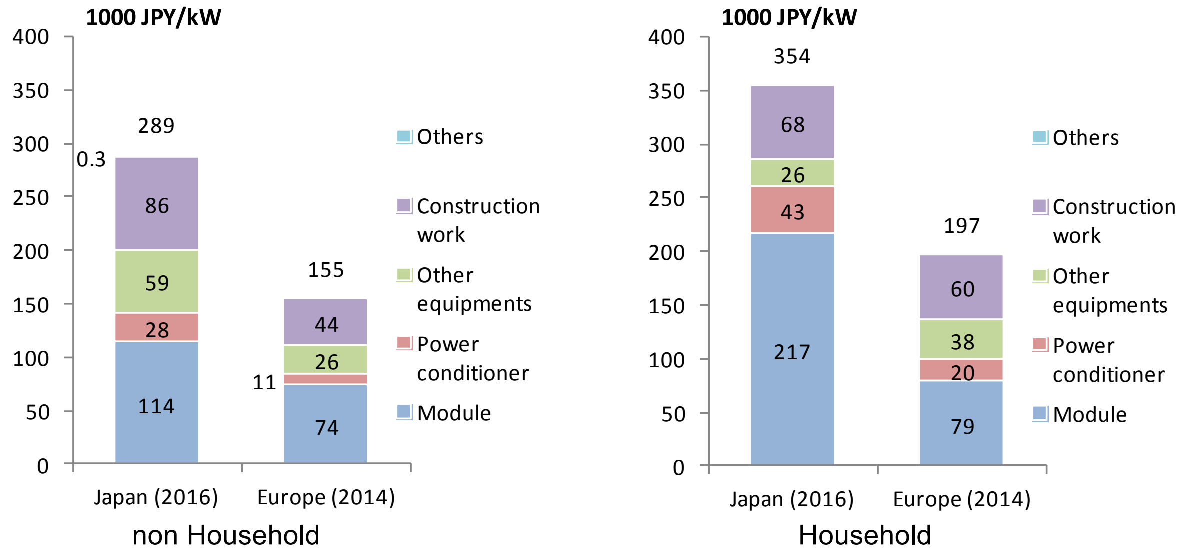


Data sources: METI (2015), BMWi (2014).
Note: A conversion rate of 1 Yen = 0.0077 Euro has been used to convert the Japanese cost data from Yen to Euro.

Fig. 9-5 Comparison of investment cost estimates of wind and solar PV technologies for Japan and Germany for several types of new plants built recently (in 2011 or 2014) and for new plants to be built in 2030

Previous studies have identified a considerable disparity in wind and solar PV investment costs between countries in general and specifically between Germany and Japan (IRENA 2016, Renewable Energy Institute 2016). Regarding solar PV, the two most important factors explaining the cost differences were found to be differences in construction costs and other expenses and differences in module prices. Furthermore, learning effects are widely seen to have been very important in decreasing costs of renewable energy technologies, specifically of solar PV and wind.

Recent studies from METI (Study group for strengthening the competitiveness of solar PV, 2016) have identified a disparity in solar PV investment costs between Japan and Europe. For non household installations, a large disparity exists for instance, in the module costs, which are 1.5 times higher and construction costs which are 2.0 times higher than that in Europe respectively. For household (roof top) installations, the largest disparity exists in module cost, which is 2.7 times higher than in Europe. The study highlighted several potential reasons for these cost differences between Japan and Europe in regard to large-scale installations. These include: immature skills of developers, less competitive pressure for the construction because of high FIT, higher design standards to protect installations against natural disasters (e.g. earthquakes, typhoons). Reasons identified for higher costs for household installations include on the one hand multi-layered distribution channels for modules which each add margins and on the consumer side limited availability of cost information and preference for higher quality and domestic products.



Sources: METI, Study group for strengthen competitiveness of solar PV, October 2016

Fig. 9-6 Cost structure of solar PV in Japan and comparison with Europe

A detailed discussion of the reasons for the cost differences between Japan and most other markets globally (IRENA 2016), the likelihood of these differences getting smaller or even disappearing in the future, and possible policy measures in Japan that may contribute to reduce these differences is beyond the scope of this report. However, further research in this area appears to be very useful.

The striking difference in LCOE and investment cost estimates of the key renewable energy technologies wind (especially onshore) and solar PV may clearly be one reason why these technologies are expected to play a larger role in the future in the analysed German scenarios compared to the analysed Japanese scenarios. It can be assumed that it is a widespread perception among researchers and politicians in Germany that the LCOE of onshore wind and solar PV will be lower by 2030 than the LCOE of fossil-fuel power plants (at least if CO_2 costs and the expected lower full load hours of conventional plants are taken into account), while it can be assumed that it is a widespread notion among researchers in Japan that the LCOE of wind and solar PV will remain higher than those of fossil fuel plants in the foreseeable future. These diverging perceptions can be expected to shape the development of energy scenarios as well as policy discussions.

At the same time it should be stressed that the LCOE estimates presented here do not include system costs of integrating new power plants into an existing electricity system. These costs, which include grid costs, balancing costs and profile/adequacy costs, are generally higher for fluctuating electricity generation from wind and solar PV compared to those of fossil fuel and nuclear power plants, especially at higher penetration rates of fluctuating sources. However,, the relevance of system costs varies from one country to another and depends not only on the penetration of solar PV and wind power, but also on other factors such as the mix of conventional power plants, the flexibility of electricity demand, the availability of storage options such as pumped storage hydro plants and the opportunity to trade electricity with neighbouring countries. The lack of electricity trade with other countries means that for Japan, the system costs of wind and solar PV may be more relevant and/or they may increase faster than is the case for a European country like Germany. However, there are mitigating measures, possibly including low-cost storage, which might be provided to a considerable extent by the already significant capacity of pumped hydro power plants in Japan[44], that can help to lower system costs in the future. According to the knowledge of this report's authors, no studies are available that compare the expected system costs of higher future shares of wind and solar PV between Germany and Japan.

Finally, it should be mentioned that very recent studies (Lazard 2017, Creutzig et al. 2017) and news reports (pv magazine 2017, Harrabin 2017) indicate that in the past one or two years, technology costs for solar PV and wind have continued to decline. Learning effects are widely seen to have been very important in decreasing the costs of renewable energy technologies, specifically of solar PV and wind technologies (Samadi 2016, 2017). Further significant cost reductions in these technologies are expected in the years and decades to come (IRENA 2016, Dykes et al. 2017).

9.2.4 Comparison of information provided by the respective studies

Regarding energy system developments

While details of the described energy system developments differ from one study to another, the German scenario studies generally provide much more detailed information on both, the energy supply and energy demand side than the Japanese studies, at least in regards to the publicly available materials. For example, the mix of energy sources in each end-use sector as well as the number of electric vehicles in use is provided by most of the analysed German scenarios, while this information is not provided by the Japanese scenario studies. Likewise, assumptions on energy demand drivers (such as km travelled) are provided in more detail in the German studies. The main reason for these differences is likely the dispari-

[44] According to the IEA (2016b), Japan had 21.7 GW of pumped hydro capacity installed in 2014. The same IEA report on Japan (IEA 2016b) noted in regard to the flexibility of the Japanese electricity system that "there are flexible resources beyond thermal generation (including hydropower, demand-side response, grid infrastructure and storage) that can be used to balance variability. For example, Japan already has ample pumped hydro storage capacities with the highest installed capacity per peak demand of all IEA countries, and could develop them further. It was also the first, and remains the only, country to develop seawater pumped-storage hydropower." However, the development of additional pumped hydro storage potential may be constrained by issues relating to its environmental impact and necessary relocations of residents. Regarding hydro power itself, METI estimates that approximately 60% of the capacity of the technically and economically feasible potential has been developed in Japan. Particularly, the 30 megawatt or above class potential is very limited, which means that the remaining potentials are basically small-scale.

ties in the format or nature of the respective reports. Both the German and Japanese scenarios are developed using modelling frameworks which contain detailed physical descriptions of the energy system as well as of key drivers of energy demand and supply. However, publicly disclosed information is comparatively limited for the Japanese studies chosen in this report, while it is more sizeable in the selected German studies. While Japanese studies are also underpinned with detailed data assumptions on energy system developments, these are often not presented in detail.

