Energy Policy ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

An economic and environmental assessment of future electricity generation mixes in Japan – an assessment using the E3MG macro-econometric model

Hector Pollitt [a,*], Park Seung-Joon [b], Lee Soocheol [c], Kazuhiro Ueta [d]

[a] Cambridge Econometrics, Covent Garden, Cambridge CB1 2HT, UK
[b] School of Policy Studies, Kwansei Gakuin University, Japan
[c] Faculty of Economics, Meijo University, Japan
[d] Graduate School of Global Environmental Studies & Graduate School of Economics, Kyoto University, Japan

HIGHLIGHTS

- We modelled 12 scenarios for Japan with different shares for nuclear power and different emission targets.
- The results showed that phasing out nuclear power would have at most a very small reduction in GDP.
- If a carbon tax with revenue recycling is applied, there could be an increase in GDP.
- But the carbon price required to meet Japan's 25% emission reduction target is very high if the share of nuclear power is reduced.

ARTICLE INFO

Article history:
Received 12 September 2013
Received in revised form
3 December 2013
Accepted 10 December 2013

Keywords:
Nuclear
Macroeconomic modelling
Japan

ABSTRACT

In this paper we consider future options for Japanese energy and climate policy. We assess the economic and environmental impacts of changing the share of electricity generated by nuclear power and varying the mid-term GHG targets. The quantitative approach we use is based on the global macro-econometric E3MG model.

Our analysis reveals that the cost of denuclearisation to Japanese GDP is close to zero, and for employment the impact is slightly positive. Our results also show a double-dividend effect if (revenue-neutral) carbon taxes are levied in order to meet the GHG reduction targets, and this double-dividend effect is largest in the scenarios without nuclear power. However, our analysis suggests that a very high carbon tax rate would have to be imposed in order to achieve a 25% reduction in GHG emissions in 2020 (compared to 1990 levels) while simultaneously phasing out nuclear power.

1. Introduction

This paper uses the global macro-econometric model E3MG to analyse the economic and environmental impacts of the three options for the share of nuclear power in electricity generation in 2030 proposed in the report *Options for Energy and the Environment* (hereafter referred to as *Options*) published in June 2012. We consider the impacts of the three options in the context of three possible mid-term targets for reducing greenhouse-gas (GHG) emissions (0%, −15% and −25% by 2020 compared to the 1990 level); and we also analyse the contribution of Environmental Tax Reform (ETR) to achieving these targets. The main aim of the analysis is to determine the costs for the Japanese economy arising from denuclearisation, ETR or a combination of both.

The Fukushima–Daiichi Nuclear Power Accident (the Fukushima Accident) of March 2011 made Japanese citizens aware of the dangers of nuclear power plants (NPPs). The Democratic Party of Japan (DPJ), which was then in government, had to respond to the public demand for denuclearisation, and so it reviewed the *Basic Energy Plan*. The *Options* report published in June 2012 proposed three options for the share of NPP in power generation in 2030 (0%, 15%, and 20%–25%). All three options were lower than the 45% share of NPP in 2030[1] that was envisaged in the most recent (June 2010) version of the *Basic Energy Plan*. After public discussion based on the *Options* report the *Innovative Energy and Environment Policy*, which declares "to implement all conceivable policy resources to enable zero NPP in the 2030s", was published in September 2012. Nevertheless, nuclear policy was not seen as a priority in the Lower House Election in December 2012 and the Upper House Election in July 2013; and this election resulted in

* Corresponding author. Tel.: +44 1223 533100.
E-mail address: hp@camecon.com (H.-n. Pollitt).

[1] See The Energy and Environment Council (2012b).

0301-4215/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2013.12.018

victory for the Liberal Democratic Party (LDP), which had previously promoted Japanese nuclear power. There is still much discussion about the direction of future energy policy and nuclear power in Japan.

When it comes to assessing the effects of denuclearisation on the Japanese economy, there are two opposing views. The first is that reducing the share of NPP in the energy mix will lead to higher costs and be harmful to the economy, while the second emphasises the potential beneficial effects of the promotion of renewable energies and energy conservation. Four institutes have carried out model-based analyses of the three options for reducing the NPP share and have found that a lower NPP share leads to a slightly worse economic performance and a small increase in electricity prices. These results are discussed in Section 3.

At the same time it is recognised that policy measures will be required to reduce GHG emissions. On this subject, the existing research shows that ETR, a policy that recycles the revenue from additional carbon/energy taxation by reducing other taxes in a revenue-neutral way, could have favourable impacts on economic indicators such as employment (see Section 4). However, as energy use in Japan is already quite efficient, the scope for emission reductions outside the power sector may be quite limited (Akimoto et al., 2010).

This paper analyses the possible effects of denuclearisation and ETR on Japan's economy and GHG emissions levels, and the interaction between the two policies. We apply the global macro-econometric model E3MG (Energy–Environment–Economy Model at the Global level), which is quite different to the CGE models that were used for the previous analysis (see Section 5). We use the scenario assumptions of *Options* as reference data so that our results can be compared with previous analyses.

Section 2 discusses the policy context in which this study has been carried out. Section 3 describes the three options in further detail, including the findings from previous analyses. In Section 4 we discuss ETR and the concept of the double dividend, and we introduce the E3MG model in Section 5. Sections 6 and 7 describe the scenarios that we assessed and present the results from the modelling exercise. Section 8 presents our conclusions.

The appendices contain further information about the assumptions that were used in forming the scenarios and about the E3MG model.

2. Review of energy policy after the Fukushima accident

The Fukushima Accident not only heightened concerns about the safety of NPP, but also raised doubts about its economic benefits. After Fukushima it became widely understood that NPP is not necessarily cheap if the risk of catastrophic accidents and its associated costs are taken into account. The report of the governmental Cost Estimation and Review Committee, published in December 2011, showed the generation cost of NPP to be at least 8.9 yen/kWh (taking into account the assumed costs of damage caused by a nuclear accident), compared to 9.5 yen/kWh for coal or 10.7 yen/kWh for gas (Cost Estimation and Review Committee, 2011; Matsuo, 2012). The report provides very important background material for this paper.

It is important to note that the marginal generation cost of existing NPP is very low, because the generation cost of NPP consists mainly of construction cost (sunk cost), while the risk of accidents or the associated costs of the policy are externalised[2]. This largely explains the considerable concern that, if generation were switched from NPP to combustion power plants, the costs of imported fuels would reduce the profits of power companies; and if the government were to permit the power companies to raise prices, this would impose additional burdens on companies and households, and perhaps lead to an economic downturn.

The former Prime Minister Kan Naoto, who was in charge of the response to the Fukushima Accident, announced that Japan would "break away from dependence on nuclear power"; and Parliament passed the Feed-in Tariff Law for Renewable Electric Energy in summer 2011. After the resignation of Kan Naoto, Noda Yoshihiko, who became Prime Minister in September 2011, set up the Energy and Environment Council in October 2011, under the National Policy Unit, which is chaired by the Prime Minister. The Council started the discussion of Japan's future energy policy, with a view to bring about substantial reductions in nuclear generation by 2030.

In June 2012 the Energy and Environment Council published its conclusions *Options for Energy and the Environment* (*Options*)[3]. This proposed for public discussion three options for the share of NPP in electricity generation in 2030 (0%, 15%, and 20%–25%). As background information, *Options* includes estimates of the potential impacts on electricity prices, real GDP and GHG emissions, as well as estimates of investment costs for renewable energies and energy conservation. These estimates were based on a modelling exercise, discussed in Section 3.

In July and August 2012 the Energy and Environment Council canvassed public opinion by holding public hearings, inviting public comments, and conducting a deliberative poll. The conclusion of the public discussions was that the zero-NPP scenario had the strongest support. Therefore, a policy plan based on the zero-NPP scenario was drawn up and published in September 2012 as the *Innovative Strategy for Energy and the Environment* (the *Strategy*)[4]. The *Strategy* sets out three principles for achieving the goal of zero NPP by 2030:

(1) The 40 years lifetime rule will be stringently applied.
(2) Only those nuclear power plants whose safety has been verified by the Nuclear Regulation Authority will be permitted to operate.
(3) No construction of new nuclear power plants will be permitted.

