An Economic and Environmental Assessment of Future Electricity Generation Mixes in Japan
- An assessment using the E3MG macro-econometric model -

Hector Pollitt, Cambridge Econometrics, hp@camecon.com
Soocheol Lee, Meijo University, slee@meijo-u.ac.jp
Seung-Joon Park, Kanseigakuin University, cce55691@kwansei.ac.jp
Kazuhiro Ueta, Kyoto University, ueta@econ.kyoto-u.ac.jp

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 scenarios in which there are reduced or no nuclear power result in the most favourable outcomes for the Japanese economy, but that the differences between the outcomes of the different scenarios are not large. Our results also show a double-dividend effect if (revenue-neutral) carbon taxes are levied in order to meet the GHG reduction targets. 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 (compared to 1990 levels) while simultaneously phasing out nuclear power.

1. Introduction

This study uses the global macro-econometric model E3MG in order to analyse the economic and environmental impacts of the three options for the share of nuclear power in energy 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 denuclearization or ETR.

The Fukushima-Daiichi Nuclear Power Accident (the Fukushima Accident) of March 2011 made Japanese citizens aware of dangers of nuclear power plants (NPP). The Democratic Party of Japan (DPJ), which was then in government, had to respond to the public demand for denuclearization, 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], 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 the zero NPP in 2030s”, was published in September 2012. Nevertheless, nuclear policy was not seen as a priority in the Lower House Election in December 2012; and this election resulted in victory for the Liberal

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

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 denuclearization 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.

Moreover, further 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).

This study analyses the possible effects of denuclearization 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) developed by Cambridge Econometrics and the University of Cambridge. 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. Post-Fukushima it became widely understood that NPP is not necessarily cheap if the risk of catastrophic accidents and the associated costs of the policy 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 externalized[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

[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)

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 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 NPP share 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 through 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 from business groups including Nihon Keidanren to the zero-NPP policy, 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%.

Nor has the new government, formed after the elections of December 2012, 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

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

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

NPP shares of 0%, 15% and 20-25%. These are very important reference material 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 (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). Accordingly, the business as usual (BAU) case is where 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 NPP, fossil combustion plants and renewable plants.

Table 1: Assumptions for tuning the economic models (in 2030)

	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

Source: Ban (2013, p. 38) and Table 2, edited by authors of the present paper.
Note: The 20% and 25% cases are combined in the later tables and in our analysis.

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 obligates 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 by 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 (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.

Table 2: Summary of Scenario Results (from the *Options* report)

			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	16 trn Yen	16 trn yen	15 trn yen
				Promoting stronger shift to gas			
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

Source: The Energy and Environment Council (2012), edited by authors.

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 Jan 2013.

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, resulting in higher electricity prices and a lower level of real GDP (Ban 2013, p. 39). In every analysis the highest power 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 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 each case. 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 3: Electricity prices in 2030 and the annual rate of increase

	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%

Source: Table 2, own calculation by authors.

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 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 49bn EUR)” (Ban 2013, p. 39). The difference between the three scenarios in terms of the annual growth rate of GDP is close to negligible.

Table 4: The gap between levels of real GDP in 2030 and the annual growth rate

	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%

Source: Table 2, own calculation of the authors.

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

After the Fukushima Accident, the switch in generation from NPP to combustion power plants raised levels of CO_2 emissions in Japan. This led to the suggestion that that the mid-term target of GHG emission levels (-25% by 2020 compared to 1990) would be very difficult to achieve. But 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, this cost may be internalised within the economic system. Although in practice it is not possible to estimate the true cost of GHG emissions, a carbon pricing 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 referred to as the "double dividend of environmental tax reform", where the first dividend is better environmental quality and the second dividend is better economic performance[5]. 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 their modelling, the method of revenue recycling was not explicitly explained. It seems 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 then misses the opportunity to reduce existing distortions caused 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 review of existing revenue recycling policies is provided in Cambridge Econometrics (2013, forthcoming).

The interaction between nuclear and climate policy makes the modelling scenarios quite complex to set up and interpret. Nevertheless, this was achieved in the analyses carried out by the four institutes. It is therefore appropriate to include the CO_2 restriction explicitly in the scenario setting so as to allow the comparison of 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 about carbon pricing policy (both EU-ETS and ETR) in Europe and globally, and have contributed to the important discussion on the issue 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

We apply the E3MG (Energy-Environment-Economy Model at the Global level) developed by the Cambridge Econometrics and the University of Cambridge. In this section we compare the features of E3MG to the models used for the previous assessment of the three options. More details about the model are provided in Appendix B.

