OPEN CLIMATE NETWORK

IGES Working Paper

Produced in partnership with the Open Climate Network

Comparative assessment of GHG mitigation scenarios for Japan in 2030

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This study conducted a comparative assessment of 48 greenhouse gas (GHG) emissions reduction scenarios for 2030 reported in seven studies based on bottom-up energy system analyses published since 2011.

Key messages

- For the scenarios that assume the highest level of mitigation efforts including those consistent with a global 2°C target, GHG emissions levels ranged between 16-39% below 1990 levels (21-43% below 2005 levels) with the nuclear power share ranging between 0-29%.
- Taking into account the government's plan to restart most of the existing nuclear reactors as well as the RE electricity deployment potential, GHG emissions reductions of more than 25% from 1990 levels (32% from 2005 levels) may be considered a minimum mitigation effort level required in the global efforts to achieve the 2°C target.
- To achieve the above-mentioned mitigation levels, strengthened pre-2020 efforts to reduce energy consumption in the end-use sectors are also essential and the choice between coal and natural gas for fossil fuel-fired electricity generation is as equally important as the share of renewable electricity generation.

May 2015

Abstract

This study conducted a comparative assessment of 48 greenhouse gas (GHG) emissions reduction scenarios for 2030 reported in seven studies published since 2011 based on bottom-up energy system analyses. This study conducted two sets of analyses. First, the scenarios were categorized into four mitigation effort levels and assessed the value ranges for GHG emissions (excluding land use, land use change and forestry (LULUCF)) as well as the key underlying energy-related indicators for each effort level category. Second, a multiple regression equation was developed to predict GHG emissions with a few energy-related explanatory variables based on the data from the 48 scenarios. Using the derived regression equation, we calculated the levels of low-carbon energy supply and end-use energy savings required to achieve different levels of GHG emissions reduction in 2030. Results of our analyses include the following:

For the scenarios that were categorized to assume the highest level of mitigation efforts including those consistent with a global 2°C target, GHG emissions levels ranged between 16-39% below 1990 levels (21-43% below 2005 levels)* with the nuclear power share ranging between 0-29%. The wide range observed for GHG emissions in the first analysis is also attributable to the differences in assumptions and projections on the share of renewable (RE) electricity and CCS-equipped electricity (RE/CCS electricity: 27-47%), the reduction level of energy end-use (12-28% from 2010 levels), which is partly influenced by the future economic growth rates, as well as the electrification rate (26-30%). In contrast, for the scenarios that were designed to reflect the continuation of existing and currently planned policy measures – as opposed to consistency with the 2°C target – the GHG emissions reductions ranged at 3-20% below 1990 levels (10-25% below 2005 levels).

Taking into account the government's plan to restart most of the existing nuclear reactors as well as the RE electricity deployment potential, GHG emissions reductions of more than 25% from 1990 levels (32% from 2005 levels) may be considered a minimum effort level required in the global efforts to achieve the 2°C target. Currently the government intends to restart the existing nuclear reactors. The results from the regression analysis showed that for a 15% nuclear power share, a level that can be achieved by operating all restartable reactors and extending the lifetime of some reactors from 40 years to 60 years, a 25% reduction of GHG emissions from 1990 levels can be achieved e.g. with a 30% share of RE/CCS electricity, a 20% reduction of final energy use (TFC) from 2010 level, and a 60% gas-fired power share in total unabated fossil fuel-fired power generation (gas power ratio). For a 20% TFC reduction, the 30% RE/CCS electricity share can be achieved with medium policy effort levels when compared to the results from a recent RE potential study commissioned by the government. A 30% reduction of GHG emissions can be achieved by increasing the RE/CCS electricity share to 35%, which can be achieved by high policy effort levels, and the TFC reduction to 22%. The 25% GHG emissions reduction can also be achieved without nuclear power with a 35% RE/CCS electricity share and a 25% reduction of TFC, which is similar to the reduction rate observed for 1970-1990 and can be achieved by reducing TFC per capita by 0.9%/yr between 2013 and 2030.

Strengthened pre-2020 efforts to reduce energy consumption in the end-use sectors are essential. The underlying assumptions for the revised 2020 mitigation target ("Warsaw Target") indicated that the TFC per capita, which has decreased by about 10% between 2005 and 2012, would again turn to an increasing trend toward 2020. In order to achieve the reduction levels for 2030 indicated above, enhanced pre-2020 efforts to reduce energy use in end-use sectors are essential.

The choice of fuel for fossil fuel-fired electricity generation is as equally important as the share of renewable electricity generation. Our first analysis showed that for all scenarios with GHG emissions reductions of more than 20% from 1990 levels, the share of unabated coal-fired electricity was found to be less than 21%. Moreover, the second analysis found that when the gas power ratio decreases from 60% to 40%, the share of RE/CCS electricity would need to be increased by 3-9 %-points to offset the increased emissions. The recent plans on new coal-fired power plants construction would need to be reconsidered if Japan is to stay on track for the long-term decarbonization of its economy consistent with the global 2°C target.

* Total GHG emissions in 1990, 2005 and 2013 (excluding LULUCF) were 1270 Mt-CO_2e, 1397 Mt-CO_2e and 1408 Mt-CO_2e, respectively.

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Abbreviations and acronyms

BAU	Business-As-Usual
BEMS	Building energy management system
BEP	Basic Energy Plan
CCS	Carbon dioxide capture and storage
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COP	Conference of the Parties of the United Nations Framework Convention on Climate Change
CPS	Current Policies Scenario
DDPP	Deep Decarbonization Pathways Project
DPJ	Democratic Party of Japan
EEC	Energy and Environment Council, National Policy Unit, Cabinet Office
EMS	Energy management system
FY	Fiscal year. In Japan, the fiscal year begins on April 1 and ends on March 31.
GDP	Gross domestic product
GHG	Greenhouse gas
GIO	Greenhouse Gas Inventory Office, Japan
GWP	Global warming potential
HEMS	Home energy management system
HEV	Hybrid electric vehicle
IDDRI	Institute for Sustainable Development and International Relations
IEA	International Energy Agency
IEEJ	Institute of Energy Economics, Japan
IGES	Institute for Global Environmental Strategies
IMF	International Monetary Fund
INDC	Intended Nationally Determined Contribution
IPSS	National Institute of Population and Social Security Research
JPY	Japanese Yen
KP	Kyoto Protocol
KP-CP1	First commitment period of the Kyoto Protocol
LED	Light emitting diode
LULUCF	Land use, land use change and forestry
MAC	Marginal abatement cost
METI	Ministry of Economy, Trade and Industry, Japan
MOE	Ministry of the Environment, Japan
Mt-CO_2	Million tonnes of carbon dioxide
Mt-CO_2e	Million tonnes of carbon dioxide equivalent
NIES	National Institute for Environmental Studies, Japan
NPS	New Policies Scenario
NPU	National Policy Unit, Cabinet Office
NRA	Nuclear Regulation Authority
NUC	Nuclear electricity generation
OECD	Organisation for Economic Co-operation and Development
PHEV	Plug-in hybrid electric vehicle
PV	Photovoltaics
RE	Renewable energy
RE/CCS	Renewable (electricity) and carbon dioxide capture and storage-equipped (electricity)
SDSN	Sustainable Development Solutions Network
t-CO_2	Tonnes of carbon dioxide
TFC	Total final consumption
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
VIF	Variance inflation factor
WRI	World Resources Institute
WWF	World Wildlife Fund
yr	Year

01 Introduction and objectives

Japan is currently in the process of formulating its Intended Nationally Determined Contribution (INDC), which is a set of greenhouse gas (GHG) emissions reduction targets and measures for the post-2020 period to be submitted before the 21st Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC). A major challenge for Japan in formulating of its INDC is that the country is also revising its energy policy following the disastrous accident at the Fukushima Daiichi nuclear power plant ("Fukushima nuclear disaster") in March 2011. The 2010 Basic Energy Plan (BEP) aimed to reduce Japan's energy-related CO_2 emissions by 30% by 2030 partly by increasing the share of nuclear power in total electricity generation to more than 50% (METI 2010), but such expansion of nuclear power has now become politically unrealistic. The Innovative Strategy for Energy and Environment (hereinafter, "the Innovative Strategy") published in 2012 by the government led by the Democratic Party of Japan (DPJ) stipulated a GHG mitigation target of about 20% from 1990 levels by 2030 and a phase-out of nuclear power during the 2030s (EEC 2012a). The document was, however, scrapped following the change in the ruling party and the Cabinet in December 2012. In order to finally decide the future electricity mix as well as the INDC, an expert committee under the Ministry of Economy, Trade and Industry (METI) is currently elaborating the future of the electricity mix (METI 2015b) and an expert committee for INDC formulation has also been set up jointly by the Ministry of the Environment (MOE) and METI (MOE & METI 2015).

After the Fukushima nuclear disaster, several modelling studies have been published on GHG emissions reduction potentials up to 2030 with reduced dependence on nuclear power (e.g., MOE 2012a; IEEJ 2013). However, no study has made an overview and comparative assessment of these studies with the focus on the relationship between GHG emissions reduction levels and the key low-carbon energy supply and energy saving indicators. Furthermore, no study has been published to date that provides a simplified yet robust description underpinned by a range of modelling studies as to how much additional GHG emissions reduction can be achieved per unit of additional low-carbon energy supply and end-use energy saving in Japan for 2030.

This study conducts a comparative assessment of GHG emission scenarios for 2030 published in the literature. This study is comprised of two sets of analyses. First, the scenarios were categorized by their mitigation effort levels to assess the value ranges for GHG emissions as well as the key underlying energy-related indicators for each effort level category (Analysis A). Second, a multiple regression equation was developed based on the data for GHG emissions and their explanatory variables. Using the derived regression equation, we calculated the levels of low-carbon energy supply and end-use energy savings required to achieve different levels of GHG emissions reduction in 2030. The regression equation is used to predict the levels of low-carbon energy supply and end-use energy savings necessary to achieve certain levels of GHG emissions reductions with sufficient level of accuracy for policy discussions without having to run a full-fledged energy system model. Based on these analyses, this paper proposes the level of mitigation Japan could aim for in its INDC (Analysis B).

This study focuses mainly on, but is not limited to, peer-reviewed journal articles and research reports commissioned by the government published after the Fukushima nuclear disaster. Moreover, this study concentrates on the studies that are based on bottom-up energy system models and investigated the GHG mitigation potential under varying policy effort levels, taking into account technical and economic constraints specifically for Japan. This study does not consider scenarios that assumed a nuclear power share higher than the pre-Fukushima levels because such a situation is unlikely to happen in 2030.

This paper is structured as follows. Section 2 provides a brief description of the current status of energy use and GHG emissions in Japan. Section 3 describes the data used and the research methodology applied in Analyses A and B. Section 4 presents the results of the analysis, describes the implications of the obtained results on the current political discussion on post-2020 mitigation target formulation, as well as the methodological limitations of the analysis. Finally, conclusions are drawn in Section 5.

02 Current status of GHG emissions and energy use in Japan

Japan's historical GHG emissions since 1990 are presented in Figure 1. During the first commitment period of the Kyoto Protocol (KP-CP1: 2008 – 2012), Japan reduced its emissions on average 8.4% compared to 1990 levels including land use, land-use change, and forestry (LULUCF) and the purchases of Kyoto Units[1] (MOE 2013). However, the average annual domestic GHG emissions excluding LULUCF and Kyoto Units between 2008 and 2012 were 1.4% above 1990 levels. The emissions reductions between 2008 and 2010, which are mainly the result of the global economic crisis (MOE 2011), have contributed significantly to Japan achieving its KP-CP1 target. The subsequent increase in emissions is a result of the economy recovering and fossil fuel-fired power generation increasing after the Fukushima nuclear disaster of 2011. For 2013, it was recently reported that Japan's GHG emissions were 1408 Mt-CO$_2$e, which is the second highest in history and 10.8% higher than the 1990 emissions (GIO 2015).

As for future mitigation targets, Japan committed to reduce its GHG emissions by 3.8% by 2020 from 2005 levels (a 5.8% increase from 1990 levels including LULUCF and the use of emission credits at the UNFCCC COP19 held in Warsaw, Poland, in 2013 (GoJ 2013). This target is referenced hereinafter as the "Warsaw Target". The Warsaw Target replaced the conditional 25% reduction from 1990 levels, which was pledged at COP15 held in Copenhagen in 2009 (GoJ 2010), following the Fukushima nuclear disaster. For the long-term future, Japan aims to reduce its GHG emissions by 80% from 1990 levels by 2050 (MOE 2012b).[2] For reference, Japan's estimated emissions in 2030 would be roughly 25% below 1990 levels when a linear interpolation between 2020 and 2050 targets is assumed. If Japan reduces its GHG emissions linearly from 2012, the final year of the first commitment period of the KP-CP1, toward the 80% reduction in 2050, then the emission level in 2030 would be about 33% below 1990 levels.