Faced by strong opposition to the zero-NPP policy from business groups, including Nihon Keidanren, the former government did not adopt the *Strategy* in Cabinet meeting.

Another consequence of the Fukushima Accident is that it has now become very difficult, or so it is widely believed, to achieve the de-facto official target of reducing GHG emissions by 25% of their 1990 level by 2020. The policies to achieve this target, set out in 2009 by the former Prime Minister Hatoyama Yukio, depended heavily on nuclear generation. The *Strategy* recognises this in the statement, "although the uncertainty of NPP operation means that we can only provide a range-estimate, under certain assumptions GHG emissions in 2020 will be between 5% and 9% below the 1990 level", instead of 25%. Duscha et al. (2013) suggests that Japan's emission reduction costs would increase by more than any other country's if nuclear power was phased out and, in November 2013, the Japanese government announced that it was effectively replacing the 25% GHG reduction target with a 3.1% increase target for 2020, based on a nuclear power share of zero (although this could be revised again).

[2] After deduction of capital cost the unit cost of NPP is 6.4 yen/kWh (Energy and Environment Council (2012b, p. 14). Fuel costs of Japanese NPP are about 1.0 yen/kWh including back-end costs for the direct disposal of spent nuclear fuels (Cost Estimation and Review Committee, 2011, p. 39).

[3] See Energy and Environment Council (2012a, 2012b).

[4] See Energy and Environment Council (2012c).

The current government, formed after the elections of December 2012, has not yet put forward any concrete plan for future energy policy. We therefore take the *Options* report published under the former administration as the primary background for our analysis.

3. The three options of the energy and environment council

The *Options* report included model simulation results provided by four research institutes for the scenarios with NPP shares of 0%, 15% and 20%–25%. These are very important reference materials for this paper. The four institutes are the National Institute for Environmental Studies (NIES), Osaka University (Prof. Ban Kanemi), Keio University (Prof. Nomura Koji) and the Research Institute of Innovative Technology for the Earth[5] (RITE).

Each institute was asked to use common assumptions about the composition of electricity generation or renewable energies, and to tune its model in line with the assumptions shown in Table 1, so as to make the simulation results as comparable as possible (Ban, 2013). It should be noted that some of the underlying assumptions of the options have been questioned and alternative scenarios have been suggested (see Homma and Akimoto (2013), McLellan et al. (2013), Zhang et al. (2012)). However, in order to draw comparisons (and as these scenarios are still the official ones) we use the same common assumptions.

In the business as usual (BAU) case the fuel mix used for electricity generation remains almost unchanged from the structure before 11th March 2011; and no additional energy conservation effort beyond the current trend is assumed. As is shown in Table 1, the level of electricity generation is largely unchanged in the scenarios, and the largest differences between the scenarios are the shares of nuclear power, fossil fuel combustion plants and renewable plants.

The *Strategy* did not propose concrete policies for promoting the uptake of renewables. However, the Feed-In Tariff Law for Renewable Electric Energy, that was passed in summer 2011 and implemented in summer 2012, had achieved fairly good results by the end of 2012. Consequently, it seems likely that this policy will play an important role in promoting renewables in Japan up to 2030. The law obliges power companies to buy up all the electricity generated by renewable power plants at a price set by the government and allows them to pass the additional cost to consumers as a surcharge. The system therefore promotes investment in renewable power sources by private funds by guaranteeing a market to which they can sell power. Costs for renewables are passed on to the consumers in their electricity bills.

Table 2 shows the three scenarios as presented in the *Options* report, but with details provided by the four institutes, about the electricity generation shares and estimates of economic indicators and CO_2 emissions. The table shows the economic effects as the difference between the scenario results and the business as usual case (BAU). However, as the *Options* report does not explicitly set out the BAU, and as the choice between the three options is of the greatest importance for our analysis, we focus on the differences between the scenario results in our analysis.

The difference between the BAU and the three scenarios relates mainly to the CO_2 emission constraints. The three scenarios restrict CO_2 emissions and increase the shares of renewables, with the result that electricity prices are higher and the level of real GDP is lower (Ban, 2013, p. 39). In every analysis the highest electricity prices and the lowest levels of GDP are seen in the zero-NPP scenario, although it should be noted that the difference between the scenarios is not large.

Table 1
Assumptions for tuning the economic models (in 2030).
Source: Ban (2013, p. 38) and Table 2, edited by authors of the present paper.

	2010	2030 (scenarios)				
		BAU	0%	15%	20%	25%
Electricity generated (trn kWh)	1.100	1.124	1.101	1.132	1.133	1.135
NPP share	26%	24%	0%	15%	20%	25%
Share of combustion power	63%	65%	62%	54%	48%	48%
Coal	24%	26%	20%	20%	17%	17%
LNG	29%	32%	37%	29%	26%	26%
Oil	10%	7%	6%	5%	5%	5%
Renewable energy share	10%	10%	38%	31%	31%	26%
Solar	–	0%	8%	7%	7%	6%
Wind	–	0%	10%	7%	7%	4%
Hydropower and geothermal	–	9%	16%	14%	14%	14%
Biomass	–	1%	4%	3%	3%	3%
CO_2 emission ($MtCO_2$)	–	999	836	825	795	789

Note: The 20% and 25% cases are combined in the later tables and in our analysis.

Table 3 shows the differences (in levels and rates of annual increase over 2010–20) in electricity prices in each of the three scenarios. The media reaction to the published results suggested that the zero-NPP option could double electricity prices (e.g. from 10 thousand yen to 20 thousand yen per month). In fact, there is not much difference between the three scenarios, mostly because the price of electricity rises in all cases. The rate of increase of electricity prices over 2010–30 was found to be between 1.7% and 3.8% per annum in the zero-NPP scenario.

Table 4 shows the differences in results for real GDP in the scenarios. Professor Ban, who led the analysis conducted by the University of Osaka, reported that “interestingly, when we compare the 0% NPP scenario and 25% NPP scenario, except for the result of RITE, the difference of NPP share does not result in a major difference in GDP outcome”… “that is, even if we choose the 0% NPP scenario, the difference between this and the 25% NPP scenario in 2030 is merely 6 trillion yen (ca. 67 bn. USD, ca 49 bn. EUR)” (Ban, 2013, p. 39). The difference between the three scenarios in terms of the annual growth rate of GDP is close to negligible.

4. The GHG restriction and the double dividend of environmental tax reform

As discussed extensively in Hong et al. (2013), a shift away from nuclear power could have a wide range of environmental and social consequences. After the Fukushima Accident, the immediate switch in generation from NPP to combustion power plants raised levels of CO_2 emissions in Japan. This led to the suggestion that the mid-term target of GHG emission levels (-25% by 2020 compared to 1990) would be very difficult to achieve (see e.g. Homma and Akimoto (2013) for a model-based assessment). This was recognised officially at the Warsaw 2013 COP when the revised emissions reduction target was announced.

However, climate policy measures are not limited to nuclear power and renewables. Another important policy tool is carbon pricing. Standard economic theory treats GHG emissions as a problem of externality, i.e. a societal (environmental) cost that is not reflected in the price of using energy or polluting. But by raising the prices of coal, oil or gas so as to include the environmental cost, it is possible to internalise this cost within the economic system. Although in practice it is not possible to estimate the true cost of GHG emissions, a carbon pricing

[5] Further details of the analysis by RITE may be found in Homma and Akimoto (2013).

Please cite this article as: Pollitt, H., et al., An economic and environmental assessment of future electricity generation mixes in Japan – an assessment using the E3MG macro-econometric model. Energy Policy (2014), http://dx.doi.org/10.1016/j.enpol.2013.12.018

Table 2
Summary of Scenario Results (from the *Options* report).
Source: The Energy and Environment Council (2012b), edited by authors.