Regarding macroeconomic implications

Macroeconomic results for the analysed Japanese and German energy transition scenarios are provided by the respective studies in regard to GDP, employment and foreign trade. In regard to GDP and employment, for both countries an increase in the penetration of low-carbon energy sources (nuclear for Japan, renewable energy for Germany) was found to have positive effects compared to the respective reference scenarios. In the Japanese transition scenarios, the demonstrated positive GDP and employment effects seem to be related to an increasing share of nuclear energy in the fuel mix. These effects are the result of the lower power generation costs of nuclear power and its substitution of fossil fired power generation which enables the reduction of fossil fuel imports. For the German scenarios, the positive results are related to the level of investment and to the model used as mentioned above. The KS 80 scenario, which is the only scenario for which a sectoral split of the demand impulses from additional investments are provided, shows major growth impulses for the construction industry, the transport sector and the real estate sector.

For Japan, the RITE analysis for the METI(2012) expect negative GDP effects for scenarios with CO_2 restrictions and these effects become larger when the CO_2 constraint becomes tougher. The reasons for this can be explained by cost assumptions of different power generation sources. In their analysis, nuclear power and coal power are assumed to be the lowest cost power generation sources. In contrast, renewable energies are, in general, assumed to be higher cost power generation sources, even though a gradual cost reduction trend is assumed for these technologies in the future. Therefore, under a tighter CO_2 restriction, which requires a larger share of renewable energy, this means higher energy costs and in turn results in negative impacts for the economy.

Positive foreign trade effects have also been presented by IEEJ (2015), as a result of lower fossil fuel imports in scenarios with higher combined shares of nuclear and renewable energy. In detail, however, the foreign trade effects depend on the breakdown of fossil fuels to be replaced.

For Germany, net exports are increasing in energy transformation scenarios according to most of the analysed studies. This is due to reduced fossil fuel imports and a possible increase of technology exports. The fossil fuel import reduction proves to be stronger in scenarios which assume strongly increasing fossil fuel market prices. However, results in regard to net exports are mixed for the analysed German scenarios. The EWS scenario analysis shows that imports are slightly increasing until 2030, which leads to a slightly negative net foreign trade balance relative to the reference scenario. Analysis for Germany also includes effects on public finance. In this regard, however, the findings of the studies are conflicting.

9.2.5 Comparison of main objectives pursued by the scenarios

All German energy scenario studies taken into account in this analysis either focus on showing how the government's medium- and/or long-term GHG emission reduction targets can be met (BMUB 2015, UBA 2013) or to show how the whole set of the government's energy transition targets (which obviously include the GHG emission reduction target) can be reached (BMWi 2014, BMU 2009). So a key objective of the analysed German scenarios is to show how the government's GHG reduction targets can be met, while at the same time the scenarios also aim to fulfil the additional energy transition targets of the German government (mainly relating to saving energy, increasing the use of renewable energy sources and phasing out nuclear power production).

In the Japanese case, on the other hand, the priority of the analysed scenario studies lies on ensuring a balance among different objectives of energy policy Furthermore, the focus lies on showing how energy self-sufficiency and energy cost competitiveness can be strengthened until 2030, while pursuing the set GHG emissions reduction targets.

9.2.6 Comparison of described energy system developments until 2030

This section compares key energy system characteristics until the year 2030 in selected scenarios of the Japanese and the German country analysis. The following characteristics are looked at:

- Final energy demand
- Electricity generation
- Primary energy consumption
- Per capita energy-related GHG emissions

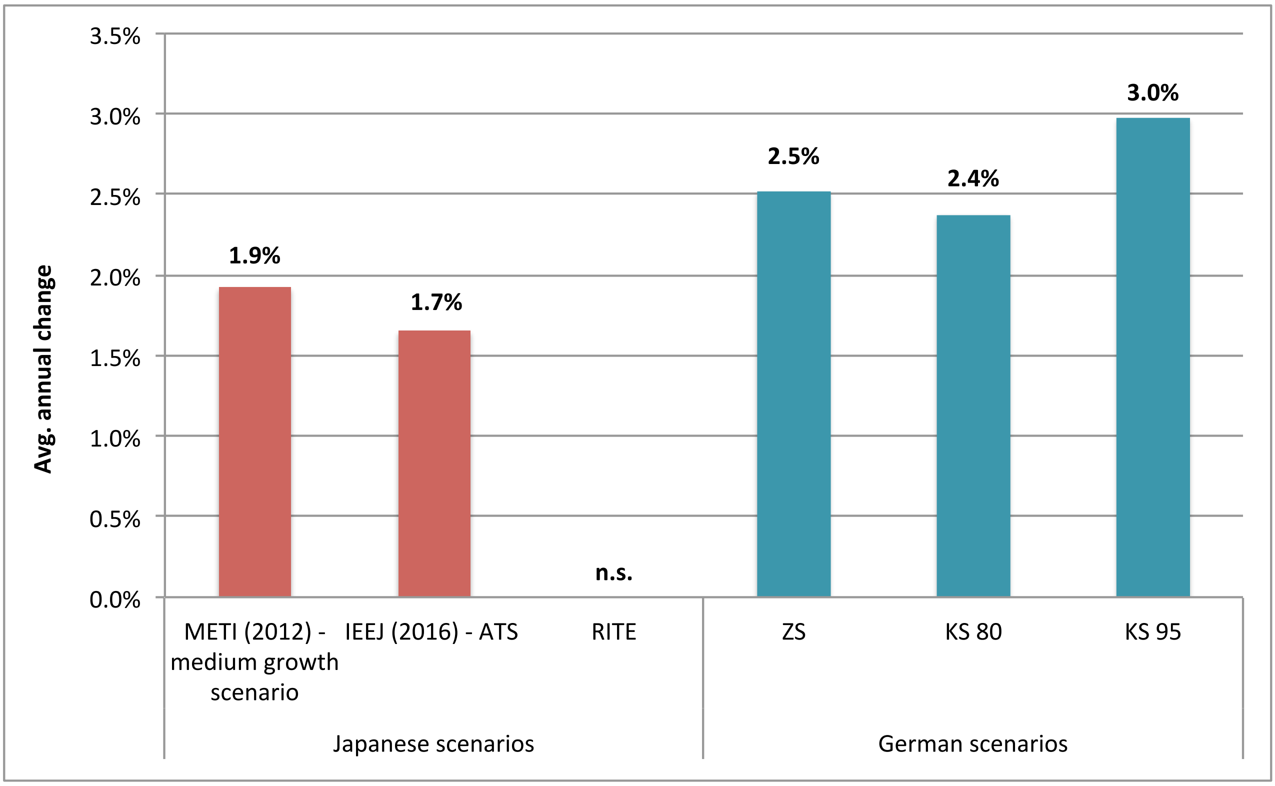
Data on framework assumptions and energy system developments differ from one study to another and in general more detailed data is publicly available for the German studies than the Japanese studies chosen in this report. This fact as well as the fact that some elements of the energy system (such as energy-demand sectors) are defined differently from one country to another make it difficult to compare energy system developments between both countries in more detail.

For reasons of clarity, the following comparisons will include only three scenarios from each country. For Germany, the scenarios ZS, KS 80 and KS 95 were selected, while for Japan the Advanced Technologies scenario of IEEJ(2016) was selected and for each comparison two additional scenarios from either METI(2012) or RITE(2015) complement the picture, depending on data availability in the respective scenarios.

Final energy demand

Mainly due to expected efficiency improvements, final energy demand decreases in all of the analysed Japanese and German scenarios. However, the decline is more pronounced in the German scenarios, with the ZS and KS 80 scenarios describing a decrease of 22% to 25% between 2010 and 2030 and the KS 95 scenario even describing a decrease of 33%. In METI's Medium GDP growth scenario, final energy demand decreases in the same 20 years by 18%, while it decreases by 13% in the Advanced Technologies scenario of IEEJ (2016).