The four institutes assessed the scenarios under the three options using neo-classical Computable General Equilibrium models (CGE). In general, CGE analyses 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, the

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

demand-side effect of policy change on consumption or private investment will not have positive effects on economic performance or employment[6].

However, the Japanese economy is still in a long-term slump, often called "the two lost decades". Consequently, the necessary additional investment in renewable energies following the phasing-out of nuclear power may boost effective demand, and thus lead to a positive economic impact. A useful tool to analyse this impact is a macro-econometric model based on the theory of effective demand.

In addition, there is also the possibility of the "double dividend of environmental tax reform". To analyse this requires a quite detailed modelling of the tax system including not only carbon taxes but also income tax, corporation tax, social security contributions and so on. Furthermore, in today's globally interacting economic context, the effect of denuclearization and ETR on Japan's economy will also be to some extent determined through a shift in the competitive conditions of firms and changes in import and export volumes. Therefore a global model has particular advantages.

E3MG is a multi-national, multi-sectoral, macro-econometric model that is based on the principle of effective demand, and which is equipped with a relatively detailed treatment of the tax system. This paper uses E3MG to compare the outcomes of the three options for different shares of nuclear power generation, under different GHG emission constraints.

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 scenarios

As in the analyses conducted by the four institutes, our approach is scenario-based. We consider twelve 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). 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* (IEA, 2012). The figures in IEA (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.

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

[6] 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.

- 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, 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, 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 emission 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 in 2020.

Table 6: Environmental outcomes in the scenarios

	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	0.0
N15Cn	10%	-2.7	0.0
N00Cn	0%	-1.1	0.0
N25C10	25%	-10.0	1,241
N15C10	10%	-10.0	2,792
N00C10	0%	-10.0	8,685
N25C15	25%	-15.0	1,882
N15C15	10%	-15.0	3,981
N00C15	0%	-15.0	10,029
N25C25	25%	-25.0	2,223
N15C25	10%	-25.0	4,136
N00C25	0%	-25.0	11,373

Sources: E3MG, Cambridge Econometrics

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

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 coal and 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 11,373 yen/tCO_2 (ca. 93 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 emission 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 means that there is a small increase in GDP overall when there is a lower nuclear share. Employment is similarly affected with most of the increase in jobs occurring in investment sectors (see sectoral impacts below). This is due primarily to higher investment in building the new plants. Overall there is an increase in fossil fuel imports. Higher electricity prices in N00Cn also lead to an increase in the overall price level that leads to a fall in real incomes and household consumption.

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

Table 7: Macroeconomic impacts of reducing the share of nuclear power (2030, % difference from N25Cn)

	N15Cn (15% share)	N00Cn (0% share)
GDP	0.07	0.03
Employment	0.05	0.07
Consumption	0.02	-0.43
Investment	0.44	2.11
Exports	0.01	0.00
Imports	0.18	0.60
Price level	0.00	0.48
CO_2 emissions	2.64	6.90

Sources: E3MG, Cambridge Econometrics

When the carbon tax is added, this 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 0.18%-0.42% (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, due to the double dividend. In summary, our analysis shows that a lower nuclear share and a higher carbon target produce better results for GDP (see Figure1).

Looking at the other macroeconomic indicators, we see an increase in household incomes and spending from the income tax cuts. Investment falls slightly, however, because the carbon tax principally falls on heavy industry (e.g. steel, cement) that makes up a large share of investment goods[7]. There is also a slight fall in exports, due to competitiveness effects from the higher fuel prices; in the longer run exports could recover some of this reduction if industry improves efficiency. Although competitiveness effects also mean higher import volumes, there is also a large reduction in imports of manufactured fuels, thus giving a decrease overall.

There is a small increase in total employment, following the increase in GDP. This means there is a similar reduction in unemployment levels.