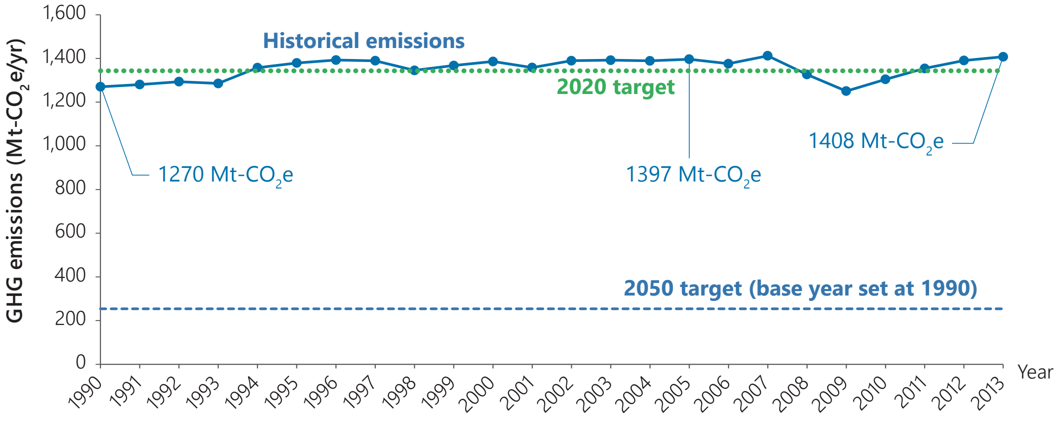

Figure 1: Japan's historical GHG emissions between 1990 and 2013, and the future mitigation targets up to 2050 (excluding LULUCF). Source: GIO (2015).

[1] "Kyoto units" is a collective term for emission allowances that are generated, cancelled, acquired or transferred through LULUCF Activities and through participation in the Kyoto mechanisms (UNFCCC 2008).

[2] In the original Japanese version, the base year is not clarified. In the English version, however, it is indicated that the base year is 1990 (MOE 2012b).

Japan's historical energy consumption in the end-use sectors since 1990 by energy carrier type is shown in Figure 2. Total final consumption (TFC)[3] has been on a decreasing trend since 2007 and the 2012 consumption is similar to the 1990 level. One reason for this are the electricity-saving efforts that took place after the Fukushima nuclear disaster. Another important reason for the decreasing TFC is that the share of electricity in TFC has increased from 19.4% in 1990 to 23.9% in 2010, although it reduced slightly following the Fukushima nuclear disaster of March 2011.

Japan's TFC per capita and GDP (in constant 2005 USD) is shown in Figure 3. It can be seen that the TFC per capita has been decreasing since 2004 and the rate of decrease has been accelerated by the global economic crisis and the Fukushima disaster. The reduction rate of TFC per GDP has been stagnant between 1990 and 2002, but it has accelerated since then.

3 TFC is "the sum of consumption by the different end-use sectors" (IEA 2014b)

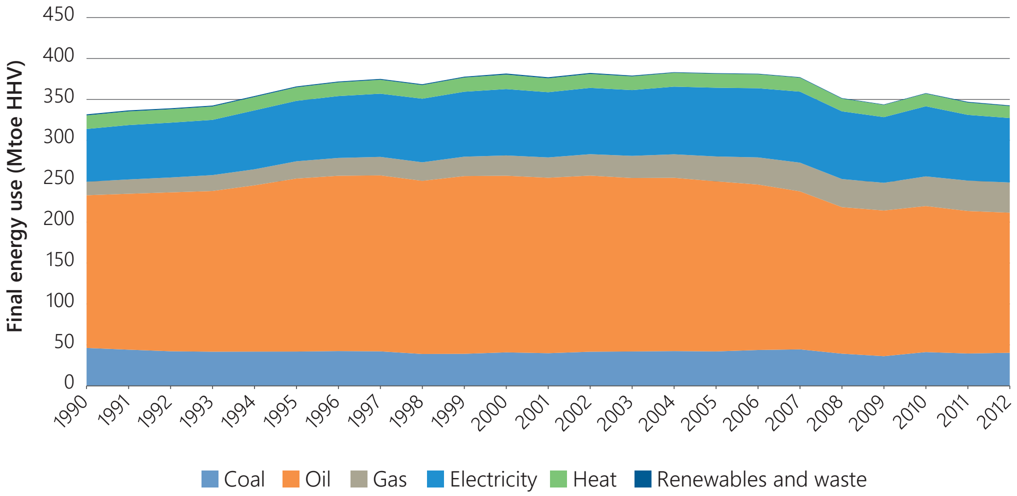

Figure 2: Japan's final energy use since 1990 by fuel. Source: METI (2014b).

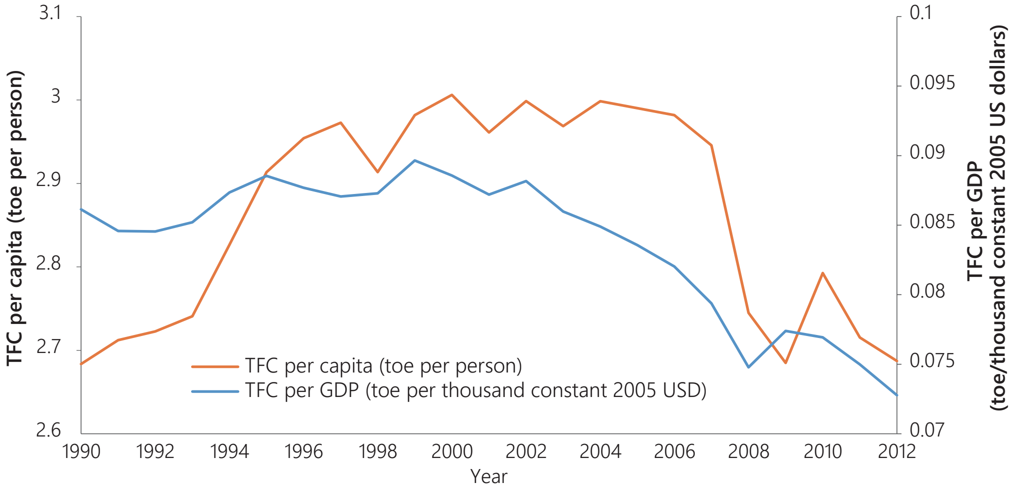

Figure 3: Japan's total final consumption (TFC) per capita and per GDP (in constant 2005 US dollars).
Source: Authors' own calculation based on METI (2014b) and World Bank (2015).

Japan's historical total electricity generation by fuel since 1990 is presented in Figure 4. Before the Fukushima nuclear disaster, nuclear, gas and coal accounted for most of electricity generation with similar shares. After the Fukushima nuclear disaster, no nuclear reactor is in operation as of February 2015 and electricity generation is currently dominated by gas and coal. The share of oil-fired power generation is one of the highest among OECD member states, although it has decreased significantly from 1990 levels (IEA 2014a). The share of gas-fired power in total fossil fuel-fired power generation has increased over the years, from 31% in 1990 to 43% in 2010 and 45% in 2013 (IEA 2014a; IEA 2013). It is worth noting that the coal-fired power generation has steadily been increasing since 1990.

Renewable (RE) electricity is gradually increasing, but its share (including large hydropower) of total generation was still less than 13% in 2013 (IEA 2014a). The latest Basic Energy Plan (METI 2014a) indicates that Japan will increase the share of RE electricity (excluding autogenerators) to at least 20% by 2030. The 2012 Innovative Strategy set a 30% renewable electricity target for 2030, but the document was scrapped by the current Cabinet.

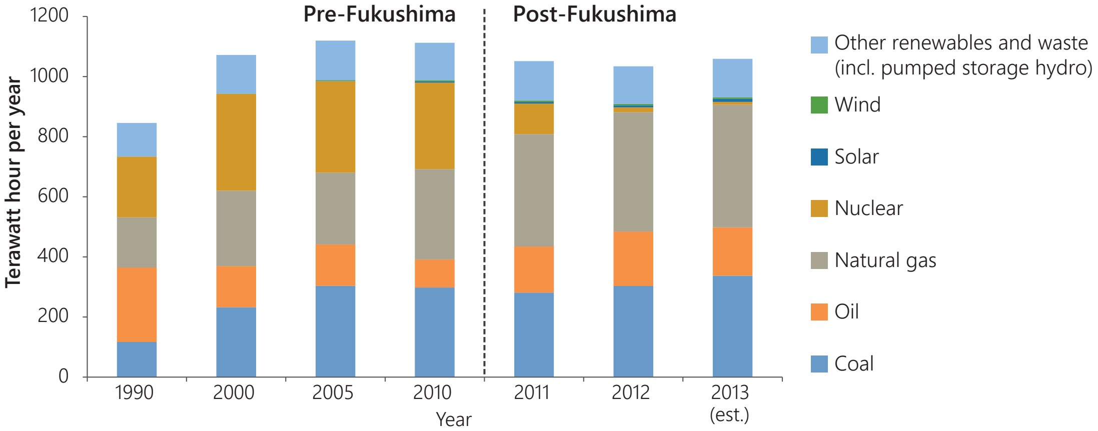

Figure 4: Japan's electricity generation since 1990 by fuel. Source: IEA (2014a).

03 Data and methods

3.1 Literature and scenarios covered

For both Analyses A and B, mitigation scenario data were collected from selected studies published between 2011 and 2015 that provided results for 2030 and met the following criteria: (i) publication based on a detailed bottom-up assessment of technology deployment potentials for all sectors taking into account foreseeable policy measures, (ii) published or co-authored by the research institutes that provide energy and GHG emissions scenarios to the government or by other internationally accredited energy research institutes, or published in the peer-reviewed literature. These criteria were set to filter out the scenarios that make overly optimistic (or pessimistic) assumptions on low-carbon technology deployment as well as societal and economic transitions that are not widely accepted by experts.

As a result, this study covered seven studies in total (MOE 2012a; IEEJ 2013b; IEA 2014c; Takase & Suzuki 2011; IEEJ 2014; IEEJ 2015; SDSN & IDDRI 2014). These include reports that served as the basis for the formulation of the 2030 GHG mitigation target stipulated in the Innovative Strategy (MOE 2012a; IEEJ 2013b). Takase and Suzuki (2011) is the only one among the seven studies that was published before the Fukushima nuclear disaster.

This study did not include all mitigation scenarios produced in the aforementioned literature. First, "frozen technology" scenarios, which assume that the stock-average energy efficiency remains at the base year level up to 2030, are excluded from the analysis. Second, with regard to the share of nuclear power in total power generation, based on the latest developments on nuclear policy and expert interviews, this study excluded mitigation scenarios that assumed nuclear power shares greater than 30%, which corresponds to the highest level observed pre-Fukushima (Figure 4). As a result, a total of 48 mitigation scenarios were assessed, of which 24 are from MOE (2012), conducted by the National Institute for Environmental Studies (NIES) and its partners, and 10 were from the Institute of Energy Economics, Japan (IEEJ 2013b). An additional six scenarios were also from IEEJ (IEEJ 2014; IEEJ 2015).

3.2 Analysis A: Comparative assessment of mitigation scenarios for 2030

This analysis considered all GHGs from all sectors excluding land use, land use change and forestry (LULUCF)[4]. The analysis assessed the following four energy-related indicators, of which three are for supply side and one for demand side: (1) renewable electricity and CO_2 capture and storage- (CCS-) equipped electricity ("RE/CCS electricity") share in total electricity generation, (2) nuclear electricity share in total electricity generation, (3) unabated coal-fired electricity share in total electricity generation,[5] (4) share of gas-fired power generation in total unabated fossil fuel-fired power generation (hereinafter, "gas power ratio") and (5) TFC as a change from 2010 levels. This study distinguished nuclear power from renewable electricity and CCS-equipped electricity although they both reduce GHG emissions and enhance energy security by reducing fossil fuel imports because of the differences in political motives behind their promotion. In Japan, RE is mainly promoted by the government for GHG emissions reduction and to a limited extent for enhanced energy security (Moe 2012), and CCS is primarily considered for GHG emissions reduction. In contrast, nuclear power is promoted by the government primarily for enhanced energy security and economical electricity supply, although the validity of the latter has been critically debated after the Fukushima nuclear disaster.

The selected indicators are the ones that are discussed extensively with regard to the 2020 and 2030 national GHG mitigation target formulation. Moreover, these are key indicators for three of the four pillars of Japan's energy policy, i.e., energy security, economic supply of energy, and GHG emissions reduction.[6] The values for these four indicators were derived directly from the data of the 48 scenarios.

The selected mitigation scenarios are classified into four mitigation effort level categories. Level 1 represents the lowest mitigation effort assuming the continuation of currently existing policies at the time of publication of the referenced literature and no additional policy implementation.[7] Level 2 takes into account the policies that are currently in planning or consideration in addition to those considered for Level 1. Level 4 represents the highest mitigation effort. The mitigation scenarios that indicate any of the following were classified as Level 4: (i) consistency with the global 2 °C target, (ii) consistency with the long-term target of 80% reduction of GHG emissions from 1990 levels by 2050, or (iii) maximum deployment of advanced technologies based on bottom-up techno-economic potential assessments. It should be noted that the three criteria are not fully comparable, and there are wide ranges of interpretations within each criterion. All scenarios that considered stronger policies than Level 2 but do not meet the criteria for Level 4 are categorised as Level 3. An overview of the literature reviewed in this study and the categorisation of GHG emission scenarios are presented in Table 1.

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[4] For Japan, LULUCF is currently considered as a net carbon sink of a relatively small scale. For 2020, about 38 Mt/yr (3% of total GHG emissions in 1990) of CO_2 removal by forest sinks is expected for 2020 (GoJ 2013), but the targeted amount for years after 2020 has not been assessed by the government to date and none of the literature compared in this study considered LULUCF.

[5] "Unabated coal" is defined as "coal burning without carbon capture and storage (CCS)…all forms of 'high-efficiency coal technologies' are counted as unabated coal, unless equipped with CCS" (Davidson et al. 2013).

[6] The 2014 Basic Energy Plan newly included "safety" as one of the four pillars of Japan's energy policy (METI 2014a).

[7] This effort level accounts for policies and measures that are not yet fully implemented, but does not account for the mitigation impacts that would have been delivered in case they are fully implemented.

Table 1: Literature reviewed in this study and the categorization of GHG emission scenarios.
N.A.: Not available.