The more optimistic assumptions in the German scenarios on the future potential to reduce final energy demand are mirrored in the development of final energy productivity (Figure 9-7). For the period of 2010 to 2030, the selected German scenarios envision an average annual improvement of 2.4% to 3.0%, while the two selected Japanese scenarios that allow this value to be calculated envision an average annual improvement of 1.7% to 1.9%. Interestingly, between 2008 and 2015, the average annual improvement of final energy productivity in Germany was only 1.3%, while it was 1.7% in Japan. This suggests that the selected scenarios for Germany assume a much stronger deviation from past developments than the scenarios for Japan.



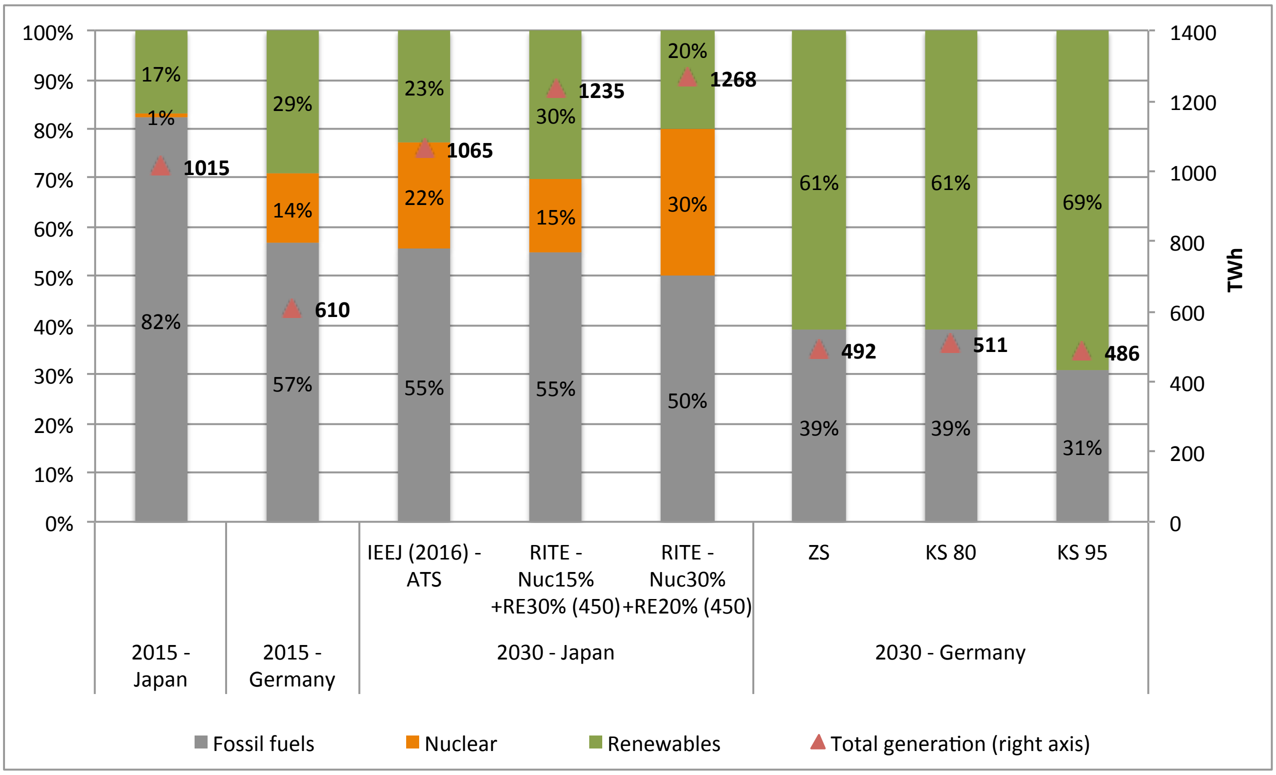
ATS = advanced technology scenario

Sources: Own figure and calculations based on the data found in the cited scenarios and studies.

Fig. 9-7 **Average annual improvements in final energy productivity between 2010 and 2030 in selected Japanese and German scenarios**

Electricity generation

The following Figure 9-8 shows that while for Japan, an increase in electricity generation of 5% to 25% is expected between 2015 and 2030, the selected German scenarios all expected a decrease in electricity generation of 16% to 20%. It should be mentioned that the decrease in electricity generation in the German scenarios is to a great extent due to the scenarios' assumptions about Germany's future net electricity imports. While currently Germany is a net exporter of electricity, all analysed scenarios expect this to change in the coming decades. Consequently, the foreseen reduction in domestic electricity *demand* between 2015 and 2030 (at 5% to 15%) is more modest than the reduction in electricity *generation*.



ATS = advanced technology scenario

Sources: Own figure based on the data found in the cited scenarios and studies and from AG Energiebilanzen (2017a) and IEA (2016) for 2015 data.

Fig. 9-8 **Total electricity generation (in TWh) and electricity generation mix in Japan and Germany in 2015 and in selected scenarios in 2030**

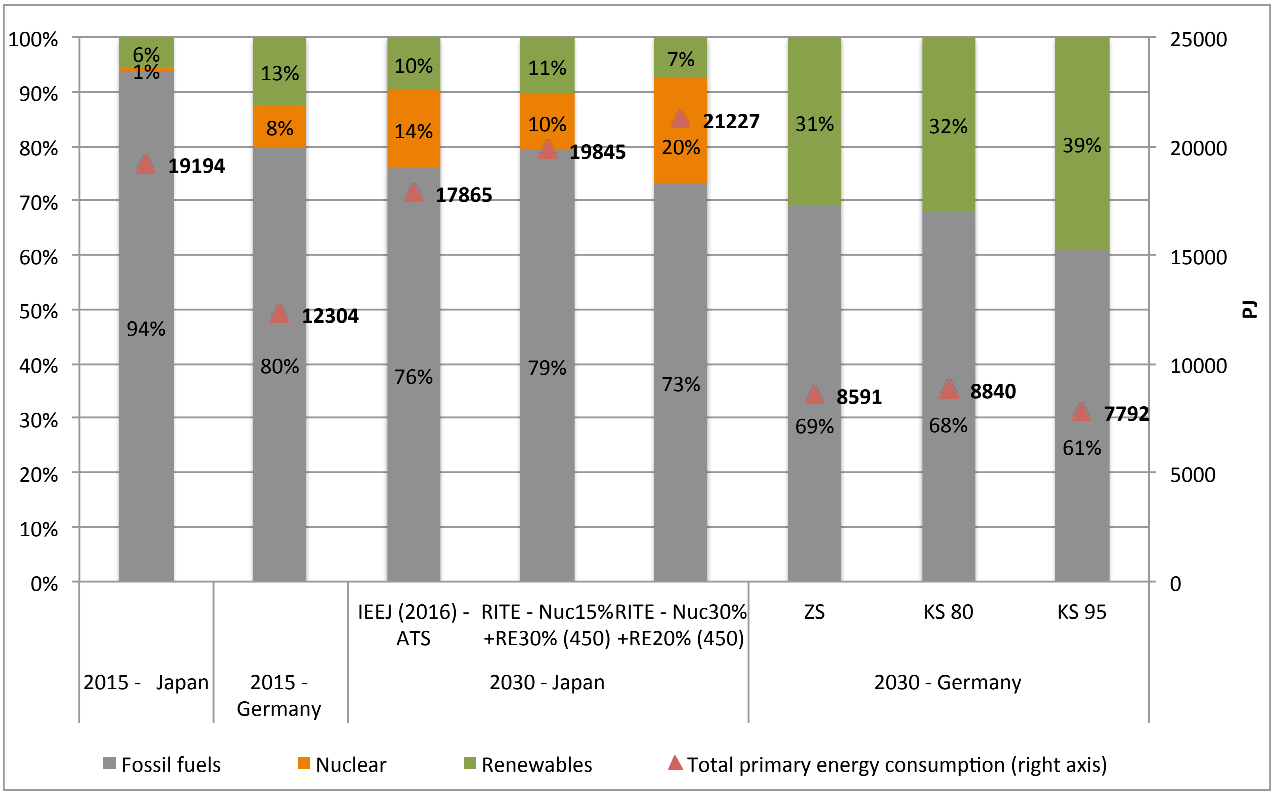
Regarding the fuel mix, in the scenarios for both countries, the share of fossil fuels in domestic power generations decreases considerably until 2030 compared to 2015. In the Japanese scenarios, this share decrease from 82% in 2015 to between 50% and 55% in 2030. In the German scenarios, the share of fossil fuels decreases from 57% in 2015 to between 31% and 39% in 2030. However, while for Japan, the scenarios foresee that fossil fuel power generation will be displaced by an increase in both, nuclear power generation and power generation from renewables, the German scenarios – reflecting the German nuclear phase-out decision – foresee that only additional renewables-based electricity generation is used to lower fossil fuel electricity generation until 2030, and to displace all of the nuclear power generation.