	2010	2030			
		0% NPP		15% NPP	20%–25% NPP
		Before additional measures	After additional measures		
Composition of electricity generation					
NPP share	26%	0% (−25%)	0% (−25%)	15% (−10%)	20%–25% (−5%–1%)
Renewables	10%	30% (+20%)	35% (+25%)	30% (+20%)	30%–25% (+20%–+15%)
Combustion	63%	70% (+5%)	65% (+0%)	55% (−10%)	50% (−15%)
Coal	24%	28% (+4%)	21% (−3%)	20% (−4%)	18% (−6%)
LNG	29%	36% (+7%)	38% (+9%)	29% (+0%)	27% (−2%)
Oil	10%	6% (−4%)	6% (−4%)	5% (−5%)	5% (−5%)
Energy conservation					
Electricity generation	1.1 trn kWh	1.0 trn kWh	1.0 trn kWh	1.0 trn kWh	1.0 trn kWh
End energy consumption	0.39 bn kL	0.31 bn kL	0.30 bn kL	0.31 bn kL	0.31 bn kL
NPP					
Dependence on NPP	26%	0% (−25%)	0% (−25%)	15% (−10%)	20%–25% (−5%–1%)
Energy security					
Dependence on fossil fuels	63%	70% (+5%)	65% (+0%)	55% (−10%)	50% (−15%)
Imported fuel values (total primary energy supply)	17 trn yen	17 trn yen Promoting stronger shift to gas	16 trn yen	16 trn yen	15 trn yen
Climate policy					
Renewable energy share	10%	30% (+20%)	35% (+25%)	30% (+20%)	30%–25% (+20%–+15%)
Non–fossil energy share	37%	30% (−5%)	35% (+0%)	45% (+10%)	50% (+15%)
Coal to gas in combustion power plants including CHP	1:1.2	1:1.3	1:1.8	1:1.5	1:1.5
GHG emission					
2030	–	−16%	−23%	−23%	−25%
2020	–	+0% (0%NPP), −5% (14% NPP)	−0% (0% NPP) −7% (14%NPP)	−9% (21% NPP)	−10%–11% (23–26% NPP)
Generation costs (yen/kWh)	8.6	–	15.1 (+6.5)	14.1 (+5.5)	14.1 (+5.5)
Transmission investment (trn yen, accumulated to 2030)	–	3.4	5.2	3.4	3.4–2.7
Energy saving investment (trn yen, accumulated to 2030)	–	80 (saving 60)	100 (saving 70)	80 (saving 60)	80 (saving 60)
Household electricity price in 2030 (10 thousand yen/month)					
NIES	1.0	–	1.4	1.4	1.4
Osaka Univ.		–	1.5	1.4	1.2
Keio Univ.		–	2.1	1.8	1.8
RITE		–	2.0	1.8	1.8
Real GDP in 2030 (trn yen)					
NIES	511	636(2030 BAU)	628	634	634
Osaka Univ.		624(2030 BAU)	608	611	614
Keio Univ.		625(2030 BAU)	609	616	617
RITE		609(2030 BAU)	564	579	581

Note 1: values in Tables 1 and 2 are from different sources and are not fully consistent.
Note 2: the exchange rate was 90.90 JPY/USD and 122.33 JPY/EUR on 27th January 2013.
Note 3: the numbers in the parenthesis indicate difference from reference case.

mechanism could still give an incentive for emissions to be reduced in a way that is economically efficient. In the EU, for example, the Emissions Trading System (EU-ETS) for combustion power plants and heavy industry is already active and (despite some problems in operation) sets a single EU-wide carbon price.

Carbon pricing is also possible by the use of carbon taxation. In Japan and many other countries, it is generally believed that the revenues from carbon taxes should be used to provide subsidies for climate policy measures. Nevertheless, the idea of revenue-neutral Environmental Tax Reform (ETR) is also worth considering. If the revenue from a carbon tax is “recycled” (put back into the economy) as a reduction in existing tax rates, such as income tax, corporation tax or social security contributions on labour payments, there is not an increase in the overall national tax burden. Furthermore, if the tax that is reduced has a distorting effect on the economy, its reduction could lead to an improvement in real GDP or employment. This is described as the “double dividend of environmental tax reform”, where the first dividend is better environmental quality and the second dividend is better economic performance[6]. This effect is worth examining.

In the published version of the analyses carried out by the four institutes, Footnote 4 of the original version of Table 2 indicates that the figures “*reflect both price increases and electricity saving. In the economic modelling, the economic burden of the energy saving is described as a carbon tax, and therefore the energy price includes this carbon tax. The electricity price in the table also reflects the carbon tax*”. However, in the modelling, the method of revenue recycling was not explicitly explained. It seems that the four institutes did not use the revenues from the carbon tax to reduce other tax rates but instead provided a 'lump sum' to each Japanese household. This approach misses the opportunity to reduce distortions caused

[6] For a deeper analysis of the mechanism of the double dividend, see UNESCAP (2012).

Table 3
Electricity prices in 2030 and the annual rate of increase.
Source: Table 2, own calculation by authors.

	Change in electricity prices (2030, 10 thousand yen per month)			Increase in electricity prices (% per year)		
	0% NPP	15% NPP	25% NPP (%)	0% NPP (%)	15% NPP (%)	25% NPP (%)
NIES	0	0	0	1.7	1.7	1.7
Osaka Univ.	+0.3	+0.2	0	2.0	1.7	0.9
Keio Univ.	+0.3	0	0	3.8	3.0	3.0
RITE	+0.2	0	0	3.5	3.0	3.0

Table 4
The gap between levels of real GDP in 2030 and the annual growth rate.
Source: Table 2, own calculation of the authors.

	The gap of real GDP (2030, trillion yen)			Annual growth rate (% per year)		
	0% NPP	15% NPP	25% NPP	0% NPP (%)	15% NPP (%)	25% NPP (%)
NIES	−6	0	0	1.04	1.08	1.08
Osaka Univ.	−6	−3	0	0.87	0.90	0.92
Keio Univ.	−8	−1	0	0.88	0.94	0.95
RITE	−17	−2	0	0.49	0.63	0.64

by the tax system and as a result cannot produce a double dividend effect.

It is therefore important to note that the economic outcomes are heavily dependent on the form of revenue recycling used. The revenue recycling through reduction of existing distortionary taxes could possibly result in a double dividend, but the lump-sum recycling will not lead to better economic performance. This is discussed further in Barker et al. (2009), and a comprehensive global review of existing revenue recycling policies is provided in Cambridge Econometrics (2013).

The interaction between nuclear and climate policy makes the modelling scenarios quite complex to set up and interpret. Nevertheless, the four institutes achieved this in their analyses. It is therefore appropriate to include the mid-term GHG reduction target explicitly in the scenarios, in order to compare our results with the previous results under the same conditions.

The E3MG model and its European equivalent (E3ME) have been used extensively to conduct a number of analyses of carbon pricing policy (both EU-ETS and ETR) in Europe and globally, and have contributed to important discussions of the double dividend (see e.g. Andersen and Ekins, 2009; Ekins and Speck, 2011). E3MG has also previously been applied to assess Japanese climate policy (see Lee et al., 2012); and it is hoped that the current paper will make an important contribution to energy and climate policy in Asia.

5. Analysis with the E3MG model

In this paper we apply the E3MG model (Energy–Environment–Economy Model at the Global level) developed by Cambridge Econometrics and the University of Cambridge. The choice of model is important, because the theory underlying the E3MG model is different from the theory used in the modelling carried out previously by the four institutes. We explain the differences by comparing the key features of E3MG to the modelling used by the four institutes. More details about E3MG are provided in Appendix B.

The four institutes assessed the three options through a scenario analysis using neo-classical Computable General Equilibrium (CGE) models. In general, CGE models assume full price adjustment and equilibrium in all markets, including the labour market. That is, there will be no (involuntary) unemployment. Therefore, the results tend to be determined by the supply-side conditions such as resource availability and labour supply. In other words, it follows from the modelling assumptions that the models yield no demand-side effects of policy change on consumption or private investment and consequently there are no positive effects on economic performance or employment[7] in the model results.

In contrast, the E3MG model is post-Keynesian in nature. It is a macro-econometric model based on the theory of effective demand in which there may be available and unused resources in the economy. A boost to investment demand could therefore lead to higher levels of economic activity and employment, including supply chain and multiplier effects.

As the Japanese economy is still in a long-term slump, often called “the two lost decades”, it is clear that there may be spare capacity in the economy and thus it is possible that investment in new electricity infrastructure could have a positive economic impact. As far as we know, this possibility has not yet been tested, because the previous CGE model-based analysis ruled it out by assumption. By using the E3MG model, in this paper, we can quantify the possibility of positive impacts of investment in infrastructure.