	Level 1: Continuation of currently existing policies and actions and no additional policy implementation	Level 2: Takes into account the policies and actions that are currently in planning or consideration in addition to those considered in Level 1.	Level 3: More aggressive policies and actions compared to Level 2, including those that are not currently considered, but it does not meet the criteria for Level 4.	Level 4: Indicates one or more of the following: (i) consistency with the global 2 °C target, (ii) consistency with the long-term target of 80% reduction of GHG from 1990 levels by 2050, (iii) maximum deployment of advanced technologies based on techno-economic potential assessments.
IEA (2014b)	Current Policies scenario (CPS): "(T)akes into consideration only those policies and implementing that had been formally adopted as of mid-2014."	New Policies scenario (NPS): "(T)akes into account the policies and implementing measures affecting energy markets that had been adopted as of mid-2014, together with relevant policy proposals, even if specific measures needed to put them into effect have yet to be fully developed." Carbon pricing of around 30 \$/t-CO_2 assumed (as shadow price)	N.A.	450 scenario: "(S)ets out an energy pathway that is consistent with a 50% chance of meeting the goal of limiting the long-term increase in average global temperature to 2°C compared with pre-industrial levels." Carbon pricing of around 100\$/t-CO_2 assumed (as shadow price).
MOE (2012a)	N.A.	Continued Effort scenarios (8 variants by nuclear share and GDP growth assumptions). Assumes the continuation of existing and currently planned policy measures.	Enhanced Effort scenarios (8 variants by nuclear share and GDP growth assumptions). Assumes reasonable economical and regulatory policies to promote low-carbon technologies.	High Effort scenarios (8 variants by nuclear share and GDP growth assumptions): Maximum introduction of low-carbon technologies through implementation of bold policy measures.
IEEJ (2013)	N.A.	N.A.	N.A.	Maximum introduction scenarios (10 variants by nuclear share and economic growth assumptions): Assume maximum deployment of advanced technologies.
IEEJ (2014)	Reference scenario: This scenario is developed based on the past trends and currently existing energy and climate policies. Only traditional and conventional policies are considered and no aggressive energy saving or low-carbon policies deviating from the past ones are considered.	N.A.	N.A.	Advanced Technologies + CCS scenario: The world is assumed to implement strong energy and climate policies. Advanced technologies including CCS are introduced as much as possible. This scenario is classified as Level 4 because its cumulative CO_2 emissions are consistent with the 500 ppm stabilisation.

IEEJ (2015)	N.A.	N.A.	Four scenarios by the share of nuclear power (0%, 15%, 25% and 30%): Steady implementation of strong energy saving measures in all sectors. Renewable electricity share between 20% and 35% depending on the scenario. These scenarios are classified as Level 3 because it clearly states that the 2030 mitigation levels are not on track to achieve 80% by 2050, unless new technologies such as artificial photosynthesis are deployed.	N.A.
SDSN and IDDRI (2014)	N.A.	N.A.	N.A.	All three scenarios reducing GHG emissions by 84% from 2010 levels by 2050.
Takase and Suzuki (2011)	Business-As-Usual (BAU) – Minimum Nuclear scenario: Assumes that existing policies continue.	N.A.	N.A.	National Alternative – Minimum Nuclear scenario: Assumes an aggressive application of energy efficiency and low-carbon energy measures. This scenario is classified as Level 4 because the literature referenced for energy demand and supply targets aim for 60%-80% reduction of GHG by 2050.

The following data were collected from the seven studies in Table 1 whenever they were available to calculate the values of the aforementioned for energy-related indicators.

- GHG emissions[8]
    - Total GHG emissions excluding LULUCF ($EM_{GHG,tot,2030}$: Mt-CO_2e)
    - Energy-related CO_2 emissions ($EM_{CO2,EN,2030}$: Mt-CO_2, when total GHG emissions data were not available,)
- Energy demand and supply
    - TFC (TFC_{2030}: Mtoe)
    - Total electricity generation including autoproducers ($EL_{tot,2030}$: TWh)
    - Share of electricity in TFC
    - RE/CCS electricity generation including autoproducers ($RECCS_{2030}$: TWh)
    - Nuclear electricity generation including autoproducers (NUC_{2030}: TWh)
    - Gas-fired electricity generation including autoproducers (GP_{2030}: TWh)
- Other underlying assumptions and information (used for in-depth analysis only)
    - GDP projection

A number of data harmonization procedures were taken in this study to make all data comparable. First, all energy figures were converted to higher heating value (HHV) terms by using the heating values data from METI Comprehensive Energy Statistics (METI 2013).[9] Second, total electricity generation is expressed in gross terms and includes generation by autoproducers.[10] When electricity generation from autoproducers were not reported in the reviewed literature, total generation values were adjusted with the autoproducer electricity generation projected for

2030 in the option document for the formulation of the Innovative Strategy (EEC 2012b). Third, final energy use data from (IEA 2014c) were adjusted to the definitions used in the METI Comprehensive Energy Statistics (METI 2013). For studies using the IEA energy balances, the adjustment was done by accounting for energy losses in blast furnaces as part of final energy use rather than as part of energy conversion (Aoshima 2009). For studies using the IEEJ energy statistics, the adjustment was made by applying a correction factor, which is the ratio of base year TFC in the METI statistics and the IEEJ statistics.[11] Fourth, as some studies only calculated energy-related CO_2 emissions, adjustments were made for non-energy related GHG emissions as a function of TFC based on (MOE 2012a; SDSN & IDDRI 2014) (see Appendix B for details).

3.3 Analysis B: Prediction of GHG emission for 2030 using a regression equation

The projection of GHG emissions is determined by many factors that underlie the calculations of energy demand and supply. Analysis B aimed to predict the GHG emissions reduction level for 2030 with a limited number of explanatory variables that are often discussed in the energy and climate policymaking process by conducting a multiple regression analysis on the data of 48 scenarios compared in Analysis A. Using the derived regression equation, the analysis assessed the energy supply- and demand-related targets required to achieve GHG emissions reductions of 20%, 30% and 40% from 1990 levels by 2030. The 20% reduction corresponds to the target stipulated in the Innovative Strategy document (EEC 2012a) and the 30% reduction corresponds to the minimum mitigation requirement suggested for OECD countries (as of 1990) under a range of effort-sharing principles by Höhne et al. (2014).

The regression analysis was conducted using the Stata software (StataCorp 2009). A step-wise regression as proposed by Fischer and Morgenstern (2006) was taken to exclude variables without significant explanatory power. In order to account for the differences in number of scenarios taken from each literature, the analysis clustered the observations from the same literature source using the "CLUSTER" command in Stata to resolve the problem of calculating standard errors when observations were taken from the same literature. A correlation test was conducted to examine collinearity between any two explanatory variables, and the variance inflation factors (VIFs) were examined to investigate multicollinearity of the explanatory variables.

Since non-energy GHG emissions were not covered in many scenarios, a regression analysis was conducted for energy-related CO_2 emissions as the dependent variable. After the regression equation for energy-related CO_2 emissions ($EM_{\mathrm{CO2,EN,2030}}$: Mt-$CO_2$/yr) was derived, the term for non-energy related GHG emissions as a function of TFC (Appendix B) was added to the equation. $EM_{CO2,EN,2030}$ is expressed as a function of five explanatory variables as follows:

$$EM_{CO2,EN,2030} = a_1 * NUC_{2030} + a_2 * RECCS_{2030} + \cdot a_3 * \Delta GP_{2030} + \cdot a_4 * TFC_{2030} + a_5 * \Delta EL_{tot,2030} \qquad \text{(Eq. 1)}$$

where:

NUC_{2030}: Nuclear electricity generation in 2030 (TWh)
$RECCS_{2030}$: RE/CCS electricity generation in 2030 (TWh)

ΔGP_{2030}: Unabated gas-fired power generation above benchmark levels in 2030 (TWh)

TFC_{2030}: Total final consumption in 2030 (Mtoe)

$\Delta EL_{tot,2030}$: Total electricity generation above benchmark levels in 2030 (TWh)

a_1: CO_2 emissions per TWh of nuclear electricity (Mt-CO_2e/TWh)

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8 The emission values in the latest GHG emissions inventory report (GIO 2015) slightly differ from those in previous reports due to the updated global warming potential (GWP) values. The future GHG emission projections from the literature were adjusted by a correction factor (ratio between the 2015 inventory report value and the scenario-specific value for 1990 emissions) when they were compared with the 2015 inventory report data.

9 Most Japanese energy statistics as well as energy analyses use HHV, while others (e.g., IEA) use lower heating value (LHV).

10 Autoproducers are privately or publicly owned entities that 'generate electricity and/or heat, wholly or partly for their own use as an activity which supports their primary activity' (IEA 2014b).

[11] The difference between the two statistics can be largely explained by the accounting approach for industrial steam generation.

a_2: CO_2 emissions per TWh of RE/CCS electricity (Mt-CO_2e/TWh)

a_3: CO_2 emissions increase per TWh unabated gas-fired electricity additional to benchmark levels (Mt-CO_2e/TWh)

a_4: CO_2 emissions per TFC (Mt-CO_2e/Mtoe)

a_5: CO_2 emissions increase per TWh unabated fossil fuel-fired electricity additional to benchmark levels (Mt-CO_2e/TWh)

The sum of the first five terms represent the energy-related CO_2 emissions and the last term represents the non-energy related GHG emissions. The derivation of Eq.1 is described in detail in Appendix C. Of the five explanatory variables, the first four (NUC_{2030}, RE/CCS_{2030}, ΔGP_{2030}, and TFC_{2030}) are directly related to the five key energy indicators used for the first analysis as described in Section 3.2.[12]

$RECCS_{2030}$ represents the impact of RE/CCS electricity deployment not only on power sector CO_2 emissions but also on the renewable energy deployment in non-power sectors. When accounting for electricity generated by CCS-equipped power plants, the generated electricity is converted to zero-emission equivalent. For example, if a 100GWh of gross electricity is generated from power plants that avoid 85% of CO_2 emissions by CCS compared to the case without CCS, we consider that 85GWh of electricity is zero-carbon electricity. When CO_2 avoidance rates were not reported in the reviewed literature, a CO_2 avoidance rate of 85% was assumed (Damen et al. 2006).

With regard to other explanatory variables, TFC_{2030} incorporates the changes in various macroeconomic activity levels, as well as the changes in electricity-fuel ratios and energy efficiency in end-use sectors. ΔGP_{2030} explains additional CO_2 emissions reductions through enhanced fuel switch from coal and oil to gas for power generation. This study defined the benchmark unabated gas-fired power generation as 50% of the total unabated fossil fuel-fired power generation in each of the scenarios. ΔEL_{2030} represents the impact of electrification rate on CO_2 emissions. For a given TFC and decarbonised power generation, a higher electricity consumption in end-use sectors results in a higher total primary energy consumption because the additional energy conversion losses in unabated fossil fuel-fired power plants outweigh the reduced fuel consumption in end-use sectors. The benchmark total electricity generation was defined as the product of TFC in 2030 projected in each scenario and the ratio of total electricity generation and TFC in 2010. This variable explains the influence of the increased electricity share in TFC on GHG emissions.

The four key energy-related indicators described in Section 3.1 can be expressed as follows:

$$\text{Nuclear electricity share} = \frac{NUC_{2030}}{\Delta EL_{tot,2030} + EL_{tot,2010} * \frac{TFC_{2030}}{TFC_{2010}}} \quad \text{(Eq.2)}$$

$$\text{RE/CCS electricity share} = \frac{RECCS_{2030}}{\Delta EL_{tot,2030} + EL_{tot,2010} * \frac{TFC_{2030}}{TFC_{2010}}} \quad \text{(Eq.3)}$$

$$\text{Gas power ratio} = GPR_{BM} + \frac{\Delta GP_{2030}}{\Delta EL_{tot,2030} + EL_{tot,2010} * \frac{TFC_{2030}}{TFC_{2010}} - NUC_{2030} - RECCS_{2030}} \quad \text{(Eq.4)}$$

$$\text{TFC as a change from 2010 levels} = \frac{TFC_{2030}}{TFC_{2010}} - 1 \quad \text{(Eq.5)}$$

where $EL_{tot,2010}$ is the total electricity generation in 2010 (1109TWh) and GPR_{BM} is the benchmark gas power ratio (0.5).

Moreover, it was also examined whether the large number of scenarios from certain models caused biased estimates of coefficients and standard errors. In addition to the five explanatory variables described above, we also examined the possible bias caused by the data source by defining the following two unobservable (dummy) variables *moe2012*, which identifies scenarios from the MOE 2012 report (MOE 2012a), and *ieej*, which identifies scenarios from IEEJ studies (IEEJ 2013b; IEEJ 2014; IEEJ 2015).

12 *ΔGP* represents both the gas power ratio and the share of unabated coal-fired power.

04 Results and discussion

4.1 Analysis A

4.1.1 GHG emissions

Figure 5 presents GHG emission projections for 2030 compared to 1990 levels by mitigation effort level and literature source. A wide range of mitigation levels was observed for all effort level categories, which is a result of the differences in various underlying assumptions including the nuclear power share, which ranged between 0% and 30%. The range was particularly large for Mitigation Effort Level 4 scenarios (between -16% and -39% from 1990 levels), which contains results from all seven studies compared. The scenario with a 39% reduction assumed RE/CCS and nuclear electricity shares of more than 40% and 20%, respectively, in addition to a 28% reduction of TFC which is partly attributable to a very low GDP growth rate (compound average of 0.3%/yr).