As a consequence, the share of renewables in power generation, which in 2015 was already higher in Germany (29% vs. 17%), is expected to further diverge until 2030, with the share of renewables in the selected Japanese scenarios increasing to between 20% and 30% and in the selected German scenarios to between 61% and 69%.

Primary energy consumption

Regarding primary energy consumption, the selected Japanese scenarios vary between expecting a decrease of 7% between 2015 and 2030 (IEEJ (2016) Advanced Technologies scenario) and an increase during the same period of 10% (RITE (2015) Nuc30%+RE20%/450 scenario) (Figure 9-9). The selected German scenarios, on the other hand, all expect a massive decrease in primary energy consumption in those 15 years, by 28% (KS 80) to 37% (KS 95). This considerable difference between the Japanese and German scenarios is mainly a reflection of the stronger final energy demand reductions expected by the German scenarios (see above) as well as a consequence of the much stronger expected expansion of wind and solar power generation in the German scenarios. After all, this type of electricity generation reduces primary energy supply when it displaces electricity generation from thermal power plants, at least when the prevalent convention of converting electricity generation from non-thermal sources to primary energy supply is used.

Comparing the primary energy mix between the selected German and Japanese scenarios (also Figure 9-9), the findings mirror those for electricity generation. In primary energy supply, too, the share of fossil fuel energy sources decreases considerably until 2030 in all Japanese and German scenarios. In the Japanese scenarios, the fossil share decreases from the current (2015) value of 94% – the highest share among IEA member countries (IEA 2016b) – to between 73% and 79%. In the German scenarios, this share decreases from 80% in 2015 to between 61% and 69%. As in the case of the electricity generation mix, the relevance of fossil fuels is expected to be reduced in Japan through both, nuclear power and renewables, while in Germany only renewables are expected to displace fossil fuels.



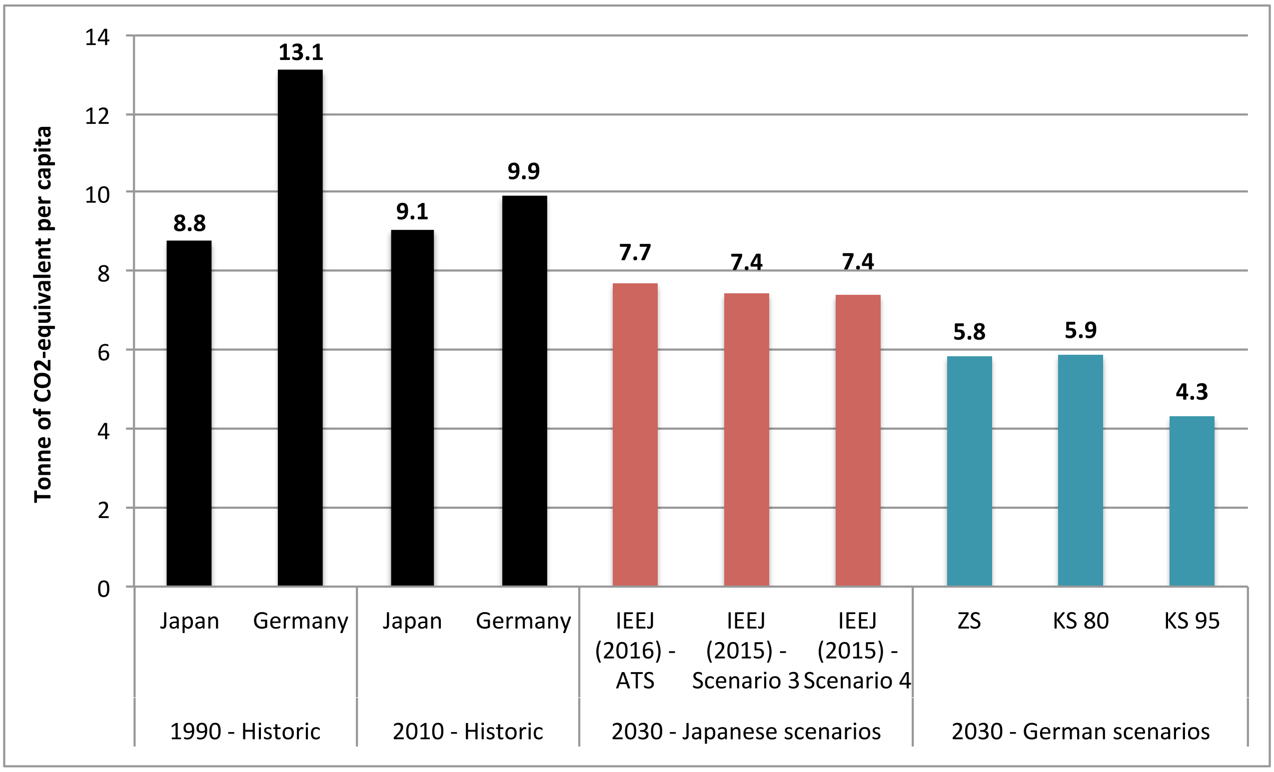
ATS = advanced technology scenario

Sources: Own figure based on data found in the cited scenarios and studies and from AG Energiebilanzen (2017b) and METI (2017) for 2015 data.

Fig. 9-9 Total primary energy consumption (without non-energetic consumption) and primary energy mix in Japan and Germany in 2015 and in selected scenarios in 2030

Per capita energy-related GHG emissions

Per capita energy-related GHG emissions in Japan and Germany have converged between 1990 and 2010 (Figure 9-10), but were still about 8% lower in Japan in 2010 (at 9.1 tonnes) than in Germany (at 10.0 tonnes). The selected Japanese scenarios foresee a decrease in per capita energy-related GHG emissions to between 7.4 and 7.7 tonnes in 2030, a decrease of 16% to 19% compared to 2010. The selected German scenarios foresee a much stronger decrease of 41% to 58% during the same period. Per capita energy-related GHG emissions in Germany would then be considerably lower in 2030 than in Japan, at 4.3 to 5.9 tonnes. These diverging developments described by the analysed scenarios for both countries mirror the different approaches, namely, back-casting from 2050 targets for Germany and bottom-up towards 2030 for Japan (see Section 9.1).



Sources: Own figure based on data found in the cited scenarios and studies and from United Nations (2017), UBA (2017c) and MoE (2017) for historic data.

Fig. 9-10 Per capita energy-related GHG emissions in Japan and Germany in 1990, 2010 and in selected scenarios in 2030

9.2.7 Comparison of expected macroeconomic implications until 2030

GDP

The German studies estimate that investments in energy efficiency and in renewable energy can generate positive impacts on GDP growth as these investments lead to increased demand directly in sectors producing the required technologies. While Japanese studies also estimate that investments in energy efficiency and renewables will immediately benefit economic growth, as discussed below, they also estimate negative effects on GDP due to higher electricity prices in mid-term.