Table 8: Macroeconomic impacts of meeting the climate targets (2030, % difference from N25Cn)

	N25C10 (-10% target)	N25C15 (-15% target)	N25C25 (-25% target)
GDP	0.18	0.27	0.42
Employment	0.02	0.02	0.05
Consumption	0.28	0.48	0.85
Investment	-0.08	-0.19	-0.53
Exports	-0.03	-0.06	-0.13
Imports	-0.06	-0.08	-0.11
Price level	0.32	0.64	1.61

Sources: E3MG, Cambridge Econometrics

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 also means that there are more revenues available for recycling. As a consequence, all of the macroeconomic effects are larger (see Tables 9 and 10). When the nuclear share falls to zero, even more must be accomplished by the carbon tax, although the differences between the zero and 15% NPP cases are small (mainly because there is such a large renewables share in zero NPP case).

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

	N15C10 (-10% target)	N15C15 (-15% target)	N15C25 (-25% target)
GDP	0.22	0.32	0.43
Employment	0.02	0.02	0.04
Consumption	0.37	0.58	0.89
Investment	-0.13	-0.27	-0.61
Exports	-0.05	-0.08	-0.14
Imports	-0.07	-0.09	-0.12
Price level	0.40	0.80	1.77

Sources: E3MG, Cambridge Econometrics

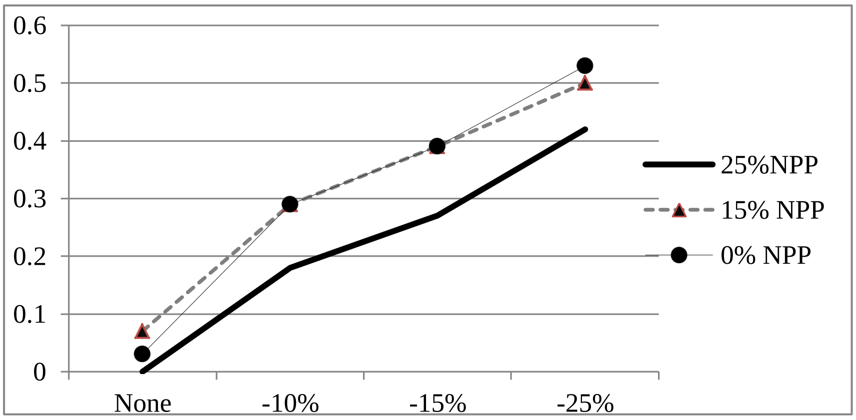
[7] If the revenue recycling was into investment subsidies or corporation tax reductions, rather than income tax reductions, this could potentially be reversed. This is suggested as a possible area for further investigation.

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

	N00C10 (-10% target)	N00C15 (-15% target)	N00C25 (-25% target)
GDP	0.26	0.35	0.50
Employment	-0.04	0.06	0.11
Consumption	0.42	0.61	1.00
Investment	-0.11	-0.20	-0.54
Exports	-0.06	-0.09	-0.15
Imports	-0.08	-0.09	-0.08
Price level	0.48	0.80	1.84

Sources: E3MG, Cambridge Econometrics

Figure 1: Impacts on GDP in 2030 for each carbon target, % difference from N25Cn



Sources: E3MG, Cambridge Econometrics

At the sectoral level, other than gas supply it is typically the sectors that provide investment goods that benefit from a reduced share of nuclear in the energy mix (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.

Table 11: Selected sectoral impacts (output, 2030)

N00Cn v N25Cn (denuclearization)			N00C25 v N00Cn (high carbon price)	
Gas Supply	8.2		Hotels & Catering	6.2
Metal Goods	4.9		Other Business Services	3.2
Mech. Engineering	4.9		Communications	3.0
Basic Metals	1.4		Professional Services	2.6
Electronics	0.6		Textiles & Clothing	2.7
Water Transport	-0.3		Other Transport Equipment	-0.4
Retailing	-0.4		Electronics	-1.1
Textiles & Clothing	-0.5		Basic Metals	-1.6
Food, Drink & Tobacco	-0.1		Mech. Engineering	-1.8
Hotels & Catering	-0.3		Motor Vehicles	-1.8

Sources: E3MG, Cambridge Econometrics

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 supplementary policies, such as Border Carbon Adjustments, may also be worth consideration (see Park et al, 2012).