There are some other advantages of using the E3MG model. In the scenarios with GHG emission constraints, there is the possibility of the double dividend, as described previously. To analyse this requires a quite detailed modelling of the tax system including not only carbon taxes but also income tax, consumption taxes, social security contributions and so on. Furthermore, in today′s globally interacting economic context, the effects of denuclearisation and ETR on Japan′s economy will also be to some extent determined through changes in the competitive conditions of firms and changes in import and export volumes. A global model can capture some effects that might otherwise be missed by the analysis.

In summary, while there are other models available that could carry out this analysis, our view is that E3MG is a tool that is particularly well suited. It is a multi-national, multi-sectoral, macro-econometric model that is based on the principle of effective demand and which allows a relatively detailed treatment of the tax system. As the previous analysis of the three options for future nuclear power was carried out using a quite different modelling approach, we hope that the results from our analysis will contribute helpfully to the ongoing policy debate.

In Sections 6 and 7 we clarify the scenario assumptions and explain the results. Further details of the E3MG model are provided in Appendix B.

6. Description of the scenarios

As in the analyses conducted by the four institutes, our approach is scenario-based. We consider 12 scenarios in total (see Table 5). They are defined in terms of share of nuclear in the power generation mix by 2030 (0%, 15% or 25%) and different reductions in CO_2 emissions (in 2020, compared to 1990 levels).

[7] There are also some CGE models which assume the rigidity of price and non-equilibrium in some markets such as the labour market, but our general description of CGE models is applicable to the analyses of the three options, as they do not focus on the issue of unemployment.

Please cite this article as: Pollitt, H., et al., An economic and environmental assessment of future electricity generation mixes in Japan – an assessment using the E3MG macro-econometric model. Energy Policy (2014), http://dx.doi.org/10.1016/j.enpol.2013.12.018

Table 5
Description of scenarios.

	Carbon target, 2020 compared to 1990 levels			
	No carbon target	−10%	−15%	−25%
Nuclear share 25% in 2030	N25Cn	N25C10	N25C15	N25C25
Nuclear share 15% in 2030	N15Cn	N15C10	N15C15	N15C25
Nuclear share 0% in 2030	N00Cn	N00C10	N00C15	N00C25

The scenario with a 25% nuclear share and no carbon targets being met is the reference scenario for the analysis.

In other aspects, the reference scenario is broadly consistent with the economic and energy projections presented in the 2012 version of *World Energy Outlook* (International Energy Agency, 2012). The figures in International Energy Agency (2012) suggest that nuclear power will account for 20% of electricity generation in 2030, and the IEA current policies scenario lies somewhere between scenarios N25Cn and N15Cn. We have used the results from the current policies scenario, translated so that they are consistent with the classifications used in the E3MG model.

The period for analysis is 2013–2030 (18 years). The model inputs for the scenarios can be summarised as

- The power generation mix.
- The target for carbon reductions.
- Investment requirements in the power sector.
- The impact on electricity costs.
- The method of revenue recycling for carbon revenues.

These are described in more detail in Appendix A but may be summarised as follows. The power generation mix and carbon targets follow the scenario definitions shown in Table 5.[8], and the required investment and electricity costs are obtained from the costs in Table 2 (taken from The Energy and Environment Council, 2012). As energy consumption in the power sector is set exogenously, we assume that the carbon tax is applied only to non-power sectors, such as businesses and households, and increased linearly in nominal terms so that the 2020 target is met. After 2020 the rate for the carbon tax is increased by 5% per annum, broadly in line with the baseline assumptions about fuel prices and, due to lagged effects, there are some further reductions in emissions. The revenues generated by the carbon tax are offset by reducing standard income tax rates.

7. Results

The model results suggest that the choice of fuel mix used in the power sector could have quite a large impact on total Japanese CO_2 emissions in the period up to 2020 (and indeed 2030). It is clear that, in the absence of other policy, a lower share of nuclear in the energy mix will lead to higher emissions levels (see N15Cn and N00Cn in Table 6).

If a cap is set on total Japanese emissions levels, then we apply a carbon tax in all economic sectors, other than the power sector, to give them an incentive to reduce emissions. If the power sector emits more CO_2 due to increased combustion of fossil fuels, then other sectors have to reduce emissions further, and so the carbon tax rate must be higher. Table 6 shows the carbon tax rates that are required in each of the scenarios to achieve the target reduction in total emissions by 2020.

[8] See Table A1 in the appendix for the detailed generation shares. In general, the reductions in nuclear generation are replaced by a combination of higher gas and renewable generation.

Table 6
Environmental outcomes in the scenarios.
Sources: E3MG, Cambridge Econometrics.

	Nuclear share in 2030 (%)	CO_2 emissions in 2020 compared to 1990 (%)	Carbon tax rate (yen / t−CO_2) in 2020
N25Cn	25	−3.8	0
N15Cn	10	−2.7	0
N00Cn	0	−1.1	0
N25C10	25	−10.0	5582
N15C10	10	−10.0	7462
N00C10	0	−10.0	9285
N25C15	25	−15.0	14,773
N15C15	10	−15.0	17,292
N00C15	0	−15.0	20,262
N25C25	25	−25.0	45,034
N15C25	10	−25.0	49,801
N00C25	0	−25.0	56,838

Note: results are for energy CO_2 emissions. Carbon tax rates are in 2010 prices.

Table 7
Macroeconomic impacts of reducing the share of nuclear power (2030, % difference from N25Cn).
Sources: E3MG, Cambridge Econometrics.

	N15Cn (15% share)	N00Cn (0% share)
GDP	0.00	−0.04
Employment	0.01	0.07
Consumption	0.00	−0.38
Investment	0.10	1.47
Exports	0.00	−0.01
Imports	0.08	0.43
Price level	0.00	0.33
CO_2 emissions	2.65	6.42

It is clear from the results under the 'Cn' scenarios that, all other things being equal, a reduction in nuclear power and an increase in gas power will lead to higher carbon emissions. The magnitude of the effect is quite substantial, some 2.7 percentage points between N25Cn and N00Cn in 2020. The difference in 2030 between the scenarios (not shown in the table) is almost double the size. However, in all three cases the emission targets (even the −10% target) cannot be achieved without other policies.

In all the scenarios it is therefore necessary to force the other sectors to make a contribution towards meeting the emissions target. This is represented by the carbon tax rate. It shows that a quite modest carbon tax is required to meet the −10% target, but this tax rate becomes much higher when a −25% target is set. In the scenario N00C25, the carbon tax rate will reach 56,838 yen/tCO_2 (ca. 435 euro/t-CO_2).

The main economic impacts of the scenarios arise from

- Changes in consumption and imports of fossil fuels.
- Changes in electricity prices.
- Investment in new power plants (see Appendix A).
- The carbon tax rate required to meet the emissions targets (see above).
- The use of revenues from the carbon tax.

The overall impacts on GDP and other main economic indicators in the 'Cn' scenarios (where the carbon targets are not met) are shown in Table 7 (compared to N25Cn, all values are in real terms except for the price level). The combination of the factors outlined above leads to a slight decrease in GDP when there is a lower nuclear share. Employment is positively affected, with most of the increase in jobs occurring in investment sectors (see sectoral

Table 8
Macroeconomic impacts of meeting the climate targets (2030, % difference from N25Cn).
Sources: E3MG, Cambridge Econometrics.

	N25C10 (−10% target)	N25C15 (−15% target)	N25C25 (−25% target)
GDP	0.24	0.45	0.79
Employment	0.07	0.14	0.26
Consumption	0.34	0.67	1.20
Investment	0.05	0.10	0.18
Exports	−0.02	−0.05	−0.09
Imports	−0.03	−0.01	0.06
Price level	0.25	0.65	1.63
Carbon tax rate (yen/tCO_2)	5582	14,773	45,034

impacts below). This increase is due primarily to higher investment in building the new plants (mostly renewables). Overall there is an increase in fossil fuel imports. Higher electricity prices in N00Cn (12%) also lead to an increase in the overall price level, which, in turn, leads to a fall in real incomes and household consumption.

It should be noted, however, that the overall macroeconomic effects are small when the costs are spread across a period of 18 years.