Differences between Germany and Japan can be seen in investments in fossil fuel and nuclear power. While Japan plans to increase investments in nuclear and highly efficient thermal power, Germany is expected to mainly invest in renewable technologies to substitute fossil fuels and nuclear.

Another difference between the analysed Japanese and German scenarios can be found in the assumed change of electricity prices. As the primary objective of the German scenarios is to reduce GHG emissions, an increase of electricity prices during the transitional period is allowed to some extent. However, LCOEs for renewables in 2030 are lower in the German studies than in the Japanese studies. The assumed further decrease in the costs of renewables (and the fact that the relatively expensive renewables deployment earlier this decade and in the last decade will eventually be paid off by German electricity consumers) is expected to lead to an eventual decline in electricity prices in Germany after 2030 at the latest and will help to spur GDP growth. In Japan, since the increase of electricity costs and prices in recent years became an overwhelming issue in public discussions on the future energy system, a reduction of electricity costs and prices became a kind of prerequisite for scenario development. And as renewable energies still have relatively high market costs compared to other technologies, focus of investment was shifted to avoid negative effects for GDP through raising electricity cost.

In general, initial increases in electricity and heat costs for final consumers can be reduced over time by energy efficiency. Most energy efficiency investments reduce costs during the lifetime or the depreciation period of the respective measures. Overall, GDP growth takes place when the positive impacts from energy efficiency over-compensate the negative effects.

Employment

The analysed German scenario studies suggest that investments in energy efficiency and renewable energy create a *direct* positive employment effect in companies which produce respective technologies and which provide services for the technologies' installation, operation and maintenance. For their part, these companies order products, material and services from other sectors and thereby create *indirect* employment in intermediate sectors and subcomponent suppliers. New direct and indirect jobs create income and *induce* additional demand for goods and services and, consequently, additional employment in other sectors. The sum of both, direct and indirect employment adds up to a positive gross employment effect. However, for a macroeconomic analysis also negative employment effects need to be considered, which mainly result from a decline in fossil fuel consumption and respective electricity generation. Higher electricity prices due to a stronger deployment of renewable energy technologies may also have a negative indirect effect on employment, as private budgets are more constrained.

Discussion of findings on macroeconomic implications

In both countries, Germany and Japan, the energy transition is often considered as an instrument of industrial policy, spurring investments in new energy efficiency and renewable energy technologies which can improve competitiveness of domestic industries and also may lead to an increase of technology exports. However, this argument does not always hold true. On the one hand, support mechanisms for renewable energies have helped companies in respective countries to spur investments into innovative technologies, enabling some companies to benefit from first mover advantages, i.e. a sustained competitive advantages on international markets due to the realization of economies of scale and/or the realization of experience effects. (A field where German companies won significant importance is the production of wind turbines.) On the other hand, such first mover advantages do not last forever: In photovoltaic manufacturing, both German and

Japanese companies have not been able to sustain their respective market positions.

Energy efficiency investments play a major role as positive economic impacts are mainly driven by energy efficiency. This is for example shown, by a sensitivity analysis conducted by EWS (UBA2013). In addition, energy efficiency improves overall economic productivity in case economically viable measures are implemented. Such measures lead to a decrease in production costs and prices. The overall competitiveness of the economy improves. Employment impulses of energy efficiency investment originate mainly in the construction and service sectors, which are labour intensive. Thus, jobs are created in domestic markets, regional and domestic value added increases, initiating indirect employment effects in other sectors. In the long run, saved energy costs are a main driver for additional consumption.

In addition, in Germany the energy transition is also seen as a means for structural and technological change as it spurs investments and can be understood as a long-term investment program into a sustainable infrastructure for the future.[45] The envisaged investments and the framework conditions incentivising these investments are also expected to initiate innovation, which will enable productivity gains. These considerations are based on modern economic thinking aiming at achieving climate change mitigation and at the same time increasing the wealth of people. For this purpose, a significant reduction of GHG emissions is needed, necessitating an urgent shift from conventional to clean technologies. Such a shift will however not be possible without policy intervention because the market size effect and the initial productivity advantage of less clean technologies would direct innovation and production to existing dirty sectors rather than to future clean fields.[46] Therefore, spurring innovation is a major element in the background of Germany's energy transition strategy.

In Japan, spurring innovation is the centrepiece of its energy transition strategy as well. However, it is not expected that innovation will be spurred by ambitious strategies for 2050. Rather, recognizing various scientific, economic, technological and societal uncertainties, Japan regards the 2050 goal as a vision and puts its emphasis on technology innovation strategies, as it is believed that only innovation would enable long-term and large scale emissions reductions. With this in mind, the National Energy and Environment Strategy for Technology Innovation towards 2050 was formulated enumerating key priority technologies where Japan would have comparative strength. To prepare an enabling environment for innovation, a robust economic growth cycle is regarded as indispensable. Therefore, in Japan, high energy cost are thought to hinder economic growth and discourage innovation. In addition, Japan's approach emphasises the broader perspective beyond national borders, i.e. 1) contributions through dissemination of Japan's efficient and environmentally friendly technologies to developing countries, 2) in-

[45] Löschel et al. (2012): Expertenkommission zum Monitoring-Prozess „Energie der Zukunft". Stellungnahme zum ersten Monitoring-Bericht der Bundesregierung für das Berichtsjahr 2011, p. Z-9.

[46] D. Acemoglu, Ph. Aghion, L. Bursztyn and D. Hemous. The environment and directed technical change. American Economic Review 2012, 102(1): 131–166

puts of efficient technologies and products to the global value chain resulting in the reduction of life-cycle emissions and 3) development of innovative technologies. These strategies are followed by both, Japan and Germany. While Germany sees them as additional co-benefits of its GHG mitigation strategy, Japan emphasises these strategies to a greater degree in their climate change mitigation efforts. Such a cross-border approach is regarded effective for simultaneously aiming at economic growth and global emissions reduction.

9.2.8 Comparison of key energy transition strategies

The following two tables (Table 9-4 and Table 9-5) each list 12 key strategies that are pursued in some or all of the analysed Japanese and German energy scenarios to achieve energy system changes. Table 9-4 evaluates qualitatively whether each strategy contributes to the following four key energy system transformation objectives in both Japan and Germany[47]:

- Mitigating climate change
- Boosting energy security / reducing energy import risks
- Reducing energy costs
- Reducing / Avoiding the risk of large-scale nuclear accidents

In that table, "+" indicates that a certain strategy helps to achieve a certain objective, while "-" indicates that a certain strategy hampers that achievement. "o" indicates that the relationship is neutral, not clear or dependent on the specific context. The table highlights that almost all energy system transformation strategies listed entail certain trade-offs between the five key policy objectives. Reducing energy demand, by improving energy efficiency or changing behaviours, is a notable exception, as energy demand reductions tend to contribute to all key policy objectives. These "Multiple Benefits of Energy Efficiency" (IEA 2014) are well known and have led to calls to prioritise energy efficiency measures ("efficiency first"), very recently for example in Germany by Agora Energiewende (Agora Energiewende 2017).

[47] A reduction of air pollution might also be regarded as an important objective of energy transition efforts. However, as such a reduction is not among the key energy policy objectives of either Japan or Germany, this objective is not included in the following table.