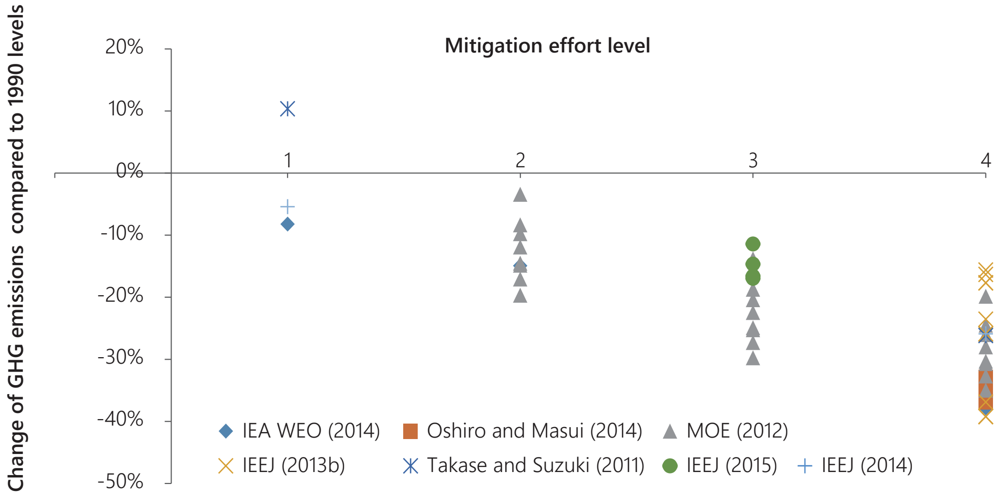

Figure 5: GHG emission projections for 2030 compared to 1990 levels by mitigation effort level and data source.

Figure 6 presents the GHG emission reduction ranges for mitigation effort Levels 1, 2, and 4 in comparison with the historical emissions as well as the two linear reduction pathways to achieve the 80% reduction in 2050. It can be seen that the Level 4 range fully covers the emission levels for 2030 estimated for the immediate action case, i.e. linearly reducing the emissions from 2012 onward, and for the delayed action case, i.e. adhering to the Warsaw Target and not taking drastic mitigation actions before 2020.

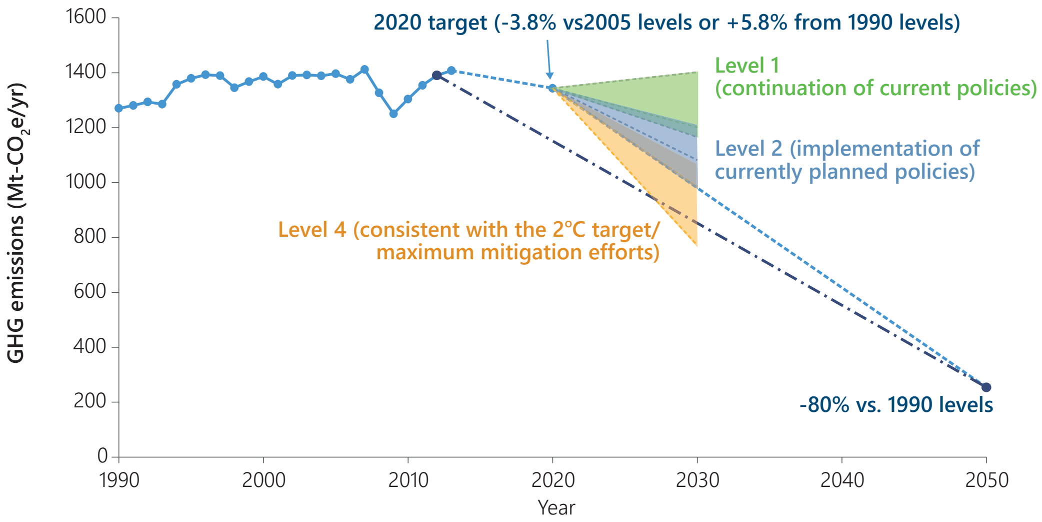

Figure 6: Historical GHG emissions, emission ranges for mitigation effort Levels 1, 2 and 4, as well as two linear reduction pathways to achieve 80% reduction in 2050.

4.1.2 Share of nuclear electricity

Figure 7 presents the GHG emission projections versus the share of nuclear electricity in total power generation in 2030. For a given nuclear power share, GHG emissions reduction levels vary widely even among the scenarios with same mitigation effort levels. It should also be noted that the energy supply mixes for some scenarios (20% and 25% nuclear scenarios of IEEJ (2013)) were intentionally developed in such a way that the energy-related CO_2 emissions will become similar across scenarios.

Although there is a large measure of political uncertainty on the future use of nuclear power, recent developments provide some indications on its possible share in 2030. As of April 2015, there are 39 reactors that can be restarted (JAIF 2015). If the 40-year operation rule is strictly applied to all reactors that can be restarted, the nuclear electricity share will roughly be 13% in 2030.[13] If all reactors that can be restarted pass the special inspections by the Nuclear Regulation Authority (NRA) for a 60-year operation, the nuclear power share will roughly be 25% in 2030.[14] Considering the strong public sentiment against nuclear power (Reuters 2015) and the uncertainty on the outcomes of safety examinations by the NRA, it may be unrealistic to expect a nuclear shares above 15%, even if the government might aims for higher levels.

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[13] About 130 TWh/yr assuming an 80% capacity utilisation factor.

[14] About 260 TWh/yr assuming an 80% capacity utilisation factor.

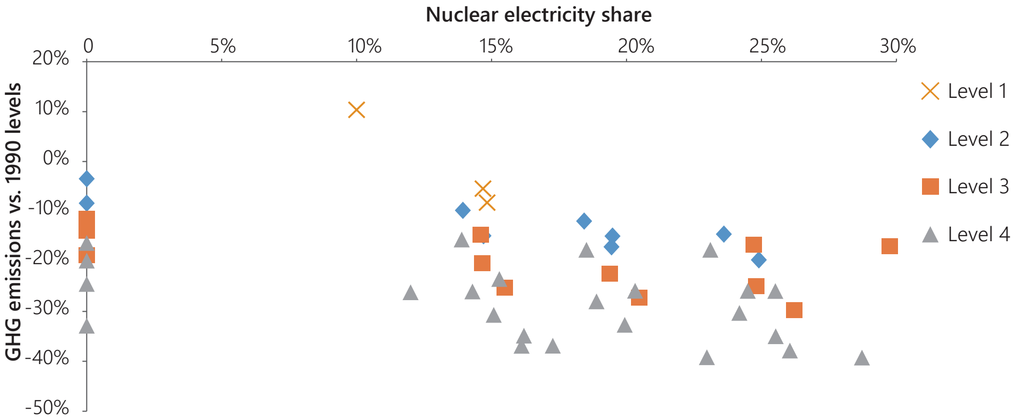

Figure 7: GHG emission projections versus the share of nuclear electricity in 2030.

4.1.3 Renewable and CCS-equipped (RE/CCS) electricity

Figure 8 shows GHG emission projections versus RE/CCS electricity share by mitigation effort level of the scenarios reviewed. A linear correlation between the GHG emissions and RE/CCS electricity share is observed. For Level 4 scenarios, the projected RE/CCS electricity shares vary largely from 27% to 47%. The lowest projection is close to the 2030 target stipulated in the Innovative Strategy, while the highest projection (47%) is based on an assumption that the share of photovoltaic (PV) in total electricity generation will increase to 27% (about 300 TWh/yr) by 2030. The latest RE potential assessment study commissioned by MOE (2014) projected that the share of RE electricity in 2030 would reach around 25-30% in the medium deployment case and 30-35% in the high deployment case, respectively.[15] Therefore, some studies compared in this study may be assuming RE electricity shares that are very ambitious for 2030.

With regard to CCS, four scenarios from two studies (SDSN & IDDRI 2014; IEA 2014c) projected CCS deployment in the power sector in 2030. If Japan chooses not to use nuclear power and finds that it is not possible to increase the RE electricity share close to 30%, then it becomes essential to realise large-scale CCS deployment by 2030 to achieve ambitious mitigation levels consistent with the global 2°C target. This may, however, prove to be a major challenge. The 2010 BEP stipulated that the new coal-fired power plants should be CCS-ready and be equipped with CCS by 2030 (on the precondition of commercialization) (METI 2010), but the post-Fukushima 2014 BEP took a step backward by not indicating a timeline for CCS deployment (METI 2014a) partly due to the large uncertainty about Japan's commitment to climate change mitigation.

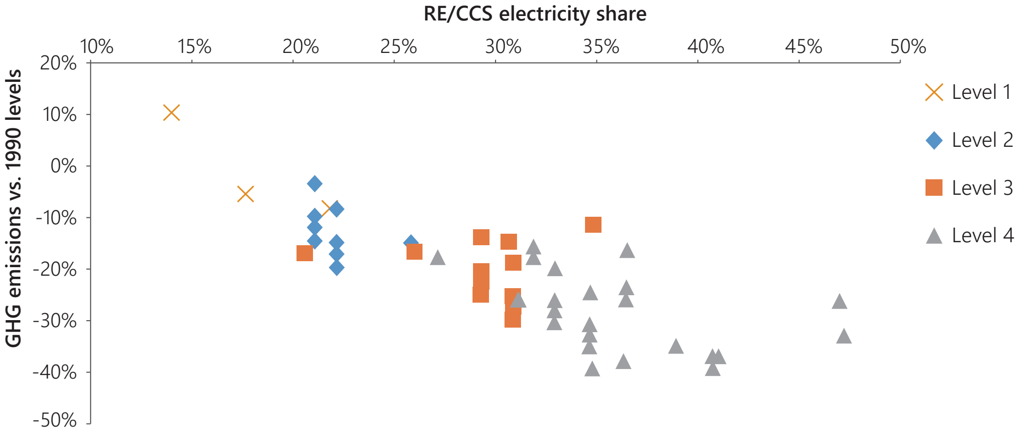

Figure 8: GHG emission projections versus renewable electricity share in total electricity generation by mitigation effort level of the mitigation scenarios reviewed.

4.1.4 Unabated fossil fuel-fired power generation

Figure 9 shows the GHG emission projections versus gas power ratio by mitigation effort level. The values for most studies ranged between 35% and 70%. The range of values become larger as the GHG emissions reduction levels increase because the absolute amount of unabated fossil fuel-fired power plants decrease. The values above 90% were observed for scenarios with CCS installation in coal-fired power plants. No clear differences were observed across different mitigation effort levels.

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[15] RE electricity projections for 2030 were 241.4 TWh for the low deployment case, 312.2 TWh for the medium deployment case, and 356.6 TWh for the high deployment case, respectively.

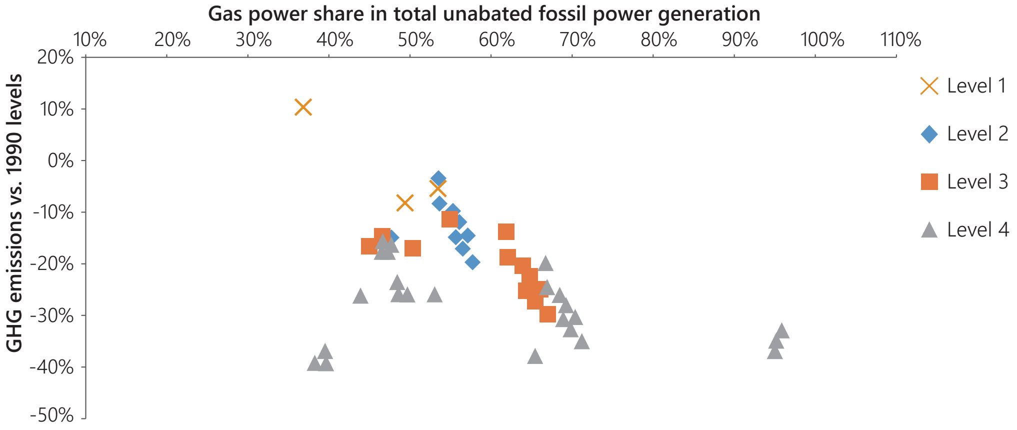

Figure 9: GHG emission projections versus gas-fired power share in total unabated fossil fuel-fired power generation ("gas power ratio") by mitigation effort level of the mitigation scenarios.

The GHG emission projections versus unabated coal-fired power in total electricity generation by mitigation effort level are presented in Figure 10. A clear relationship can be seen between the coal-fired power share and the level GHG emissions reductions. For all scenarios with GHG emissions reductions of more than 20% from 1990 levels, coal-fired power shares were found to be lower than 21%.

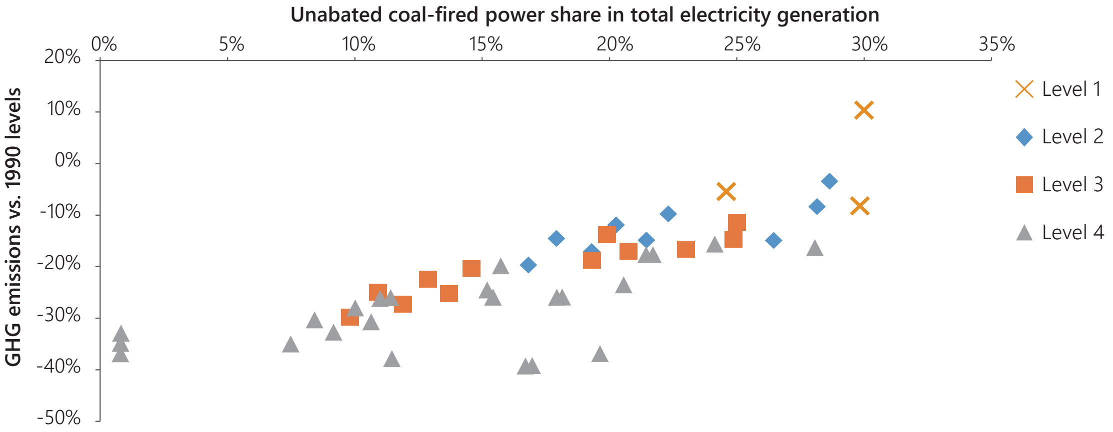

Figure 10: GHG emission projections versus unabated coal-fired power share in total electricity generation by mitigation effort level of the mitigation scenarios.