Adding the carbon tax to non-power sectors has a negative impact on output from the fuel sectors and the sectors that are intensive users of fuels. However, the carbon pricing mechanism generates revenues for the Japanese government, which can be used to reduce income taxes. The combined effect of this Environmental Tax Reform is positive, as shown in Table 8. An increase in GDP of up to 0.8% (in 2030, compared to N25Cn) is possible. In this case, the higher the CO_2 reduction target, and therefore the required carbon tax rate and revenue from it, the higher the positive GDP impact from the double dividend. In summary, our analysis shows that a lower nuclear share does not noticeably affect GDP and a higher carbon target produces better results for GDP (see Fig. 1).

Looking at the other macroeconomic indicators, we see an increase in household incomes and spending from the income tax cuts. Investment increases but only very slightly, because the carbon tax principally falls on heavy industry (e.g. steel, cement) that accounts for a large share of investment goods[9]. There is also a slight fall in exports, due to competitiveness effects from the higher fuel prices; in the longer run some of the lost exports could be recovered if industry improves its efficiency. Although competitiveness effects also lead to higher import volumes, there is also a large reduction in imports of manufactured fuels, resulting in a very slight change in the overall level of imports.

There is a small increase in total employment, as a result of the increase in GDP. Consequently, there is a corresponding reduction in unemployment levels.

When there is a smaller share of nuclear in power generation, a larger part of the emissions target must be met by the other sectors and a higher carbon tax rate is applied (see Table 6). But this yields more revenues for recycling. As a consequence, all of the macroeconomic effects become larger (see Tables 9 and 10). When the nuclear share falls to zero, a higher carbon tax rate is needed, but economic performance will be improved because of the double dividend effect.

[9] If the revenue recycling were into investment subsidies or corporation tax reductions, rather than income tax reductions, this could potentially be reversed. This is suggested as a possible area for further investigation.

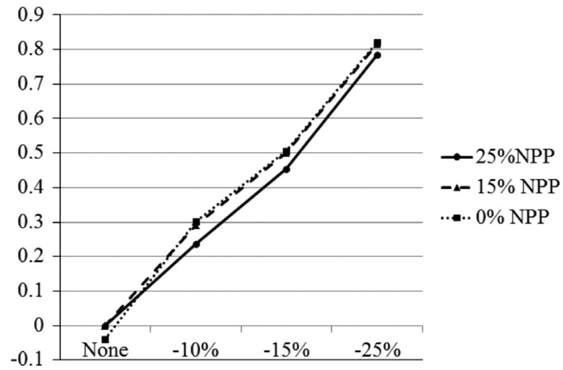

Fig. 1. Impacts on GDP in 2030 for each carbon target, % difference from N25Cn.
Source: E3MG, Cambridge Econometrics.

Table 9
Macroeconomic impacts of meeting the climate targets with reduced nuclear power (2030, % difference from N15Cn).
Sources: E3MG, Cambridge Econometrics.

	N15C10 (−10% target)	N15C15 (−15% target)	N15C25 (−25% target)
GDP	0.29	0.50	0.82
Employment	0.09	0.16	0.27
Consumption	0.43	0.75	1.25
Investment	0.06	0.11	0.18
Exports	−0.02	−0.05	−0.10
Imports	−0.02	0.00	0.06
Price level	0.33	0.73	1.79
Carbon tax rate(yen/tCO_2)	7462	17,292	49,801

Table 10
Macroeconomic impacts of meeting the climate targets with no nuclear power (2030, % difference from N00Cn).
Sources: E3MG, Cambridge Econometrics.

	N00C10 (−10% target)	N00C15 (−15% target)	N00C25 (−25% target)
GDP	0.34	0.55	0.86
Employment	0.11	0.18	0.29
Consumption	0.50	0.81	1.33
Investment	0.08	0.13	0.20
Exports	−0.04	−0.06	−0.12
Imports	−0.02	0.01	0.09
Price level	0.40	0.81	1.95
Carbon tax rate (yen/tCO_2)	9285	20,262	56,838

Table 11
Selected sectoral impacts (output, 2030).
Source: E3MG, Cambridge Econometrics.

N00Cn v N25Cn (denuclearisation)		N00C25 v N00Cn (high carbon price)	
Gas supply	8.3	Hotels & catering	6.5
Metal goods	3.2	Other business Services	3.9
Mech. engineering	3.1	Communications	3.8
Basic metals	0.9	Textiles & clothing	3.4
Electronics	0.4	Agriculture	2.5
Communications	−0.4	Electrical Engineering	0.2
Textiles & clothing	−0.4	Education	−0.2
Retailing	−0.4	Mech. engineering	−0.3
Other business services	−0.2	Basic metals	−0.6
Agriculture	−0.2	Gas supply	−14.6

At the sectoral level, it is typically the sectors that provide investment goods that benefit from a reduced share of nuclear in the energy mix (and also gas supply, see Table 11). This is not surprising as these are the sectors that would be most involved in building new renewable capacity and installing energy-efficient equipment. The sectors that lose out are those that rely on household demand; as households must spend a larger share of income on electricity, they have less to spend on other consumer goods.

The impacts are to some extent reversed in the scenarios with high carbon taxes and revenue recycling. Consumer sectors benefit from higher household spending (due to the lower income tax rates) but the energy-intensive sectors and those exposed to international competition may lose out. Clearly, this would be an important consideration in implementing ETR; and so there is a case for considering supplementary policies, such as Border Carbon Adjustments (see Park et al., 2012).

8. Conclusions

This paper assesses three scenarios for the share of nuclear power in electricity generation in Japan. The scenarios reflect the three 'Options' that were reported by Japan's Energy and Environment Council in 2012. The share of nuclear power in electricity generation is set at 0%, 15% and 25%[10] in 2030 in the three scenarios. As in the *Options* report, when the share of nuclear power falls, it is assumed to be replaced with a combination of natural gas and renewables plants, with only very small increases in coal and oil-fired plants. The result is higher electricity prices, as generators must recoup the costs of increased natural gas consumption and the construction of renewables plants.

The *Options* report contained estimates of the impacts of the three scenarios prepared by four Japanese research institutes using Computable General Equilibrium (CGE) macroeconomic models. These estimates showed that the scenario with zero nuclear power had the least favourable outcomes for GDP growth in Japan, but the differences between the scenarios were quite small (in most cases around 1%). However, the CGE models rely on economic assumptions about price adjustment that prevent them from assessing the effects of demand-side stimulus. Given the current economic situation in Japan, our view is that the assessment should include the possibility that spare capacity is available and consequently that higher demand could lead to increased rates of economic activity.

The macro-econometric model that we apply in the analysis, E3MG, allows for this possibility. In the scenarios that were modelled we find that higher electricity prices and higher gas imports have a depressing effect on GDP, but there are benefits to GDP from higher levels of investment. Although we still find a very small reduction in GDP (0.04%) when nuclear power is removed from the mix, if the share of nuclear is reduced from 25% to 15% the net impact is zero. Furthermore, as the construction of new renewable plants is a labour-intensive exercise, reducing nuclear power could lead to a small *increase* in employment (0.08%).

In our analysis we have tested a range of emissions reduction targets for 2020 under the different shares of nuclear power, using a revenue-neutral Environmental Tax Reform (ETR) on all non-power sectors to meet the targets. The model results show that a double-dividend from ETR is possible, with reductions in GHG emissions accompanied by increases in GDP ranging from 0.2% to 0.8% and some increases in employment. Again these model results reflect the fact that there is spare capacity in the Japanese economy and that diverting spending from fossil fuel imports to domestic production could lead to higher output.

However, the model results also show that the carbon tax rate needed to achieve the targets can rise quite substantially if the share of nuclear power is reduced. For example, the previous mid-term GHG reduction target (−25% from the 1990 level) would require a tax of more than 56,000 yen/t-CO_2 (around 435 euro/t-CO_2) if the nuclear share is zero. In political terms, this seems an unattainably high rate, especially when compared with the current Japanese carbon tax rate (about 300 yen/t-CO_2).

In summary, the results from the analysis find that denuclearisation does not necessarily have a cost to the Japanese economy. Setting and meeting more stringent GHG reduction targets could yield a small benefit, if well implemented. Our results also find an important interaction between the two policies that will need to be considered carefully by policy makers.