Tab. 9-4 Contribution of key transition strategies to achieving major energy transition

	Mitigating climate change	Boosting energy security / reducing energy import risks	Reducing energy costs	Reducing / Avoiding the risk of large-scale nuclear accidents
Energy demand reductions				
Final energy demand reductions through energy efficiency measures	+	+	+ [a]	+
Final energy demand reductions through behavioural changes	+	+	+ [b]	+
Changing primary energy mix and final energy mix				
Increased use of domestic renewable energy sources	+	+	o	+
Phasing out the use of nuclear power	-	o/- [c]	- [d]	+
Continuing the use of nuclear power	+	o/+ [c]	+ [d]	-
Substitution of fossil fuels through clean, low-carbon electricity	+	o	o/-	o/-
Use of renewable energy based H_2 or synthetic fuel as final energy carriers	+	+/o	-	o
Importing low-carbon or carbon-free energy sources/carriers				
Net power imports from low-carbon energy sources (except nuclear)	+	-/o [e]	o	+
Net imports of bioenergy	+ [f]	-/o [e]	o	+
Net imports of H_2 or synthetic fuels from low-carbon/carbon-free sources	+	-/o [e]	- [g]	o
Using CCS				
Use of CCS technology to reduce industrial GHG emissions	+	o	-	o
Use of CCS technology to reduce power sector GHG emissions	+	o	-	+

+ yes
- no
o not clear / depending on the context

[a] At least as long as only the economic ("no-regret") efficiency potential is realised.
[b] Assuming behavioural changes are associated with no or only negligible loss in comfort.
[c] Nuclear power is often regarded as a quasi-domestic energy source because of the low frequency of uranium fuel imports. A nuclear power plant can run about 12 months without requiring additional fuel, hence it is less exposed to fuel supply security risks. Nuclear power can therefore improve supply security when it is used to reduce the need for imported fossil fuels.
[d] At least as long as this refers to existing nuclear power plants which have not yet reached the end of their technical lifetime. Whether new nuclear power plants are competitive or not is disputed.
[e] Can be neutral or even positive if the use of imported fossil fuels can be reduced.
[f] Assuming the imported biomass fulfils minimum sustainability standards.
[g] Costs are expected to be high, at least in the foreseeable future.

Table 9-5 assesses qualitatively if and to what extent the 12 identified key energy transition strategies are pursued in three selected Japanese and three selected German energy scenarios.

Tab. 9-5 Overview of the level of reliance on key energy transition strategies in selected scenarios for Japan and Germany until the year 2030

	Germany			Japan		
	ZS	KS 80	KS 95	METI (2012) multiple models and scenarios	IEEJ (2015) multiple scenarios	RITE (2015) multiple scenarios
Energy demand reductions						
Final energy demand reductions through energy efficiency	Strong reductions	Strong reductions	Very strong reductions	Reductions	Reductions	Reductions
Final energy demand reductions through behavioural changes	Not considered	Not considered	Moderately considered	Moderately considered	Moderately considered	Moderately considered
Changing the use of energy sources						
Increased use of domestic renewable energy sources	Strong use	Strong use	Strong use	Moderate use	Moderate use	Moderate use
Phasing out the use of nuclear power	Complete phase-out	Complete phase-out	Complete phase-out	Yes (in some scenarios)	Yes (in some scenarios)	Yes (in some scenarios)
Continuing the use of nuclear power	No	No	No	Yes	Yes	Yes
Substitution of fossil fuels through electricity	Strong substitution	Very strong substitution	Very strong substitution	Moderate substitution	Moderate substitution	Moderate substitution
Use of renewable energy based H_2 or synthetic fuels as final energy carriers	No use (until 2030)	No use (until 2030)	No use (until 2030)	No use	No use	No use
Importing low-carbon or carbon-free energy sources/carriers						
Net imports of electricity	No net imports	No net imports	Moderate net imports	No trade	No trade	No trade
Net imports of bioenergy	No imports (until 2030)	No imports	No imports	No imports	No imports	No imports
Net imports of H_2 or synthetic fuels	No imports	No imports	No imports (until 2030)	No imports	No imports	No imports
Using CCS						
Use of CCS technology to reduce industrial GHG emissions	Not used	Not used	Starting to be used in 2030	Not used	Not used	Not used
Use of CCS technology to reduce power sector GHG emissions	Not used	Not used	Not used	Not used	Not used	Yes

Notes: For Japan's analysis, the METI (2012), the IEEJ (2015), and the RITE (2015) studies are composed of multiple results delivered from different models or scenarios. This table compiles the general or majority trend of these different models and scenarios.

The table highlights that there are a number of similarities but also some general differences between the energy transition strategies typically selected in Japanese energy scenarios on the one hand, and those typically selected in German energy scenarios on the other hand. Scenarios from both countries pursue:

- Energy demand reductions through energy efficiency
- Increasing the use of domestic renewable energy sources
- Substituting the direct burning of fossil fuels through electricity

However, in contrast to the Germany energy scenarios, the Japanese tend to:

- Keep relying on nuclear power
- Increase the penetration of renewable energy sources to a lesser degree
- Not prepare for the use of new decarbonisation technologies (such as hydrogen and CCS) in anticipation of the post-2030 period

Key reasons for these differences are the following:

- Although both Japan and Germany aim at a balanced pursuit of energy security, economic efficiency, and environmental sustainability in their respective energy transition strategies, Japan seems to put relatively higher priority on energy security and economic efficiency (low electricity prices) while Germany seems to put stronger focus on GHG emissions reduction.
- These differences mirror differences in priorities among the public, which in turn may be explained by cultural and geographical differences (Germany: Historically relatively strong environmental movement and strong anti-nuclear sentiment, Japan: Country's geographical isolation, very low self-sufficiency, and soaring electricity price has always lead to an emphasis on the importance of supply security and economic issues).
- Renewable energy potential: Germany's population density is smaller than in Japan, which may make renewable energy deployment easier; furthermore: Germany's electricity grid is well connected to neighbours and can in principle be further expanded to allow a substantial exchange with and net imports of renewable electricity generation from regions with strong potential for renewables (Southern Europe → sun, Northern Europe → wind, hydro, MENA region (longer-term option): sun, wind). In Japan, the potential for wind power and solar PV are reported to be significant (JWPA 2016, MoE 2014, JPEA 2015). However, much of the country's wind potential is geographically eccentrically located, hence cost of electricity transmission and local acceptance become an issue. Although potential of geothermal power and biomass power exist, this potential is rather small compared to the total electricity demand. In addition, the absence of power grid interconnections with neighbours leads Japan to limit the use of variable renewable energy before appropriate technologies and sufficient capacity to absorb fluctuating power output – including additional pumped hydro storage capacity, which can be further developed in Japan (IEA 2016b) – are developed and can be deployed. Furthermore, the high relevance in Japan of reducing energy prices, as well as the perceived high costs of renewable energies make a rapid increase of renewable energy, together with the related grid integration re-

quirements, difficult within a short period. These limitations in Japan can help to explain the more moderate assumptions regarding the increase in the penetration of renewable energy in Japanese scenarios compared to German scenarios.[48]

- Cost of power generation: Another important difference between Japan and Germany to explain the choice of energy sources and specifically the degree of renewable energy penetration are the assumed future costs of power generation. In Germany, the LCOE of many renewable energy sources, including the key technologies of onshore wind and solar PV are already today similar to or only slightly above various forms of fossil fuel power generation. In Germany, the LCOE of wind and solar technologies are expected to further decline in the years and decades ahead. In the analysed Japanese scenarios, on the other hand, nuclear power is estimated to be one of the most cost competitive energy sources in 2030 together with coal, and most renewable energies are expected to remain relatively expensive even though further cost decrease are assumed for the future.
- Public's familiarity with renewable energy/decentralised electricity generation: In Germany, there has been decade-long experience with wind and solar power, including widespread efforts of individuals and regions to become more energy independent through the use of renewables. This has lead to a relatively high familiarity of the public with renewables. In addition, the rather decentralized and multi-layered structure of the German energy industry, which includes municipal utilities ("Stadtwerke"), makes it easier for Germany to realize changes towards a more decentralized energy system. Furthermore, for Germany, long-term, high renewables energy scenarios have been developed and discussed for many years, helping to make stakeholders and decision makers aware of the related issues.
- On the other hand in Japan, although the country was a frontrunner to develop solar PV and solar thermal water heater technology since 1980s, the widespread use of decentralised electricity generation from renewables failed to become popular because grid supplied electricity has been stable and cheaper compared to decentralized electricity. Furthermore, the vertically integrated and centralized energy industry structure of Japan makes the country relatively unfamiliar to a decentralized energy system.
- A high medium-term (2030) GHG reduction target for Germany, combined with the long-term (2050) GHG reduction target also helps to explain why German scenarios describe a more radical reduction of GHG emissions. On the other hand, in Japan, a mid-term target (2030) was developed based on

[48] In recent years several scenarios have been developed for Germany showing that high shares of renewables in electricity generation (up to 100%) are feasible even when assuming that no electricity trade with other countries is possible (SRU 2011, Fraunhofer ISE 2013b). However, costs are expected to be higher in such self-supply scenarios, especially in case of very high shares of renewables. For Japan, recent studies also suggest that high shares of renewables (mainly wind and PV) of about 85% in electricity generation (Kainuma et al. 2015) or even 100% in primary energy (WWF Japan 2017) might be feasible by 2050. In the latter scenario, a unified national electricity grid and the production of hydrogen from excess wind and solar power are assumed.

bottom-up approaches underpinned by specific measures and technologies. Japan is taking a more flexible approach on the pathway towards 2050 due to multiple uncertainties. These different approaches in regards to national targets influence the modelling either directly, e.g. when studies are commissioned by governments and the respective targets are specified to be met, or indirectly, via perceptions and assumptions of the modellers.