4.1.5 Total final consumption (TFC) and total electricity generation

Figure 11 shows GHG emissions versus TFC as a change from 2010 levels by mitigation effort level of the scenarios. It can be seen that the reduction of TFC contributes significantly to GHG emissions. For Level 4 scenarios, the projected TFC reduction levels vary largely from 12% to 28%, which can be attributable to varying underlying assumptions on, e.g. GDP growth and sector-specific activity growth rates, efficiency of end-use technologies and electrification rates.

There is large uncertainty as to how much TFC can be reduced. The reduction potential for TFC would largely be influenced by Japan's future economic growth levels, which ranged widely between 0.31%/yr and 1.6%/yr (compound annual average) for the scenarios compared in this study. Moreover, Japan was not successful in reducing its final energy use in the residential and commercial sectors to the targeted levels during the KP-CP1 (Kuramochi 2015b). At the same time, Japan's population is expected to decrease by 9% from 2010 levels by 2030 (projection based on medium mortality rates and medium birth rates, IPSS 2012). A 25% reduction of TFC by 2030, for example, can be achieved by reducing the TFC per capita at a rate of about 0.9%/yr (IPSS 2012). This reduction rate is smaller than that observed between 2005 and 2012 (1.5%/yr, Figure 3). In contrast, assuming a compound average GDP growth rate of 1%/yr for 2012-2030, which lies between a 1.7%/yr for 2013-2030 based on the government's growth target (METI 2015a) and a 0.6%/yr for 2013-2020 assumed by the International Monetary Fund (IMF 2015), TFC per real GDP would need to be reduced by about 40%. This reduction rate is similar to that observed between 1970 and 1990 (IEEJ 2013a).

In addition, there are conflicting views on how much of the additional electricity savings that were achieved right after the Fukushima nuclear disaster would be sustained up to 2030. For the formulation of the Innovative Strategy, it was assumed that the total electricity generation will reduce by about 10% from 2010 level to 1000 TWh/yr by 2030, reflecting the considerable electricity savings realized following the Fukushima nuclear disaster (EEC 2012a).[16] Homma and Akimoto (2013),[17] on the other hand, projected much higher total electricity generation under the same GDP assumptions (about 1150 TWh/yr), arguing that the Innovative Strategy overestimated the electricity savings induced by the Fukushima nuclear disaster that can be sustained up to 2030. For the aforementioned reasons, it can be seen in Figure 12 that the share of electricity in TFC projected for 2030 in the literature varies greatly from 25% to 35%, compared to 23.9% in 2010. The results indicate the large differences in the estimation of post-Fukushima electricity savings that are sustained up to 2030 and electrification rates in the end-use sectors for 2030.

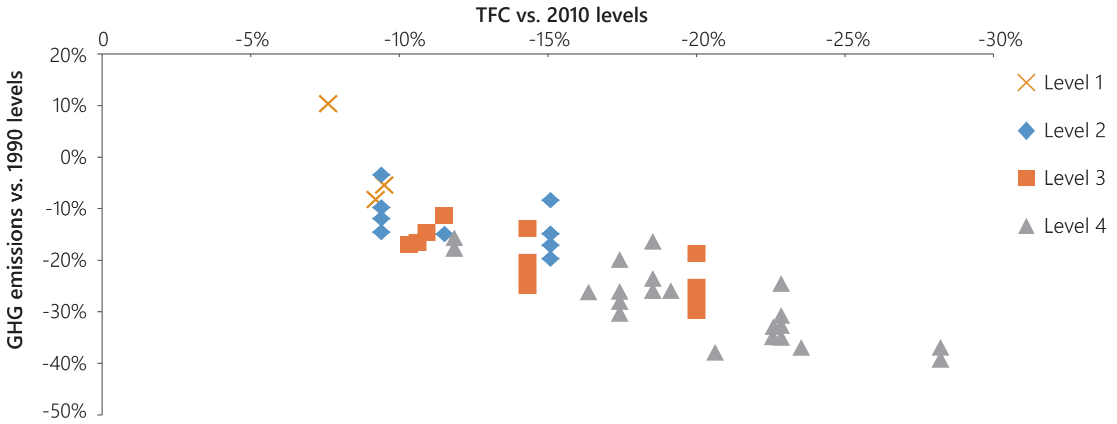

Figure 11: GHG emission projections versus total final energy consumption (TFC) as a change from 2010 levels by mitigation effort level of the mitigation scenarios reviewed.

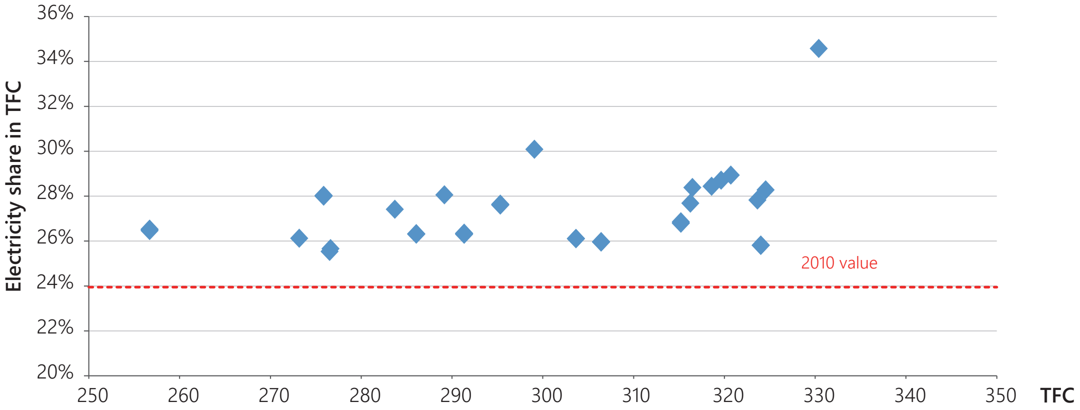

Figure 12: Electricity share in total final consumption (TFC) in 2030 for the mitigation scenarios reviewed. Note that not all 48 data points are visible in the figure due to overlapping.

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[16] This assumption is also applied in the medium GDP growth scenarios in (MOE 2012a; IEEJ 2013b).

[17] The referenced study was not included in the assessment because it did not conduct bottom-up technology assessment of mitigation potentials in non-electricity sectors.

4.1.6 Summary

Table 2 summarises the findings presented above. A relatively wide range of values was observed for all key indicators related to GHG emissions reductions at all mitigation effort levels. These results can be explained by the differences in the assumptions on technical, economic and politically feasible deployment potentials of low-carbon energy supply technologies and energy saving technologies as well as on economic growth rates and other activity drivers.

Table 2: The value range of key indicators related to GHG emissions reductions for 2030 observed in the literature.

Effort level category (number of scenarios)	Nuclear power share (%)	RE/CCS electricity share (%)	Unabated coal-fired power share (%)	Gas-fired power share in total unabated fossil fuel-fired power (%)	Total final consumption as a change from 2010 levels (%)	Total electricity generation (TWh)	GHG emissions as a change from 1990 levels (%)
Level 1 (3)	10 – 15	14 – 22	25 – 30	37 – 53	-8 – -9	1150 – 1460	+10 – -8
Level 2 (9)	0 – 25	21 – 26	17 – 29	48 – 58	-9 – -15	1010 – 1120	-3 – -20
Level 3 (12)	0 – 30	21 – 35	10 – 25	45 – 67	-10 – -20	960 – 1180	-11 – -30
Level 4 (24)	0 – 29	27 – 47	1 – 28	38 – 96	-12 – -28	870 – 1150	-16 – -39

4.2 Analysis B

4.2.1 Regression analysis

The following equation was derived for energy-related CO_2 emissions in 2030 as a result of the multiple regression analysis (Eq.6). The detailed results of the statistical analysis are presented in Appendix D.

$$EM_{CO2,EN,2030} = -0.593*NUC_{2030} - 0.630*RECCS_{2030} - 0.364*\Delta GP_{2030} + 3.72*TFC_{2030} + 0.338*\Delta EL_{2030} \qquad \text{(Eq. 6)}$$

$$(0<NUC_{2030}<353,\ 203<RECCS_{2030}<541,\ -146<\Delta GP_{2030}<218,\ 257<TFC_{2030}<330,\ 45<\Delta EL_{2030}<436,\ R^2 = 0.99)$$

Of the seven variables, the two dummy variables related to the literature source (“*moe2012*” and “*ieej*”) were found to be without significant explanatory power at α = 0.05. Moreover, the constant term was also found not to be significant. In addition, the results are clear of collinearity, as VIFs were 1.7 or lower for all five significant explanatory variables (a VIF of 10 is a signal of collinearity, according to Chatterjee & Hadi 2012) (see Appendix D).

The derived regression equation signifies the following:

- One TWh increase of nuclear electricity generation reduces GHG emissions by 0.593Mt-CO_2e;
- One TWh increase of RE/CCS electricity generation reduces GHG emissions by 0.630Mt-CO_2e;
- One TWh switch from coal- or oil-fired electricity to gas-fired electricity reduces GHG emissions by 0.364Mt-CO_2e;
- One Mtoe increase of TFC increases GHG emissions by 3.72 Mt-CO_2e;
- One TWh higher electricity generation for a given TFC increases GHG emissions by 0.338Mt-CO_2e;

The results show that the GHG emissions reductions per one TWh increase of RE/CCS electricity generation is about 5% larger than that per one TWh increase of nuclear electricity generation. As assumed in Appendix C, a TWh increase of RE/CCS electricity generation may be coupled with an increased use of non-electricity renewable energy such as solarthermal boilers and biofuels in end-use sectors.

By adding the term for non-energy related GHG emissions (Appendix B), economy-wide GHG emissions for Japan in 2030 can be expressed as:

$$EM_{GHG,tot,2030} = -0.593*NUC_{2030} - 0.630*RECCS_{2030} - 0.364*\Delta GP_{2030} + 4.22*TFC_{2030} + 0.338*\Delta EL_{2030} \quad \text{(Eq. 7)}$$

$$(0<NUC_{2030}<353,\ 203<RECCS_{2030}<541,\ -146<\Delta GP_{2030}<218,\ 257<TFC_{2030}<330,\ 45<\Delta EL_{2030}<436)$$

4.2.2 Assessment of pathways to achieve 20% and 30% mitigation by 2030

Figure 13 presents the required renewable electricity share and total final consumption level to achieve: (a) 20%, (b) 25%, (c) 30% and (d) 40% reduction of GHG from 1990 levels by 2030, respectively, based on the regression equation obtained in section 4.2. The results are presented for the share of nuclear power ranging from 0%, 15% and 25%, respectively. This range in the nuclear share is based on the remarks made by the members of the METI expert committee on the formulation of the 2030 electricity mix (Asahi Shimbun 2015). For reference, the RE electricity share calculated from a recent potential assessment study conducted by MOE (2015) is also presented. The share of electricity in TFC was assumed to be 28%, which is higher than in most scenarios produced for the formulation of the Innovative Strategy and is similar to the values observed for IEA WEO 2014 scenarios. The width of coloured areas reflects the gas power ratio between 0.4 and 0.6,[18] respectively.

A 25% reduction of GHG emissions by 2030 (Figure 13(b)) was found to be achievable with e.g. a 15% nuclear power share, a level that can be achieved by operating all restartable reactors and extending the lifetime of some reactors from 40 years to 60 years, a 30% RE/CCS electricity share, a 20% reduction of final energy use (TFC) from 2010 level, and a 60% gas power ratio. For a 20% TFC reduction, the 30% RE/CCS electricity share can be achieved with medium policy effort levels when compared to the results from MOE (2015). The 25% GHG emissions reduction can also be achieved with zero nuclear power if the RE/CCS electricity share can be increased to 35% combined with a reduction of TFC by 25% from 2010 level.

Larger GHG emissions reductions require higher levels of low-carbon energy supply and energy savings (Figure 13(c-d)). Figure 13(c) indicates that a 30% reduction of GHG emissions can be achieved with e.g. a 15% nuclear power share, a 35% RE/CCS electricity share, a 22% TFC reduction, and a gas power ratio of 0.6. The 35% RE/CCS electricity share will require high policy effort levels when compared to the results from MOE (2015). Without nuclear power, a roughly 40% RE/CCS electricity share and a 30% reduction of TFC from 2010 levels would be required. One scenario from the DDPP study achieves GHG emissions reductions of more than 30% by increasing the RE/CCS electricity share beyond 45% (SDSN & IDDRI 2014) but these scenarios assume large-scale CCS deployment by 2030. A 40% reduction of GHG emissions will unlikely be achieved without a large nuclear power share of e.g. 25%.

Figure 13 also shows the importance of the gas power ratio upon setting energy and climate targets. For a given GHG emissions reduction target, increasing the gas power ratio from 0.4 to 0.6 can reduce the renewable electricity share requirement by about 3-9%-points depending on the TFC reduction level.

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[18] The values reflect different views on the optimal fossil fuel-fired electricity mix envisioned by MOE and METI upon the formulation of the Innovative Strategy. A gas power ratio of 0.6 is representative of the values observed in the MOE report (MOE 2012a), which put emphasis on GHG emissions reductions. A gas power ratio of 0.4 is representative of the values observed in the METI report (METI 2012), which put emphasis on energy security and economical energy supply.