[10] This is our interpretation of the 20%–25% NPP share option.

Appendix A. Key assumptions in the scenarios

The power generation mix is given by assumption and is set as exogenous in the scenarios. The source for the information is The Energy and Environment Council (2012b), and all the following assumptions are set according to this source unless otherwise stated. Table A1 summarises the power generation mix under each scenario in 2030. As the total power generated is assumed to be 1000 TWh, we can obtain amounts generated by each power source category for each scenario as shown in Table A2. The values in parentheses stand for additional generation required.

Our estimate, based on a 40-year lifespan of existing plants, is that an additional 124 TWh of nuclear generation would be required in the 25% NPP scenario (we assume no additional construction of NPP for the 15% scenario), in line with the *Options* report. All the scenarios require additional renewable capacity but in the scenarios with high shares of nuclear power less generation is needed from renewables. For natural gas and other fossil fuels it is expected that enough existing capacity will remain in place, as no decommissioning is assumed. This assumption does not significantly affect our analysis, because we focus on differences between scenario results. However, in the 0% NPP scenario, an additional 60 TWh must be produced by natural gas.

The level of investment (defined as Gross Fixed Capital Formation) that must be made by the power sector is estimated using

Table A1
Power mix in the scenarios, % of generation, 2030.
Source: The Energy and Environment Council (2012b).

	25% NPP	15% NPP	0% NPP
Nuclear	25	15	0
Renewables	25	30	35
Coal	18	20	21
Gas	27	29	38
Oil	5	6	6

Table A2
Generation required in 2030 (additional to 2010 values) (TWh).
Source: The Energy and Environment Council (2012b).

	2010 value	25% NPP	15% NPP	0% NPP
Nuclear	*290*	250 (124[a])	150 (0)	0 (0)
Renewables	*110*	250 (140)	300 (190)	350 (240)
Natural gas	*320*	270 (0)	290 (0)	380 (60)
Other fossil fuels	*390*	230 (0)	260 (0)	270 (0)

[a] Based on 40-year lifetime of existing plants.

Please cite this article as: Pollitt, H., et al., An economic and environmental assessment of future electricity generation mixes in Japan – an assessment using the E3MG macro-econometric model. Energy Policy (2014), http://dx.doi.org/10.1016/j.enpol.2013.12.018

the unit capital costs [yen/kWh] for each type of plant that is built, multiplied by the amount of electricity generated from new power sources. It is important to note that this is a simplified approach to investment. In reality, the investment is lumpy and made up front before the plant becomes operational. However, under this approach it is not necessary to make assumptions about the level of borrowing that is made by the power sector. The key point to note from this approach is that in the period up to 2030 the investment costs and benefits are matched to prevent a bias in the modelling results. For example, if a new power plant were built in 2025, it would require a large investment in 2025 (with positive economic effects) that would need to be paid for through higher electricity prices in later years (say, 40 years, with negative economic effects). However, in the modelling we only include the share of the investment that is paid for via electricity production in the years up to 2030, thus balancing costs and benefits.

The main data source for estimating the investment cost of new plants is The Energy and Environment Council (2012b). It provides the following information:

Levelised costs for new plants, in yen/kWh for each technology.
Levelised costs for existing plants (in 2010).

The difference between these two figures is assumed to be the capital (investment) cost. The cost in 2010 is around 28 yen/kWh for solar, 10 yen/kWh for onshore wind and 2.4 yen/kWh for biomass.

However, The Energy and Environment Council (2012b) also shows that costs are expected to fall over time for wind power and, especially, for solar. Assuming that the reason for this is lower capital costs, we base our calculations on an average of the 2010 and 2030 costs. This means that the costs become around 16.5 yen/kWh and 9.8 yen/kWh for solar and wind, respectively.

For offshore wind there is no existing capacity, and so we assumed that the capital cost is the same as for onshore wind plus the expected cost differential between the two in 2020. This means that the entire cost difference between onshore and offshore wind is capital, giving offshore wind a capital cost of 12.9 yen/kWh. This falls only slightly in the period to 2030.

Some additional gas capacity is also required in the 0% NPP scenarios, as the share of gas generation increases to 38%. The investment cost is assumed to be 1.0 yen/kWh. Generation levels are lower in 2030 than in 2010 for all other fossil fuels. It is therefore assumed that no additional investment is required in these plant types; if some additional generation is required because some plants are retired, this is met by increasing load factors in existing plants. As mentioned above, however, this assumption does not have much impact on the results.

Some additional nuclear capacity is required for the 25%NPP case because existing plants are retired at the end of their 40-year lifespans. A rate of 2.5 yen/kWh is used to estimate the cost of this.

The share of each technology in the scenarios is also given in The Energy and Environment Council (2012b), for onshore wind and solar. It is assumed that the remaining share is split equally between offshore wind and biomass. These shares are converted into annual required generation (assuming the given total of 1 trillion kWh) and multiplied by the unit costs (shown in Table A3). In this way we can obtain annual investment in 2030 (Table A4).

Total investment in new plants over 2013–30 may be calculated from these results. In 2013 there is almost no generation from new renewables plants and so the investment required is low. But the investment increases linearly up to 2030; total investment over the period is therefore equal to the totals in Table A4 multiplied by 18 years and divided by 2 (e.g. for 0% NPP, 2685 [bill. yen/yr] × 18 [yr]/2 = 24.2 [tril. yen]). For new nuclear capacity, however, a separate calculation is carried out by estimating annual capacity retired under the 40 years lifetime rule (this comes to a total of 2.2 trillion yen). Figures for total investment are presented in Table A4.

Table A5 shows the investment on new power plants together with additional investment in power lines (3–5 trn yen) and energy efficiency (80–100 trn yen), based on the figures in The Energy and Environment Council (2012b). These investments are divided evenly over the period 2013–30 and added to the investment in the macroeconomic model. The impact on electricity prices is taken from the value in Table 2 in the main text (Generation Costs), for the sake of comparability to other calculations. We assume that this includes the costs of investment in new plants. We also allow electricity prices to rise further so as to recoup the investment in other energy infrastructure by sharing the cost across all purchasers of electricity over the period to 2030. The generation cost is 8.6 yen/kWh in 2010; it is 15.1 yen/kWh (+6.5 yen/kWh) in 2030 in the 0%NPP scenario, and 14.1 yen/kWh (+5.5 yen/kWh) in the 15%NPP and 25%NPP scenarios in 2030: a difference of only 1 yen/kWh. This is acceptable because the difference of 1 yen/kWh roughly corresponds to the gap of investment costs (0.56 or 0.64 yen/kWh) which can easily be obtained from the values (total) in Table A4 divided by 1000 TWh. Table A6 shows the unit generation costs, unit grid costs and efficiency costs to be added to the electricity price, by dividing the value in Table A5 by 18 TWh.

Table A3
Additional generation (TWh) and unit investment costs (2030).
Source: The Energy and Environment Council (2012b).

	25% NPP (TWh)	15% NPP (TWh)	0% NPP (TWh)	unit investment cost (yen/kWh)
Nuclear	124	0	0	2.5
Solar	62.8	62.8	68.3	16.5
Onshore wind	62.0	62.0	86.0	9.8
Offshore wind	7.6	32.6	42.85	12.9
Biomass	7.6	32.6	42.85	2.4
Natural gas	0	0	60	1.0
Total	264	190	300	

Table A4
Additional investment in the scenarios (2030).
Source: The Energy and Environment Council (2012b).

bn yen (2030)	25% NPP	15% NPP	0% NPP
Nuclear	310	0	0
Solar	1036	1036	1127
Onshore wind	608	608	843
Offshore wind	98	421	553
Biomass	18	78	103
Natural gas	0	0	60
Total	2070	2143	2685

Table A5
Additional investment in the scenarios (total over 2013 – 30).

	New plants	Power lines	Energy efficiency	Sum
25% NPP	18.0 trn yen (RE 15.8, NPP 2.2)	3.0 trn yen	80 trn yen	101.0 trn yen
15% NPP	19.3 trn yen	3.4 trn yen	80 trn yen	102.7 trn yen
0% NPP	24.2 trn yen	5.2 trn yen	100 trn yen	129.4 trn yen

Note: figures for new plants are authors' own calculations (see above). Figures for power lines and energy efficiency are essentially the same as those in Table 2 in the main text.