- Type of models typically used: Using econometric models, as in the case of most analysed scenarios for Japan, tends to lead to scenarios with rather moderate (or – depending on the perspective – one might also say “realistic and achievable”) changes compared to past developments. Using bottom-up energy system models and back-casting approaches to scenario development, in contrast, makes it easier to construct scenarios describing more radical departures from past developments.
- Application of new technologies: Some of the differences between Germany’s and Japan’s scenarios can also be explained by differences in the chosen time horizons. The German scenarios all extend the time horizon to 2050, while the selected scenarios for Japan focus on the time period until 2030[49].From the German perspective this limits the focus on and the choice of more radical technologies during the outlook period, such as hydrogen and CCS. Furthermore, from the German perspective focussing on the time period until 2030 can entail the risk that potential lock-ins into pathways that are not optimal in the longer term are overlooked, particularly given the need for further very significant GHG emission reductions after the year 2030.

  From Japanese perspective, Japan is addressing these long-term technological development through its National Energy and Environment Strategy for Technology Innovation to 2050.
- In regards to emphasis on domestic emissions and global emissions: Japan explicitly takes a cross-country approach since climate change is a global issue and aims at contributing to global emissions reduction through dissemination and development of efficient and environmentally friendly technologies with a belief that this approach would enable simultaneous achievement of economic growth and global mitigation. Germany on the other hand is very keen on achieving its domestic reduction targets within its boundaries, as this is believed to benefit the energy transition with its multiple benefits and to be a credible signal to other countries of the seriousness of its policy to mitigate climate change. Contributing to global emissions reduction via dissemination and development of efficient and environmentally friendly technologies is regarded as a strategy coming on top of domestic action.

[49] There are scenarios in Japan which analyze a future up until 2050. Example is “Pathways to Deep Decarbonization in Japan (Kaminuma, et al, 2015)” in the Box 3. Meanwhile, at the moment, there is no official process to discuss 2050 scenarios.

9.3 Recommendations for decision-makers in Japan and Germany

9.3.1 Policy recommendations for Japan and Germany

A general insight from the analysis of selected energy scenarios for both Japan and Germany is that in both countries considerable developments in the energy system are needed in order to reach the countries' respective 2030 energy transition targets. In the following areas, additional measures are particularly necessary and will need to be induced by appropriate policies:

- Final energy demand reductions in all sectors through energy efficiency and/or more energy-sufficient lifestyles; in Germany, for example, final energy intensity in all but one scenario is expected to decrease by between 2% and 3% per annum in this decade and the next, while it decreased by only 1.4% per annum between 2000 and 2015.
- Energy demand reductions, fuel mix changes and CO2 emission reductions in the transport sector.
- Increased implementation of energy-saving measures in the existing buildings stock, as all analysed scenarios achieve considerable reductions in space heating demand.
- Wind and solar PV penetration will need to continue to increase steadily in the years and decades to come. Therefore, a reliable policy framework is needed that provides enough certainty to investors that investments in these technologies can be refinanced.
- Capabilities to absorb variable power output from wind and PV, such as demand side management, utilization and development of pumped hydro storage and research and development in new storage technologies need to be strengthened, developed and implemented along with their increasing role in electricity generation.
- Technological and socio-economic research on the energy transition needs to be supported. More specific suggestions on future research needs are mentioned below.

Although, carbon pricing is a complex issue that requires to take different factors into account, it can be assumed that, a sufficiently high price on CO_2 emissions would considerably facilitate GHG emission reductions in all sectors. Currently, the CO_2 price in the European ETS (not applicable to emissions from all sectors) is around 5 Euro per tonne, while in Japan a CO_2 tax of about 3 Euro/ton is applied. This CO_2 price is well below the price needed to noticeably support meaningful CO_2 reduction efforts. Policies should aim for a higher CO_2 price and a meaningful and sufficiently certain increase of the CO_2 price over time as assumed in the German scenarios, so as to support the required broad investments in low carbon technologies. Alternatively, if a particular country does not wish to implement CO_2 price-based instruments, alternative policy instruments with similar mitigation effectiveness would need to be enacted.

It should be born in mind that there is no common global carbon price so far and therefore, pricing carbon in each country needs to take into account its specific national circumstances including current energy costs and actions taken by major trading partners. In doing so, careful considerations need to be made in order to protect consumers, in particular low income households, and not to harm industrial competitiveness. This is particularly true for Japan where energy costs are already higher than for its major trading partners, namely, China and the U.S. In addition, when considering the high marginal CO_2 abatement cost, e.g. ranging from approx. JPY 10,000/ton-CO_2 to JPY 30,000/ton-CO_2 (EUR 77-231/ton-CO_2)[50] (see section 7.1.3.1), it is questionable how realistic high CO_2 prices are and hence the CO_2 price alone cannot be the only measure. Therefore, other policies complementing carbon price policies are to be developed and implemented as well. Until present, targeted support for renewable energies by fixed feed-in tariffs was one such policy, which helped to achieve the targeted volumes of renewable electricity in Germany. In Japan, energy taxes, energy efficiency regulation, FiT and industry sector's voluntary action plans constitute "implicit carbon pricing". As explained above, the necessity of additional carbon pricing would need to be subject to careful examinations, taking into account current energy costs and the behaviour of major trading partners.

9.3.2 Recommendations regarding German-Japanese cooperation in the energy field

- Sharing experience with PV, onshore wind and offshore wind cost reduction, deployment, and system integration (successful policies, identification of barriers and of solutions to overcome them).
- Sharing experience with energy efficiency policies (successful policies, identification of barriers and of solutions to overcome them)
- Sharing of experience with energy savings/sufficiency policies (e.g. success of Japanese „Setsuden"/"Ampere Down" movement following the Fukushima accident)
- Cooperation in the field of electric cars, hybrid cars and hydrogen cars, as both countries are home to several car industry leaders. Cooperation could focus on improving technologies and harmonizing standards.
- In regards to achieving climate-neutral transport systems, there is also a potential to cooperate and learn from each other in the urban and traffic planning sector to reduce transport needs and increase public and non-motorised transport, or car-sharing.
- Exchanging ideas on potential solutions for the long-term decarbonisation of energy and emission-intensive materials processing industries, possibly with a strong participation of industrial stakeholders. Mitigation in this area will be complex and capital-intensive, so a mutual approach of industrialised countries to this challenge appears to be of great importance.

[50] A conversion rate of 1 Yen = 0.0077 Euro has been used to convert the Japanese cost data from Yen to Euro.