8. Conclusions

This study has used the E3MG model to evaluate the three options for the share of nuclear in power generation (0%, 15% and 25%[8]), focusing on economic indicators such as real GDP or employment, with a set of mid-term GHG reduction targets for 2020 imposed as restrictions. Revenue-neutral Environmental Tax Reform (ETR) is treated as the way to meet the GHG reduction targets, in which the revenue from carbon taxes is recycled through reductions in income tax rates.

The CGE model-based analysis conducted by the four research institutes showed that the zero-NPP scenario had the least favourable results in terms of electricity prices and levels and growth of real GDP, although the differences from the other two scenarios were very small. In contrast, our analysis showed the most favourable effects as arising from the zero and 15%NPP scenarios, although we also find that results are quite similar for all the scenarios (GDP changes less than 0.1% in 2030). The reason for the small differences between scenarios in our analysis is that, in the case of zero-NPP scenario, the additional investment required for renewables boosts effective demand, resulting in higher employment and levels of real GDP. This more than compensates for the small negative effect on consumption of the slight increase in electricity prices. This is the principal contrast between our results and the results of the CGE-based analyses.

On the other hand, the carbon tax rate needed to achieve the mid-term GHG reduction target (-25% from the 1990 level) is more than 11,000 yen/t-CO_2 (more than 90 euro/t-CO_2) if the NPP share is zero. In political terms, this seems an unattainably high level if we compare it with the current Japanese carbon tax rate (about 300 yen/t-CO_2). However, according to our results, the revenue-neutral environmental tax reform, which does not increase the national tax burden, will result in higher levels of employment and GDP, compared with the scenario without a carbon tax. This implies that the "double dividend" is possible.

In summary, the results from the analysis find that both denuclearization and meeting the GHG reduction targets can have small benefits for the Japanese economy, if well implemented. Our results also find an important interaction between the two policies that will need to be considered carefully by policy makers.

[8] 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). Table A1 summarises the power generation mix under each scenario in 2030.

Table A1: Power mix in the scenarios, % of generation, 2030

	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

Source: The Energy and Environment Council (2012b)

The level of investment (defined as Gross Fixed Capital Formation) that must be made by the power sector is estimated using the capital costs for each type of plant that is built. The source is again The Energy and Environment Council (2012).

In the scenarios where a high share of nuclear power remains, the investment requirements are lower, because the plants already exist and, in many cases, may be run with higher load factors. In the other scenarios there is an increase in investment (which can lead to higher levels of GDP and jobs), even though the capital stock may remain unchanged. Table A2 shows the generation required in 2030, with additional generation over 2010 values shown in brackets.

Table A2: Generation required in 2030 (additional to 2010 values) (TWh)

	2010 value		25% NPP	15% NPP	0% NPP
Nuclear	*290*		250 (0)	150 (0)	0 (0)
Renewables	*110*		250 (140)	300 (190)	350 (240)
Natural gas	*300 (IEA)*		270 (0)	290 (0)	380 (80)
Other fossil fuels	*390*		230 (0)	260 (0)	270 (0)

Source: The Energy and Environment Council (2012b)

The required investment is calculated on this basis, with the results presented below. Details of the calculation, including assumptions about unit investment costs, are provided below.

Additional investment in power lines (3-5 trn yen) and energy efficiency (80-100 trn yen) is also added in, based on the figures in The Energy and Environment Council (2012). These costs are divided evenly over the period 2013-30 and added to the final price of electricity.

It is important to note that we do not assume an automatic ‘crowding-out’ effect and that the total level of investment is capable of changing in response to variations in trade and overall changes in output levels. In the scenarios it is assumed that the investment is financed by higher electricity prices.

Table A3: Additional investment in the scenarios

	New Plants	Power Lines	Energy Efficiency
25% NPP	30.5trn yen	3.0 trn yen	80 trn yen
15% NPP	38.7 trn yen	3.4 trn yen	80 trn yen
0% NPP	48.7 trn yen	5.2 trn yen	100 trn yen

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

The impact on electricity prices is taken from The Energy and Environment Council (2012). 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 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, so that the emission target (interpreted as the level of CO_2 emissions in 2020 being a fixed amount below 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 main data source for estimating the investment cost of new plants is The Energy and Environment Council (2012). 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. It is around 28 yen/kWh for solar, 10 yen/kWh for onshore wind and 2.4 yen/kWh for biomass (although in practice it might be possible to convert existing fossil fuel plants to use biomass).