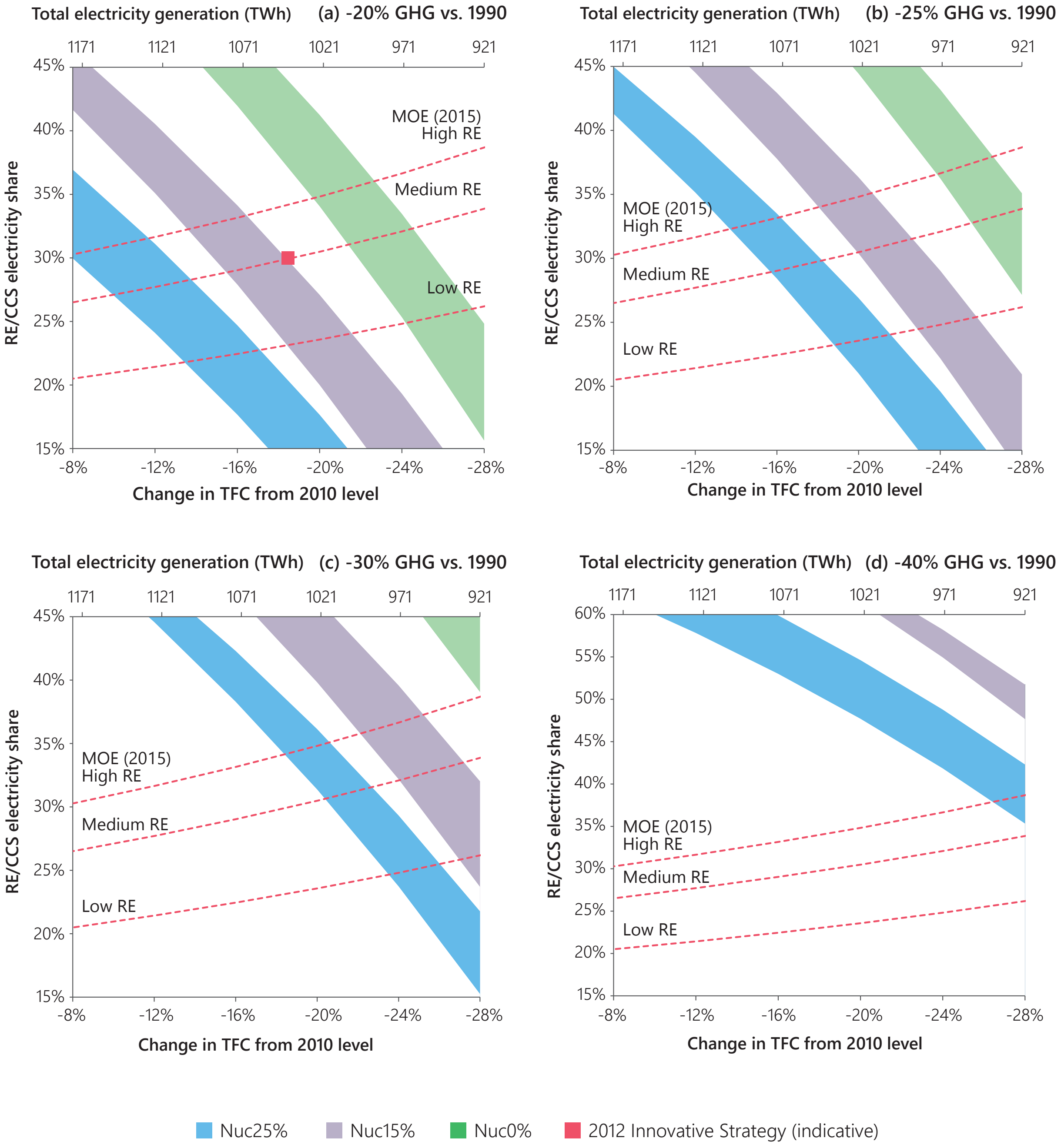

Figure 13: Required renewable electricity and CCS-equipped (RE/CCS) electricity shares and total final consumption (TFC) levels to achieve GHG emissions reductions of (a) 20% (b) 25% (c) 30% and (d) 40% from 1990 levels by 2030, respectively, for different nuclear power shares represented by coloured areas. The share of electricity in TFC is assumed to be 28%. The width of coloured areas represent the range of gas-fired power shares in total unabated fossil fuel-fired power generation (0.4-0.6). For reference, the renewable electricity shares calculated from a recent potential assessment study (MOE 2015) and the indicative data point for the 2012 Innovative Strategy (about 20% reduction from 1990 levels with a nuclear phase-out during 2030s) are also presented.

4.2.3 Sensitivity analysis

The results presented in Figure 13 assumed a 28% electricity share in TFC. There are, however, studies that project significantly higher shares (Takase & Suzuki 2011; Homma & Akimoto 2013) as well as significantly lower shares (e.g. MOE (2012a); IEEJ (2013b)). Figure 14 presents the Influence of the electricity share in total final consumption (TFC) on the required renewable electricity shares for achieving 20% GHG emissions reductions by 2030. The results were found to be fairly robust for the range of electricity shares in TFC considered in this study.

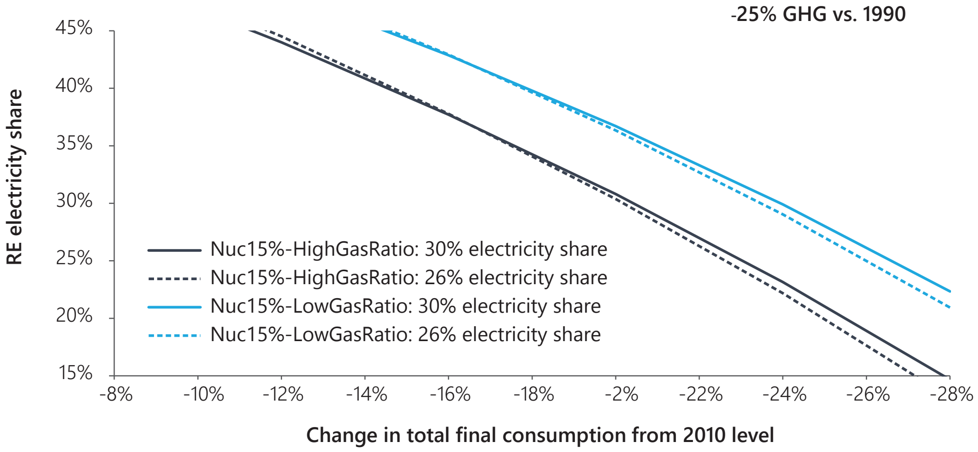

Figure 14: Influence of the electricity share in total final consumption (TFC) on the required renewable electricity shares for achieving 25% GHG emissions reductions by 2030.

4.3 Policy implications of the results

This section discusses the level of Japan's GHG emissions reductions required in the global efforts to achieve the 2°C target. The results of Analysis A have indicated a 16-39% reduction from 1990 levels for high mitigation effort levels, including those consistent with the 2°C target. Moreover, the results of Analysis B showed that for a 15% nuclear power share, a probable level if the government continues to support the restart of existing reactors, a 25% reduction of GHG emissions from 1990 levels can be achieved with medium policy effort levels for RE deployment if a 20% reduction of TFC from 2010 level can be achieved. The 25% GHG emissions reduction was also found to be achievable with the RE/CCS electricity share that can be realized with high policy effort levels and a 25% reduction of TFC, which is similar to the reduction rate observed for 1970-1990 and can be achieved by reducing TFC per capita by 0.9%/yr after 2013. If the government is determined to restart most of the restartable nuclear reactors, a 25% reduction from 1990 levels may be considered the minimum mitigation level required in the global efforts to achieve the 2°C target. A 30% reduction of GHG emissions may also be achievable, but such a mitigation level may require a national consensus that a large number of nuclear reactors can be restarted. For further emissions reductions beyond a 25% reduction, Japan may want to use emission credits acquired from other countries through international market mechanisms.

Moreover, the gas power ratio that can be achieved in 2030 can be affected by the recent plans on new coal-fired power plants construction. The Analysis B found that when the gas power ratio decreases from 60% to 40%, the share of RE/CCS electricity would need to be increased by 3-9 %-points to offset the increased emissions. However, as of April 2015 there are coal-fired power plant construction plans for a total 21.2 GW (Kiko Network 2015). Assuming an 80% capacity utilisation factor, these plants would generate about 150 TWh or roughly 15% of total electricity generation in 2030. It is also likely that these plants will be in operation up to 2050. If Japan is to stay on track for the long-term decarbonisation of its economy consistent with the global 2°C target, these coal power plant construction plans need to be scrutinised.

In addition, the lenient Warsaw Target for 2020 may have a significant negative impact on the reductions of TFC toward 2030 and beyond. The Warsaw Target assumes that TFC in 2020 remains unchanged from the 2010 level (GoJ 2013). This means that the TFC per capita increases by 3% between 2012 and 2020. Figure 15 presents future pathways for a 15% and 25% reduction of TFC for two action cases. Immediate action pathways assumes a linear reduction of TFC, whereas delayed action pathways adhere to the TFC level indicated for the Warsaw Target for 2020. The impact of delayed action is particularly significant if Japan is to reduce its TFC by 25% from 2010 levels by 2030; the annual compound average reduction rate for 2020-2030 increases from 0.9%/yr to 1.8%/yr.

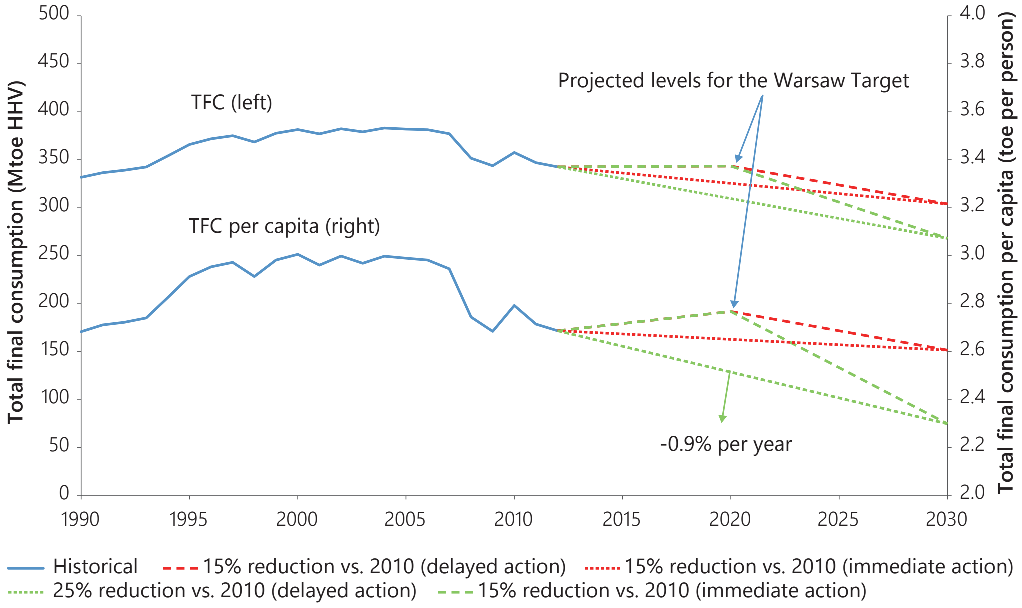

Figure 15: Future pathways for the reduction of total final consumption (TFC) and TFC per capita. Immediate action pathways assume a linear reduction of TFC, whereas delayed action pathways adhere to the TFC level indicated for the Warsaw Target for 2020. The projections for future population were taken from the National Institute of Population and Social Security Research (IPSS 2012) for the calculation of TFC per capita.

4.4 Methodological limitations

There are a number of methodological limitations. With regard to the analytical framework, one limitation relates to the coverage of the literature. There are several other studies published on Japan's GHG emission reduction potential for 2030 that do not meet the selection criteria described in Section 3.1 (e.g. WWF Japan 2011a; WWF Japan 2011b; WWF Japan 2013a; WWF Japan 2013b; Utagawa et al. 2015). Some of these studies have been reviewed by Asuka et al. (2015), which found that there were several bottom-up analyses demonstrating that GHG emissions reduction of more than 40% from 1990 levels is achievable by 2030. The literature selection criteria applied in this study may have unintentionally excluded scenarios that are scientifically robust and feasible from technical, economic and political perspectives. Moreover, most of the 48 scenarios compared in this study are (co-) authored by one of two research institutes: NIES and IEEJ. While the regression equation also fitted well with the GHG emissions data of the scenarios from other studies and the statistical analysis results showed that no significant bias was caused, it is recommended to add more scenarios to the analysis whenever sufficient data are available to improve the robustness of the analysis.

It should also be noted that this study did not discuss the economic implications for different mitigation effort levels. While economic implications were out of our research scope, economic assessment results are often considered as one of the most important indicators for formulating national GHG emissions reduction targets. However, the case of the Innovative Strategy indicates that the economic costs for a given GHG mitigation level can vary significantly across studies. In 2012, four research institutions calculated the marginal abatement costs (MACs) for Japan to reduce its GHG emissions by 20%-25% from 1990 levels by 2030 under different shares of nuclear power in total electricity generation (NPU 2012). For nuclear power share between zero and 25%, the calculated MACs for non-power sectors ranged between JPY_{2010} 3629 – 56183/t-CO_2 ($\text{US\$}_{2010}$ 41 – 640/t-CO_2) depending on the research institution. Therefore, future work needs to be conducted relationship between the GHG emissions reduction levels and the associated economic costs observed across studies.