It should be noted that we do not assume an automatic 'crowding-out' effect and that the total level of investment could change in response to variations in trade and overall changes in output levels.

The change in energy mix provides information for emissions from the power sector, but the other sectors of the economy must take action if the carbon targets are to be met. This is modelled by applying a carbon tax to all other sectors of the economy, following the approach in Lee et al. (2012). The rate of the carbon tax is set to rise gradually over time, to ensure that the emissions target (interpreted as the level of CO_2 emissions in 2020 being a fixed proportion below the 1990 level) is met. After 2020 the carbon tax rate is increased by 5% per annum in nominal terms so that there is no rebound in emissions.

The revenues from the carbon tax are used to reduce direct income tax rates. This means that the scenarios are revenue-neutral, and represent a shift in taxation (from income to energy consumption) rather than an increase or decrease in the overall level of taxation.

The carbon tax does of course have an indirect impact on electricity demand, for example through fuel switching. We have factored this into our analysis by scaling total generation up or down in response, without changing the overall shares of each technology. The impacts on electricity demand are in fact quite small (up to 1%) and do not have a large influence on the scenario results.

Appendix B. The E3MG model

Introduction

This section briefly describes the E3MG model that was used to carry out the analysis. For further information about the model, the reader is referred to Barker et al. (2005) and the website www.e3mgmodel.com.

Table A6
Unit generation costs, grid costs and efficiency costs (yen/kWh).
Source: Authors' calculation.

	Generation costs (new plants)	Grid	Energy efficiency	Sum (Gap from 25%)
25% NPP	14.1 (2.07)	0.17	4.44	18.7 (–)
15% NPP	14.1 (2.15)	0.19	4.44	18.7 (+0.0)
0% NPP	15.1 (2.71)	0.29	5.56	21.0 (+2.2)

Note: generation costs are from Table 2, costs for new plants are calculated from Table A5. Carbon tax does not affect the electricity sector by assumption.

Basic model structure

The E3MG model (Energy–Environment–Economy Model at the Global level) is a computer-based tool constructed by international teams led by Cambridge Econometrics and the University of Cambridge. The model is econometric in design and is capable of addressing issues that link developments and policies in the areas of energy, the environment and the economy. The essential purpose of the model is to provide a framework for policy evaluation, particularly policies aimed at achieving sustainable energy use over the long term. However, the econometric specification that the model uses also allows for an assessment of short-term transition effects.

The current version of E3MG covers 22 world regions, although in this analysis we focus solely on Japan. The basic structure of E3MG is presented in Fig. 2. The model integrates energy demand and emissions with the economy; fuel demand is determined by prices and economic activity, with feedback through the energy supply sectors. Energy combustion results in greenhouse gas emissions.

The economic module in E3MG contains a full representation of the National Accounts, as formulated in Cambridge by Richard Stone, and formally presented in European Communities (2009). A key feature of E3MG is its sectoral disaggregation, with 42 economic sectors, linked by input–output relationships; this aspect is particularly important in modelling carbon taxes, because the different sectors use different fuels in varying degrees of intensity and have different technological options for changing consumption patterns.

E3MG's treatment of energy demand is largely top-down in nature. Econometric equations are estimated for aggregate energy demand and demand for the four main fuel types (coal, fuel oil, natural gas, and electricity). Energy demand, for 22 different user groups, is a function of economic activity, relative prices and measures of technology. The model solves all equations simultaneously and adjusts the individual fuels to sum to the total for each user. Feedbacks to the economy are provided by adjusting input–output coefficients and household energy demand.

The exception to this top-down treatment is in power generation, as the historical data do not provide the basis to estimate econometric equations in new technologies. However, for these scenarios we have fixed the power sector as exogenous, to accord with the scenarios as described in Section 6 above.

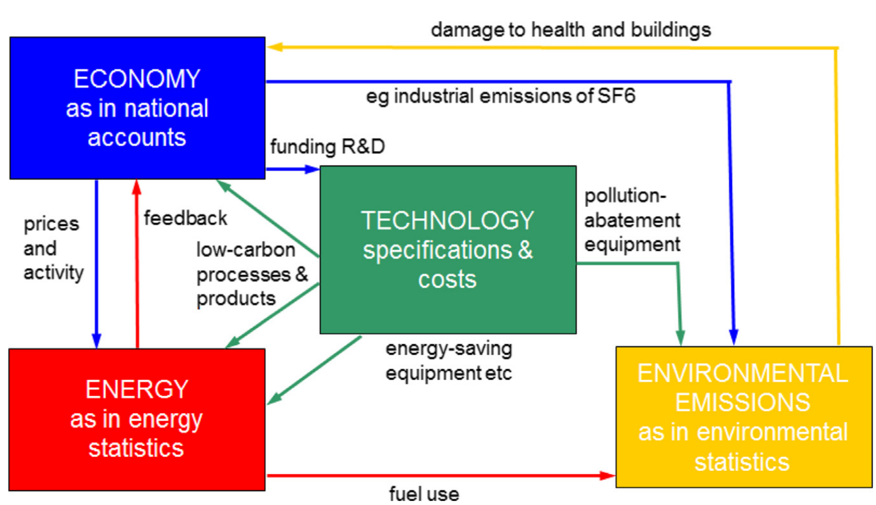

Fig. 2. E3 interactions within E3MG.

Emissions are estimated using a fixed coefficient to fuel demand. Non-energy emissions are included in the model so that global totals are met, but are treated as exogenous in this paper.

E3MG includes endogenous measures of sectoral technological progress. The indices used in the model are functions of accumulated capital, enhanced by R&D, an approach adapted from Lee et al. (1990). Endogenous technological progress is allowed to influence several of the model's equation sets, including energy demand, international trade, price formation and the labour market.

Data sources and model equations

As an econometric model with sectoral detail, E3MG requires extensive data inputs. A large time-series database covering each year from 1970 to 2010 has been constructed, based mainly on international data sets. For Japan the main source for economic data is the OECD Structural Analysis database, with other macro-level indicators being obtained from the IMF and the World Bank. Any gaps in the data are filled by using national figures. The main cross-sectional data (the input–output table and bilateral trade flows) are sourced from the OECD.

The main source for energy data is the IEA. CO_2 emissions have also been made consistent with IEA figures.

E3MG consists of 22 estimated sets of equations (each disaggregated by sector and by country). These cover the components of GDP, prices, the labour market and energy demand. The estimation method utilises developments in time-series econometrics, in which dynamic relationships are specified in terms of error correction models (ECMs) that allow dynamic convergence to a long-term outcome.

The specific functional form of the equations is based on the econometric techniques of cointegration and error-correction, particularly as promoted by Engle and Granger (1987) and Hendry et al. (1984). In brief, the process involves two stages. The first stage is a levels relationship, whereby an attempt is made to identify the existence of a cointegrating relationship between the chosen variables, selected on the basis of economic theory and a priori reasoning, e.g. for employment demand the list of variables contains real output, real wage costs, hours-worked, energy prices and a measure of technological progress. If a cointegrating relationship exists, then the second-stage regression is known as the error-correction representation, and involves a dynamic, first-difference, regression of all the variables from the first stage, along with lags of the dependent variable, lagged differences of the exogenous variables, and the error-correction term (the lagged residual from the first-stage regression).

Previous analysis with E3MG

The E3MG model has been under development for much of the past decade. It is now used for policy analysis at European level, including the 2010 European Commission communication on the impacts of moving to a 30% GHG target (European Commission, 2010). The model has also been used repeatedly for assessing decarbonisation pathways at different international levels (Barker et al., 2005, 2006, 2008; Barker and Scrieciu, 2009) and in the UK (Dagoumas and Barker, 2010). Most recently E3MG was applied in Barker et al. (2012) to provide an economic assessment of the IEA's 450ppm scenario (IEA, 2010).

In Japan, E3MG has been applied for an assessment of the economic costs of meeting Japan's Copenhagen pledge of reducing GHG emissions by 25% below 1990 level by 2020 (see Lee et al., 2012). The model results showed this to have a modest economic cost, which could be turned into a modest benefit if efficient revenue recycling methods were used.