However, The Energy and Environment Council (2012) also shows that costs are expected to fall over time for wind power and, especially, for solar. Assuming this is explained by 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, so it is 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 zero 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. However, as the shares for these technologies are quite similar across the different scenarios, this assumption does not have much impact on the results.

The share of each technology in the scenarios is also given in National Policy Unit (2012), 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 costs. The investment is given in Table A4.

For the purposes of simplification, it is assumed that the carbon tax levied on other sectors does not influence the level of electricity demand and the level of investment required. In reality the carbon tax could have some impact on electricity demand, e.g. from fuel switching or from the small increase in GDP, and on the costs of investing in new plants. However, our results suggest that the differences would be too small to influence investment decisions.

Table A4: Additional investment for renewables in the scenarios

bn yen per year	25% NPP	15% NPP	0% NPP
Solar	1036	1127	1127
Onshore wind	608	608	843
Offshore wind	45	426	555
Biomass	8	79	103
Natural gas	0	0	80
Total	1697	2149	2708

Source: The Energy and Environment Council (2012b)

The total investment shown in Table A3 is cumulative for the whole period 2013-30, i.e. those in Table A4 multiplied by 18.

It is important to note that this is a simplified approach. 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.

Appendix B: The E3MG model

Introduction

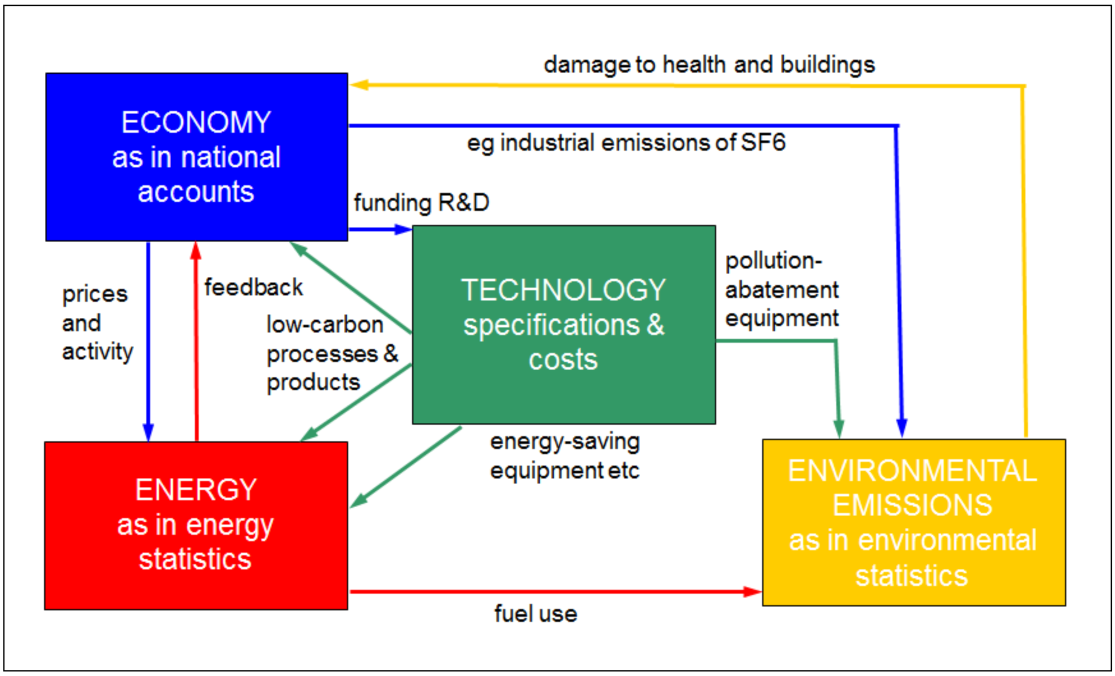
This section briefly describes the E3MG model that was used to carry out the analysis. For further information about the model, the reader is referred to Barker et al (2005) and the website www.e3mgmodel.com

Basic model structure

The E3MG model (Energy-Environment-Economy Model at the Global level) is a computer-based tool that has been 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 Figure B1. 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.

Figure B1: E3 interactions within E3MG



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 et al (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, 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 match with the scenario definitions described in Section 6 above.

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 data 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 (ECM) 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 the 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 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).

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