With regard to the categorisation of scenarios by their mitigation effort levels in Analysis A, Level 4 covered a wide range of mitigation effort levels by itself. The three criteria set for Level 4 are not always comparable because the first criterion on the 2°C target is top-down in nature whereas the third criterion on the maximum deployment of advanced technologies is bottom-up in nature. Moreover, none of the scenarios compared in this study considered emissions allowances consistent with the 2°C target based on equity indicators as discussed in, e.g. Höhne et al. (2014). In addition, for the first criterion, not all studies necessarily mean the same when they indicate that their scenarios are "consistent with the 2°C target". Furthermore, on the third criterion, "maximum deployment" may be calculated based on different assumptions on, e.g. payback time, consideration of regulatory measures, and the grid capacity for the acceptance of intermittent renewable electricity. These assumptions, however, could not be examined due to lack of information.

There are a number of limitations also on Analysis B. First, the regression analysis conducted in this study aimed to describe Japan's GHG emissions reductions in 2030 with only a few energy-related explanatory variables that are of political interest. The emissions calculated from the derived regression equation fitted the data well, indicating that the five explanatory variables are sufficient to predict the GHG emissions with high accuracy at least for the scenarios compared. However, there are also many other factors that are important to consider when discussing GHG mitigation levels, e.g. deployment of non-electricity renewable energy and macroeconomic activity levels that underlie the TFC. While the impacts of these factors on GHG emissions as a whole are represented by the coefficients $a_1 - a_5$,[19] in-depth discussions on the 2030 mitigation target may require to single out the impacts of these factors.

The second limitation relates to the potential explanatory variables such as the production levels of industrial sectors which were not investigated in this study. For example, one of the major criticisms following the formulation of the Innovative Strategy was that the production levels of carbon-intensive industries such as the iron and steel industry and the petrochemical industry were overestimated (Kuramochi & Asuka 2012). For example, studies commissioned by the government (MOE 2012a; IEEJ 2013b) assumed an ethylene production of 5.3-6.9 Mt in 2030, depending on GDP growth rates, but ethylene producers themselves are preparing for the reduced production level below 5 Mt by 2020 due to declining competitiveness in the export markets (Mitsubishi Chemical Holdings 2012) and a recent report by METI (2014c) projected that the production level may decline to 3.1 Mt by 2030. The overestimation of future production levels have also been pointed out for the iron and steel industry (e.g., Kuramochi & Asuka 2012). Moreover, the use of recycled materials such as steel scrap in the iron and steel industry may be underestimated (Kuramochi 2015a). Therefore, many of the scenarios reviewed in this study may be overestimating both the energy intensity per GDP and as the baseline GHG emissions, consequently underestimating the GHG emissions reduction potential. This study, however, could not examine the impact of future industrial growth assumptions on the GHG emissions due to lack of data.

Third, it should be noted that the regression equation derived in this study is only valid for 2030. Although there are calls for all Parties to make mitigation commitments for 2025 in the post-2020 climate agreement (e.g. Morgan et al. 2015), there was not enough data to conduct the assessment for 2025. The analysis conducted in this study implicitly assumed that technology levels, e.g. energy efficiency of appliances and energy conversion efficiency of power plants, are similar across all studies. For years earlier than 2030, for example, an extra TWh of renewable electricity may further reduce GHG emissions because the efficiencies of fossil fuel-fired power plants are lower.

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19 For example, the impacts of non-electricity renewable energy deployment on GHG emissions are partly reflected in the coefficient a_2, whereas the impacts of economic activity levels are largely reflected in the coefficients a_4 and a_5.

05

Conclusions

This study conducted a comparative assessment of 48 GHG emissions scenarios (excluding LULUCF) up to 2030 reported in seven bottom-up studies published between 2011 and 2015 that conducted detailed bottom-up assessments of technology deployment potentials for all sectors taking into account foreseeable policy measures.

Analysis A found that for the scenarios that are categorised to be consistent with the 2°C target (Level 4 scenarios), GHG emissions levels ranged between 16-39% below 1990 levels with the nuclear power shares ranging between 0-29%. The observed wide range is also attributable to the differences in assumptions and projections on the RE/CCS electricity share (27-47%), the reduction level of energy end-use (12-28% from 2010 levels), which is partly influenced by the future economic growth rates, as well as the electrification rate (26-30%). In contrast, for the scenarios that took account of the continuation of existing and currently planned policy measures (Level 2), the GHG emissions reductions ranged between 3-20% below 1990 levels. Another important finding is that the share of unabated coal-fired electricity was found to be less than 21% for all scenarios with GHG emissions reductions of more than 20% from 1990 levels.

The results of Analysis B calculated the levels of low-carbon energy supply and end-use energy savings required to achieve different levels of GHG emissions reduction in 2030 based on the regression equation derived from the data of the 48 mitigation scenarios. The results found that for a 15% nuclear power share, a 25% reduction of GHG emissions from 1990 levels can be achieved e.g. with a 30% RE/CCS electricity share, which can be achieved with medium policy effort levels, a 20% reduction of TFC from 2010 level and a 60% gas power ratio. Moreover, the 25% GHG emissions reduction can also be achieved without nuclear power by increasing the RE/CCS electricity share to 35%, which can be achieved by high policy effort levels, and strengthening the TFC reduction to 25%. From Analyses A and B, it can be concluded that by taking into account the government's plan to restart most of the existing nuclear reactors as well as the RE electricity deployment potential, the GHG emissions reductions of more than 25% from 1990 levels (32% from 2005 levels) may be considered the minimum mitigation effort level required in the global efforts to achieve the 2°C target.

In addition, Analysis B has found that when the gas power ratio decreases from 60% to 40%, the share of RE/CCS electricity would need to be increased by 3-9 %-points to offset the increased emissions. The choice of fuel for fossil fuel-fired electricity generation is, therefore, as equally important as the share of renewable electricity generation. The recent plans on new coal-fired power plants construction should be scrutinised if Japan is to stay on track for the long-term decarbonisation of its economy that is consistent with the global 2°C target.

The feasibility of TFC reduction toward 2030 was also discussed in comparison with Japan's 2020 mitigation target ("Warsaw Target"). The underlying information for the Warsaw Target indicates that the TFC per capita, which decreased by about 10% between 2005 and 2012, would again turn back to an increasing trend toward 2020. In order to achieve the reduction levels for 2030 indicated above, enhanced pre-2020 efforts to reduce energy use in end-use sectors are essential.

Acknowledgements

The authors thank Juan-Carlos Altamirano, Jenna Blumenthal, Thomas Damassa, and Taryn Fransen (WRI) for their feedback and editing that helped shape this paper. The authors also thank Markus Hagemann (NewClimate Institute, Germany); Jusen Asuka (Tohoku University, Japan); Junichi Fujino (National Institute for Environmental Studies, Japan); Shuzo Nishioka and Kentaro Tamura (IGES) for their valuable comments on earlier drafts of the report. The authors would also like to thank Manabu Utagawa (National Institute of Advanced Industrial Science and Technology, Japan) for his advice of the treatment of Japan's energy statistics and Ken Oshiro (Mizuho Information and Research Institute) for data provision. The authors also thank Emma Fushimi (IGES) and Mamiko Tomita for their editorial and design work.

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Appendix A: Details of the studies and scenarios considered in the analysis

Source	Approach/ Model	GHGs and sectors	Scenario name	GDP growth and Population	Description/
IEA (2014b)	Bottom up approach (Econometric analysis is used to determine the share of technologies based upon their specific costs	Energy related CO_2	Current Policies scenario (CPS)	GDP growth rate: 1.1% Population: 115 million in 2040	"Takes into account only those policies and measures affecting energy markets that were formally enacted as of mid-2013."
			New Policies scenario (NPS)		"In addition to CPS, it also takes account of other relevant commitments that have been announced, even when the precise implementation measures have yet to be fully defined."
			450 scenario		"This scenario shows what is needed to set the global energy sector on a course compatible with a near 50% chance of limiting the long-term increase in the average global temperature to two degrees Celsius (2 °C)." Carbon pricing of around 100$/t-$CO_2$ assumed (as shadow price).
MOE (2012a)	Bottom up approach	6 gases from all sectors excluding LULUCF	Moderate economic growth scenarios 1-3 with 4 options for nuclear power energy share (0%, 15%, 20%, 25%)	GDP growth rate: 1.1% for 2010-20, 0.8% for 2020-30. Population: 97 million in 2050	**Low effort on Energy efficiency, Renewable energy level:** Continue current policies and implement policies under the development
					Middle effort on Energy efficiency, Renewable energy level: To promote low carbon technologies and products that can be implemented at "reasonable cost
					High effort on Energy efficiency, Renewable energy level: To implement all possible low carbon technologies and product as long as those can bring social benefit regarding resource efficiency and energy security
			Economic growth scenarios 1-3 with 4 options for nuclear power energy share (0%, 15%, 20%, 25%)	GDP growth rate: 1.8% for 2010-20, 1.2% for 2020-30 Population: 97 million in 2050	**Low effort on Energy efficiency, Renewable energy level:** Continue current policies and implement policies under the development
					Middle effort on Energy efficiency, Renewable energy level: To promote low carbon technologies and products that can be implemented at "reasonable cost"
					High effort on Energy efficiency, Renewable energy level: To implement all possible low carbon technologies and product as long as those can bring social benefit regarding resource efficiency and energy security

Technologies considered			
Power	Industry	Transport	Buildings
- Support for renewables generation	- Mandatory energy efficiency benchmarking - Tax credit for investments in energy efficiency -Energy management for large business operators - Top runner programme setting minimum energy standards	- Fuel-economy target for PLDVs: 16.8 km/l by 2015 and 20.3km/l by 2020 - average fuel-economy target for road freight vehicles: 7.09 km/l by 2015 - Fiscal incentives for hybrid and electric vehicles	Energy efficiency standards for building and houses (300m^2 or more)
- Lifetime of nuclear plants typically amounting to 40 years	- Higher efficiency CHP systems - Promotion of state-of-the-art technology and faster replacement of aging equipment	Target share of next generation vehicles 50% by 2020	- Net zero-energy buildings by 2030 - Gas and renewable energy - high-efficiency lighting
- Share of low-carbon electricity generation to increase by 2020 and expand further by 2030 - Introduction of CCS to coal-fired power generation - expansion of renewables support	- Enhanced energy efficiency standards - Policies to support the introduction of CCS in industry	- Fuel on-road emission target for PLDVs, light commercial vehicles and medium and heavy freight vehicles - Aviation: 55% efficiency improvement by 2040	- Net zero-carbon footprint for - High-efficiency lighting for non-public buildings
See "Description"	- Green procurement, - GHG reporting, - Top runner - Carbon disclosure	- Eco driving - Research on biofuel - Car sharing	- Top runner system - HEMS, BEMS
See "Description"	- Carbon disclosure - Carbon tax - Green investment	- Eco driving with ICT - Promotion of biofuel - Car sharing	- Energy efficiency standard - Labeling
See "Description"	- GHG supply chain management - Setting emission target	- Eco driving with ICT - Promotion of biofuel - Modal shift - Car sharing	- Energy efficiency - Green investment
See "Description"	- Green procurement, - GHG reporting, - Top runner - Carbon disclosure	- Eco driving - Research on biofuel - Car sharing	- Top runner system - HEMS, BEMS
See "Description"	- Carbon disclosure - Carbon tax - Green investment	- Eco driving with ICT - Promotion of biofuel - Car sharing	- Energy efficiency standard - Labeling
See "Description"	- GHG supply chain management - Setting emission target	- Eco driving with ICT - Promotion of biofuel - Modal shift - Car sharing	- Energy efficiency - Green investment

Source	Approach/ Model	GHGs and sectors	Scenario name	GDP growth and Population	Description/
IEEJ (2013b)	Bottom up approach (CGE analysis is conducted using the result from bottom up analysis)	Energy related CO_2	Economic growth scenarios 1-3	GDP growth rate: 1.8% for 2010-20, 1.2% for 2020-30 Population 116 million in 2030.	Nuclear power 15%, RE 30% in 2030 (Choice 15%)
					Nuclear power 20%, RE 30% in 2030 (Choice C)
					Nuclear power 25%, RE 25% in 2030 (Choice D)
			Moderate economic growth scenario 1-4	GDP growth rate: 1.1% for 2010-20, 0.8% for 2020-30. Population 116 million in 2030.	Nuclear power 0%, RE 35% in 2030 (Choice B)
					Nuclear power 15%, RE 30% in 2030 (Choice 15%)
					Nuclear power 20%, RE 30% in 2030 (Choice C)
					Nuclear power 25%, RE 25% in 2030 (Choice D)
			New moderate economic growth scenario1-3	GDP growth rate: 0.2 % for 2010-20, 0.4% during 2020-30 Population 116 million in 2030.	Nuclear power 15%, RE 30% in 2030 (Choice 15%)
					Nuclear power 20% in 2030 (Choice C)
					Nuclear power 25% in 2030 (Choice D)
SDSN and IDDRI (2014)	Bottom up approach	Energy related CO_2	Decarbonization pathway	GDP growth rate: 1.1% Population: 97 million in 2050.	The gradual phase-out of nuclear but it still represents 19% of electricity generation in 2030 and 5% in 2050.
			Decarbonization pathway without nuclear power		The additional deployment of renewable energy and natural gas equipped with CCS.
			Decarbonization pathway with s deployment of CCS:		The share of renewable energy in electricity supply reaches approximately 85% in 2050 and intermittent renewable energies account for about 63% in electricity generation in 2050
Takase and Suzuki (2011)	Bottom up approach	Energy related CO_2	BAU scenario	N.A.	Assuming that existing policies continue with three options for nuclear power generation capacity (BAU, Minimum Nuclear and Maximum Nuclear)
			National alternative scenario		Aggressive application of energy efficiency and renewable energy measures with two options for nuclear power generation (Minimum Nuclear and Maximum Nuclear)
IEEJ (2014)	Bottom up approach	Energy related CO_2	Reference scenario	GDP growth rate: 1.44% Population 121 million in 2030	Only traditional and conventional policies are incorporate in to the Scenario. Any aggressive energy conservation or low carbon policies will not be adopted.
			Advanced Technology Scenario		The world are assumed to implement strongly energy and environment polices.
IEEJ (2015)	Bottom up approach	Energy related CO_2	Nuclear 0% scenario	GDP growth rate: 0.97% Population: N.A.	No nuclear power plant will operate.
			Nuclear 15% scenario	GDP growth rate: 1% Population: N.A.	Only nuclear power plants that are satisfied with the standard will operate. The life time period is 40years.
			Nuclear 25% scenario	GDP growth rate: 1.01% Population: N.A.	Only nuclear power plants that are satisfied with the standard will operate. The life time period is 60 years.
			Nuclear 30% scenario	GDP growth rate: 1.02% Population: N.A.	Only nuclear power plants that are satisfied with the standard will operate. The life time period is 60 years. Load factor is 90%.