Comparison to CGE modelling

In terms of basic structure, purpose and coverage, there are many similarities between E3MG and comparable CGE models, such as GTAP (Hertel, 1999), in terms of geographical coverage and accounting structure. However, the modelling approaches differ substantially in their treatment of behavioural relationships and the structure of markets. Furthermore, CGE analyses assume full price adjustment and equilibrium in all markets including the labour market. That is, there will be no (involuntary) unemployment. On the other hand, in E3MG the price is set by the mark-up principle and the wage is determined by the wage-bargaining process between employers and employees. The rigidity of price adjustments and the possibility of market disequilibrium lead to a structure where effective demand, including consumption, private investment and government spending, has a very important impact on total gross output.

In light of the fact that the analyses carried out by the four research institutes of three scenarios with a reduced share of nuclear power in energy generation in Japan followed the CGE approach, it is important to highlight the differences between that approach and ours. These differences are discussed in more detail, in the context of Japanese climate policy, in Lee et al. (2012).

References

Akimoto, K., Sano, F., Homma, T., Oda, J., Nagashima, M., Kii, M., 2010. Estimates of GHG emission reduction potential by country, sector, and cost. Energy Policy 38, 3384–3393.

Andersen, M.S., Ekins, P., 2009. Carbon-Energy Taxation, Lessons from Europe, Oxford University Press, 2009.

Ban, K, 2013. The relationship between energy policy and economic growth, Keizai Seminar, No. 669, pp. 35–41 (in Japanese) (伴金美(2013)「エネルギー政策と経済成長の関係––経済モデルによる検証」『経済セミナー』No.669, pp. 35-41.

Barker, T., Pan, H., Köhler, J., Warren, R., Winne, S., 2005. Avoiding dangerous climate change by inducing technological progress: scenarios using a large-scale econometric model. In: Schellnhuber, H.J., Cramer, W., Nakicenovic, N., Wigley, T., Yohe, G. (Eds.), Avoiding Dangerous Climate Change. Cambridge University Press. (Chapter 38).

Barker, T., Pan, H., Köhler, J. Warren, R., Winne, S., 2006. Decarbonizing the global economy with induced technological change: scenarios to 2100 using E3MG. In: Edenhofer, O., Lessmann, K., Kemfert, K., Grubb, M., Köhler, J. (Eds.), Induced Technological Change: Exploring its Implications for the Economics of Atmospheric Stabilization, Energy Journal (special issue on the International Model Comparison Project).

Barker, T., Foxon, T., Scrieciu, S.S., 2008. Achieving the G8 50% target: modelling induced and accelerated technological change using the macro-econometric model E3MG. Climate Policy 8, S30–S45. (special issue on modelling long-term scenarios for low-carbon societies).

Barker, T., Scrieciu, S.S., 2009. Unilateral climate change mitigation, carbon leakage and competitiveness: an application to the European Union. Int. J. Global Warm. 1 (4), 405–417.

Barker, T., De-Ramon, S., Pollitt, H., 2009. Revenue recycling and labour markets: effects on costs of policies for sustainability. In: Bosetti, V., Gerlagh, R., Schleicher, S. (Eds.), Modelling Sustainable Development: Transitions to a Sustainable Future. Elgar, Cheltenham, UK.

Barker, T., Anger, A., Chewpreecha, U., Pollitt, H., 2012. A new economics approach to modelling policies to achieve global 2020 targets for climate stabilisation. International Review of Applied Economics. Routledge. (special issue on economic policies of the new thinking in economics), London.

Cambridge Econometrics, 2013. An Appraisal of Carbon Pricing Revenue Recycling Options. International Council on Mining and Metals, London.

Cost Estimation and Review Committee, 2011. The Report of the Cost Estimation and Review Committee, The Energy and Environment Council, the Cost Estimation and Review Committee 2011.12.19. (in Japanese) (コスト等検証委員会(2011)『コスト等検証委員会報告書』エネルギー・環境会議、コスト等検証委員会、平成23年12月19日).

Dagoumas, A., Barker, T., 2010. Pathways to a low-carbon economy for the UK with the macro-econometric E3MG model. Energy Policy 38 (6), 3067–3077.

Duscha, V., Schumacher, K., Schleich, J., Buisson, P., 2013. Costs of meeting international climate targets without nuclear power. Climate Policy, http://dx.doi.org/10.1080/14693062.2014.852018.

Ekins, P., Speck, S., 2011. Environmental Tax Reform (ETR), A Policy for Green Growth, Oxford University Press, 2009.

Engle, R.F., Granger, C.W.J., 1987. Cointegration and error correction: representation, estimation and testing. Econometrica 55, 251–276.

European Commission, 2010. Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage, COM (2010) 265 final, Brussels, 26/05/2010.
European Communities, 2009. International Monetary Fund, Organisation for Economic Co-operation and Development, United Nations and World Bank, System of National Accounts 2008, New York.
Hendry, D.F., Pagan, A., Sargan, J.D., 1984. Dynamic specification. In: Griliches, Z., Intriligator, M.D. (Eds.), Handbook of Econometrics, vol. II. Amsterdam, North Holland.
Hertel, T., 1999. Global Trade Analysis: Modeling and Applications. Cambridge University Press, New York, USA.
Homma, T., Akimoto, K., 2013. Analysis of Japan′s energy and environment strategy after the Fukushima nuclear plant accident. Energy Policy 62, 1216–1225.
Hong, S., Bradshaw, C.J.A., Brook, B.W., 2013. Evaluating options for the future energy mix of Japan after the Fukushima nuclear crisis. Energy Policy 56, 418–424.
International Energy Agency (IEA), 2010. World Energy Outlook 2010, OECD/IEA, Paris.
International Energy Agency, 2012. World Energy Outlook 2012. OECD Publishing.
Lee, K., Pesaran, M.H., Pierse, R.G., 1990. Aggregation bias in labour demand equations for the UK economy. In: Barker, T., Pesaran, M.H. (Eds.), Disaggregation in Econometric Modelling. Routledge, London, (Chapter 6).
Lee, S.C., Pollitt, H., Ueta, K., 2012. A model- based econometric assessment of Japanese environmental tax reform. Sci. World J. 2012. (Article ID 835917) http://www.hindawi.com/journals/tswj/2012/835917/.
Matsuo, Y., 2012. Summary and Evaluation of Cost Calculation for Nuclear Power Generation by the Cost Estimation and Review Committee, Institute for Energy Economics Japan (IEEJ), May 2012.
McLellan, B., Zhang, Q., Utama, N.A., Farzaneh, H., Ishihara, K.N., 2013. Analysis of Japan′s post-Fukushima energy strategy. Energy Strategy Rev. 2 (2), 190–198.
Park, S.J., Yamazaki, M., Takeda, S., 2012. Environmental Tax Reform: Major findings and policy implications from a multi-regional economic simulation analysis, Background Policy Paper for the Low Carbon Green Growth Roadmap for Asia and the Pacific, UNESCAP.
The Energy and Environment Council, 2012a. Options for Energy and the Environment on 29th July 2012 (in Japanese) (エネルギー・環境会議(2012a)『エネルギー・環境に関する選択肢』平成24年6月29日).
The Energy and Environment Council, 2012b. Options for Energy and the Environment, The Energy and Environment Council Decision on June 29, 2012 [Outline, in English], National Policy Unit, July 2012.
The Energy and Environment Council, 2012c. Innovative Strategy for Energy and the Environment on 14th September 2012 (in Japanese) (エネルギー・環境会議(2012b)『革新的エネルギー・環境戦略』平成24年9月14日).
UNESCAP, 2012. Double dividend and revenue neutrality, in Part III: Fact Sheets and Case Studies of Low Carbon Green Growth Roadmap for Asia and the Pacific, UNESCAP, http://www.unescap.org/esd/environment/lcgg/.
Zhang, Q., Ishihara, K.N., Mclellan, B.C., Tezuka, T., 2012. Scenario analysis on future electricity supply and demand in Japan. Energy 38 (1), 376–385.

Please cite this article as: Pollitt, H., et al., An economic and environmental assessment of future electricity generation mixes in Japan – an assessment using the E3MG macro-econometric model. Energy Policy (2014), http://dx.doi.org/10.1016/j.enpol.2013.12.018