- Establish a joint database of market-ready energy and efficiency technologies to help decision-makers to identify and compare suitable technology options in order to increase the adaption rates

9.3.3 Recommendations regarding business opportunities in Japan and Germany in the coming years and decades

Assuming both countries take additional steps in the coming years to accelerate the energy transition so as to be able to reach their medium and long-term targets, business opportunities will likely arise especially in the following areas:

- Highly energy-efficient end-use technologies can be expected to benefit more strongly in the future.
- Technology that facilitates demand side management/demand response and the optimisation of distributed electricity generation (for households and businesses) can be expected to become more relevant as a result of the expected strong future expansion of wind and solar PV power generation. This includes ICT technologies as well as storage systems (e.g. batteries, perhaps in the medium term also power-to-gas technologies).
- Offshore wind power plants (possibly in the medium-term future with innovative floating technology that allows such plants to be build at deep-water sites), including construction and operation.
- Highly energy-efficient cars and electric cars, including key parts of electric cars, especially advanced batteries.
- Development and foreign market expansions of the railroad industries in both countries
- Efficient public transport means in combination with advanced urban planning, that focuses increasing public and non-motorised transport, or car-sharing.
- Efficient public transport means together with urban design.
- Long-distance, high voltage direct current (HVDC) technology.
- In the medium-term, companies in the energy-intensive industries that plan ahead and devise roadmaps on how they may achieve strong emission reductions in the decades to come, can potentially achieve competitive advantages over other companies in the medium to long-term future.

9.4 Research recommendations

9.4.1 Research addressing scenario development:

Given the considerable difficulties experienced during the course of this study in comparing assumptions and results of Japanese scenario studies with German scenario studies and inferring insights in regard to promising energy transformation strategies and especially the expected macroeconomic implications, it would be desirable to develop scenarios for both Japan and Germany applying a common methodology based on comparable basic energy system and similar macroeconomic assumptions. This could be realised by a joint German-Japanese scenario modelling group. In particular, such energy scenario research could address the following issues:

- What energy transition strategies have the greatest potential to lead to a sustained positive impact on industrial activity in Japan and Germany?
- A decomposition analysis of CO_2 emission changes should be applied to the developed scenarios. Such analysis can determine what energy transition strategies and specific technologies are expected to contribute to what extent to CO_2 emission reductions in Japan and Germany, both at the energy system level as well as on a sector-specific level. Similarities and differences between the main drivers of CO_2 changes between Japanese and German scenarios could be identified. The decomposition analysis would provide helpful input for energy policy makers, as it would highlight quantitatively which strategies and technologies are most important at what phases of the energy transition in reducing CO_2 emissions. Early on in the scenario modelling exercise it should be ensured that the information required for a comprehensive decomposition analysis can indeed be provided.
- In order to identify which differences in the scenarios can be attributed to the modelling approaches, the implication of the modelling approaches should be analysed in more detail via modelling experiments.
- How should scenarios and underlying models be designed and documented in order to reflect best the questions regarding energy transition strategies in both countries? Are different approaches needed or advisable to cover the full range of questions?
- How and in which partnerships could such methodologies be implemented?
- How can comparable methodologies as well as documentation standards be used for the international discussion on mainstreaming the methodologies underlying national level scenario analyses of NDCs as well as long term decarbonisation strategies?
- Could existing modelling approaches from Japan be implemented for Germany together with German researchers and vice versa?
- How could Germany’s highly differentiated electricity system modelling be applied to the Japanese situations and in which contexts?
- What technological or social innovations offer the highest potential for synergies and mutual learning between the countries?
- What energy system transformation strategies are promising for both Japan and Germany and in what regard will transformation strategies likely diverge, for example because of differences in public priorities, geographical or economic conditions.
- What developments are assumed for both countries in regards to energy storage and electric mobility and how and why do these differ?

- Japan's and Germany's geographic preconditions differ strongly, as Japan is an island state and Germany is located centrally within Europe. To better understand and compare the energy transition strategies of both countries, it is therefore recommendable to further examine the German energy strategies in relation to the strategies of its neighbouring countries. Especially, in regards to the future electricity import and export potentials of intermittent renewable energy.
- The presented analysis is mainly focused on 2030, as most Japanese scenarios run until 2030 and as the targets for both countries are much more detailed for 2030 than for 2050. Due to the high relevance of long-term strategies for the energy transition it is however recommended to conduct further research on energy transition strategies and their implications until 2050 and beyond.

9.4.2 Research addressing the short to medium-term energy system transformation:

- What kind of changes to the current electricity market frameworks are needed to enable sufficient investments into renewable energy technologies while ensuring a high reliability of power supply. Do recommendations differ between Japan and Germany, due to structural differences?
- Comparative analyses of potential of demand response measures to better integrate solar and wind power and to reduce electricity costs, including framework needed to incentivise demand response measures (especially in the commercial and industrial sectors)
- How can more energy-sufficient behaviour contribute to both countries' energy transition targets and what instruments can be used to promote behavioural changes? Can the same instruments be applied in Japan and Germany to achieve behavioural changes?
- What kind of effects would a breakthrough in decentralised PV electricity generation (assuming continuing drastic price decreases in PV systems and batteries) potentially have on both countries' energy system?
- What is the socially accepted level of onshore wind expansion in both Japan and Germany? And what factors influence this acceptance?
- How can offshore wind costs continue to go down, and how can deep-water sites such as those dominating near the cost of Japan be exploited?
- Further research is required to understand how the full efficiency potential in both countries can be realised and what the countries can potentially learn from each other on the implementation of efficiency strategies.
- A more detailed analysis of the future developments in the transport sector should be conducted to answer the questions how the transition in the transport sector can be realised and how Germany can learn from Japan in this regard?

9.4.3 Research addressing the long-term energy system transformation:

- Research on long-term electricity storage (Power-to-X) technologies, aiming to ensure their technological maturity, increasing their conversion efficiency and reducing their costs.
- What are synergies and trade-offs between electricity generation from nuclear energy and renewable energy in Japan? Is it technologically and economically reasonable to continue to use both low-carbon sources even in the long-term? If so, what would be an optimal mix?
- Does the fact that Japan is an island make it technologically impossible or economically unfeasible to realise a future electricity supply system with very high shares of wind and solar PV? What kind of technologies, infrastructures and regulatory frameworks would be conducive to allow Japan to realise high shares of these potentially very cheap (on an LCOE basis) forms of electricity generation?
- Are energy system developments which meet the Japanese government's 2030 targets in line with ambitious long-term GHG emission reductions required to contribute adequately to the Paris Agreement? Or will such a 2030 energy system (due to certain lock-ins) require costly changes in the post-2030 decades to comply with the Paris Agreement objectives?
- Is a 2050 energy system in Germany that is in line with the 80% GHG emission reduction target as described by several German scenario studies a good first step for additional emission reductions in the post-2050 decades, or is such a system configuration sub-optimal for further emission reductions (due to certain lock-ins)?
- Resilience of possible future energy systems to terrorism, wars or natural disasters such as a huge volcanic eruption (or the use of nuclear weapons) somewhere on earth with corresponding atmospheric changes for months or years.
- Are low-carbon energy imports required in the long-term future to realise zero-GHG emission in both countries, and if so, where could they come from and in what form?
- What are potential solutions for the long-term decarbonisation of energy/emission-intensive industries?

9.4.4 Research addressing the macroeconomic implications of energy system transformation:

- What are the macroeconomic implications of different energy scenario developments? Currently, there is only very little such analysis available for both Japan and Germany, and the data documented is often different and difficult to compare. A detailed and transparent analysis of macroeconomic implications for several scenarios for both Japan and Germany should be conducted, ideally using the same model approach in order to create a basis for better understanding why different impacts may occur in one country compared to the other. In a next step, different types of economic models could be applied and the differences in the results between these models (both for individual countries as well as for the difference between Japan and Germany) could then be analysed. In all modelling exercises, uncertainties should be discussed in a broad and transparent manner.

- Impact indicators should be analysed in a more detailed structure, such as the development of employment by sectors and the development of GDP by components of GDP.
- The macroeconomic analysis could be improved by taking into account possible crowding out effects of investments, making assumptions on the opportunity costs of financing investments more precise.
- Studies could investigate what realistic productivity increases are that can be gained by different energy system development paths.
- Further analysis should address the question of the efficiency of investments in renewable energy and efficiency measures.

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