Technologies considered			
Power	Industry	Transport	Buildings
Not specifically mentioned	Not specifically mentioned	Not specifically mentioned	Not specifically mentioned
RE, Nuclear, Energy efficiency, CCS (implemented from 2020), Demand response, Reinforcement of electricity interconnection	Energy efficiency, Fuel Switching, CCS (implemented from 2020)	Reduction of a passenger total mobility, a combination of energy efficiency, electrification of the fleet as well as hydrogen and small diffusion of gas fueled vehicles	Electrification and energy efficiency
RE, Nuclear, Energy efficiency	N.A.	N.A.	N.A.
BAU technologies	BAU technologies	BAU technologies	BAU technologies
RE, Nuclear, High efficient coal fire plant, CCS	Use of BAT	Highly fuel efficient vehicle. EV, FCV, Plug in hybrid	Efficient electrical appliances, Efficient lighting, Heat insulation.
Share of renewables in power sector : 26%	Energy efficiency	PV, FCV	High efficient electrical appliances, LED, BEMS, heat insulation
Share of renewables in power sector : 22%			
Share of renewables in power sector : 19%			
Share of renewables in power sector : 14%			

Appendix B: Estimation of non-energy related GHG emissions

The estimation of non-energy related GHG emissions is based on two studies (SDSN & IDDRI 2014; MOE 2012a), the data of which showed a linear relationship between the emissions and TFC (Figure A-1). In case of no data, non-energy related GHG emissions (EMGHG,NEN,2030: Mt-CO_2e/yr) are calculated as:

$EM_{GHG,NEN,2030}$= 0.5 (t-CO_2e/toe) *TFC_{2030} (Mtoe/yr) (Eq. A-1)

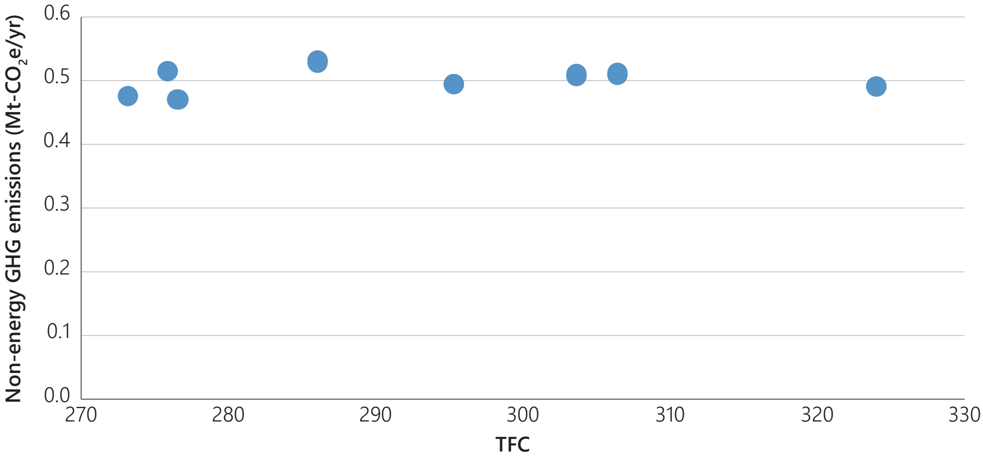

Figure A-1: GHG emissions other than energy-related CO_2 emissions as a function of total final consumption (TFC) in 2030. Source: SDSN & IDDRI (2014) and MOE (2012a).

Appendix C: Derivation of the simplified equation for estimating energy-related CO_2 emissions

$EM_{GHG,tot}=EM_{CO2,EN}+EM_{GHG,NEN}=EM_{CO2,FC}+EM_{CO2,EL}+EM_{GHG,NEN}$ (Eq. A-2)

where:

$EM_{CO2,EN}$: Energy-related CO_2 emissions (Mt-CO_2/yr)

$EM_{GHG,NEN}$: Non-energy related GHG emissions (Mt-CO_2e/yr).

$EM_{CO2,FC}$: CO_2 emissions from fuel consumption in end-use sectors including conversion losses in the transformation sector (Mt-CO_2/yr);

$EM_{CO2,EL}$: CO_2 emissions from electricity generation including autoproducers (Mt-CO_2/yr);

If we assumed that the CO_2 emissions from the power sector is influenced mainly by the total unabated fossil fuel-fired power generation and the share of gas-fired power generation, EMCO_2,EL can be expressed as follows:

$EM_{CO2,EL}$={(TFC*$f_{EL,BM}$+ΔEL_{tot})-$RECCS$-NUC}*$EF_{ELF,BM}$+ΔGP*($EF_{EL,GP}$ - $EF_{EL,HC}$) (Eq. A-3)

where:

TFC: Total final consumption (Mtoe)

$f_{EL,BM}$: Conversion factor to calculate benchmark total electricity generation from *TFC* (TWh/Mtoe)

ΔEL_{tot}: Electricity generation additional to benchmark levels estimated from *TFC* (TWh, including autoproducers)

RE/CCS: Total renewable electricity and CCS-equipped electricity generation (TWh, including autoproducers)

NUC: Nuclear electricity generation (TWh, including autoproducers)

$EF_{ELF,BM}$: Average CO_2 emission factor for a benchmark mix of unabated fossil fuel-fired electricity generation (kt-CO_2/TWh)

ΔGP: Unabated gas-fired power generation additional to benchmark levels (TWh, including autoproducers)

$EF_{EL,GP}$: CO_2 emission factor for unabated gas-fired power generation (kt-CO_2/TWh)

$EF_{EL,HG}$: CO_2 emission factor for unabated power generation from high-carbon fuels (kt-CO_2/TWh)

If we assume that the composition of fuel consumption in the end-use sectors is similar across scenarios and that the CO_2 emissions reductions through enhanced renewable fuel and heat use is proportional to renewable electricity generation, EMCO_2,FC can be expressed as follows:

$$EM_{\mathbf{CO2,FC}}=\{TFC-(TFC*f_{\mathbf{EL,BM}}+\Delta EL_{\mathbf{tot}})*c\}*EF_{F,BM}-RECCS*d$$
(Eq. A-4)

where:
c: Conversion factor to calculate end-use electricity consumption from total power generation including transmission and distribution losses (Mtoe/TWh)

$EF_{F,BM}$: Average CO_2 emission factor for fuel use in the end-use sectors including losses in the transformation sector (t-CO_2/toe)

d: Specific CO_2 emissions reduction through enhanced renewable fuel and heat use induced by the increased renewable electricity generation (kt-CO_2/TWh)

Therefore,

$$EM_{CO2,EN}=\{TFC-(TFC*f_{EL,BM}+\Delta EL_{tot})*c\}*EF_{F,BM}-RECCS*d$$
$$+\{(TFC*f_{EL,BM})+\Delta EL_{tot})-RECCS-NUC\}*EF_{ELF,BM})$$
$$+\Delta GP*(EF_{EL,GP}-EF_{EL,HC})$$
(Eq. A-5)

Thus,

$$EM_{CO2,EN}=TFC*(EF_{F,BM}-f_{EL,BM}*EF_{F,BM}+f_{EL,BM}*EF_{ELF,BM})$$
$$-RECCS*(d+EF_{EGFF,BM})-NUC*EF_{EGFF,BM}-\Delta EG_{tot}*$$
$$(c*EF_{F,BM}+EF_{EGFF,BM})-\Delta EG_{NG}*(EF_{EG,GP}-EF_{EG,HC})$$
(Eq. A-6)

Hence,

$a_1 = EF_{F,BM}-f_{EL,BM}*EF_{F,BM}+f_{EL,BM}*EF_{ELF,BM}$

$a_2 = d+EF_{EGFF,BM}$

$a_3 = EF_{EGFF,BM}$

$a_4 = c*EF_{F,BM}+EF_{EGFF,BM}$

$a_5 = EF_{EG,GP}-EF_{EG,HC}$

Appendix D: Detailed results of the multiple regression analysis

Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
nuclearpower	48	163.602	91.86968	0	353
re_ccs	48	310.9873	64.73729	203.3	540.5
deltagas	48	39.3634	64.47504	-146	218.4594
tfc	48	298.23	19.66149	256.7038	330.4035
deltaelec	48	108.9971	63.86962	45.24953	435.7346
netenergyco2	48	838.7505	123.0115	637.8	1226.625

Regression analysis

(standard errors adjusted for 7 clusters by literature source)

Number of obs	48
F (5, 6)	40516.98
Prob > F	0
R-squared	0.9998
Root MSE	13.718

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
nuclearpower	-0.59272	0.028352	-20.91	<0.001	-0.66209	-0.52334
re_ccs	-0.6303	0.017423	-36.18	<0.001	-0.67293	-0.58766
deltagas	-0.36361	0.062797	-5.79	0.001	-0.51727	-0.20995
tfc	3.719231	0.029715	125.16	<0.001	3.646521	3.79194
deltaelec	0.338088	0.039719	8.51	<0.001	0.2409	0.435276

Correlation among explanatory variables

	nuclearpower	re_ccs	deltagas	tfc	deltaelec
nuclearpower	1				
re_ccs	-0.1747	1			
deltagas	-0.2691	0.2164	1		
tfc	0.0543	-0.497	-0.3474	1	
deltaelec	0.1069	0.0172	-0.5	0.3437	1

Descriptive statistics

Figure A-2 compares the GHG emissions in 2030 (as a change from 1990 levels) as reported for the 48 scenarios and the predicted GHG emissions based on the multiple regression equation using the five explanatory variables reported for 48 scenarios. The reported values and the predictions using the regression equation were found to match up well.

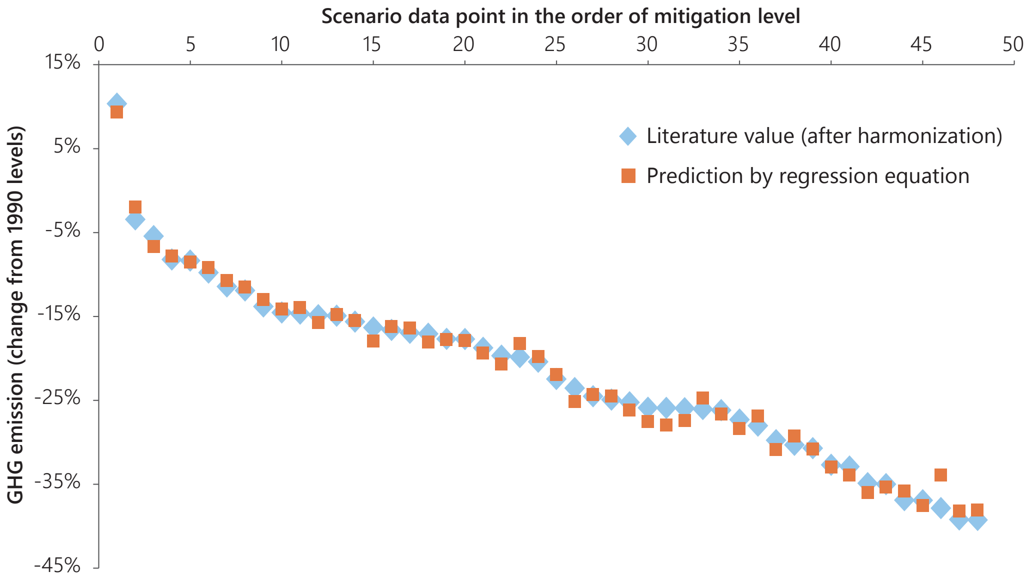

Figure A-2: Comparison of GHG emissions in 2030 (change from 1990 levels) reported in the literature and the predictions based on the multiple regression equation.

About IGES

The Institute for Global Environmental Strategies (IGES), established under an initiative of the Government of Japan in 1998, is an international research institute conducting practical and innovative research for realizing sustainable development in the Asia-Pacific region. IGES research focuses on three issues of critical importance: climate change, natural resource management, and sustainable consumption and production. IGES also serves as the secretariat for various international initiatives and research networks, actively contributing to policy formulation in the form of information sharing and policy proposals.

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The Open Climate Network (OCN) brings together independent research institutes and stakeholder groups to monitor countries' progress on climate change. We seek to accelerate the transition to a low-emission, climate-resilient future by providing consistent, credible information that enhances accountability both between and within countries. http://www.openclimatenetwork.org

This paper is part of an OCN initiative to inform the post-2020 GHG mitigation goals in Intended Nationally Determined Contributions under the United Nations Framework Convention on Climate Change. The OCN Secretariat, based at the World Resources Institute, is managing this multi-country effort. For more information regarding OCN and/or this initiative, contact openclimate@wri.org

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IGES Publication Code WP1502
