Development of CO2 Emission Calculation Software for the Japanese Economy in 2040 --- Possibility of "Counterfactual Estimation

(This paper is originally written in Japanese. It is shown at the Journal of Japan Society of Energy and Resources Vol.40,Num.4,2019, English version is made by Deepl.)

Yasuhiro Murota *

This paper presents a simulator which could calculate future Japanese economy and its CO2 emission in 2040, It is characterized by high-speed calculation, model integrality and easy handling. By using this simulator, we could get quantitative answer on the economic-environmental questions about future Japanese CO2 emission.

By using Monte-Carlo type simulation, we find that the relation between GDP and CO2 emission would be relaxing in the future because of economic structural change.

Keywords : Simulator, CO2 emission, Japan, Economic model

1. introduction

Global warming countermeasures are an unavoidable problem for Japan in the future. The author has developed a simulation software (EYE_2040) to help us understand this issue. This software integrates a macro model, an input output table, and an energy model, and can obtain the Japanese economy and CO2 emissions in 2040 under various assumptions in a consistent manner. In addition, since the solution is obtained instantaneously, it is possible to respond to "what if questions" regarding energy (counterfactual estimation). Using this method, we performed Monte Carlo calculations and found the possibility of disentangling the relationship between GDP and CO2 emissions.

2. characteristics of the global warming problem and how to find a solution

The global warming problem is characterized by the fact that it is a "wicked problem" [1]. This means that (1) different people have different opinions on the definition of the problem, and (2) various specialties and stakeholders are involved in the problem. Therefore, there is no simple and clear-cut solution, nor can the answer be obtained from only one field of expertise. The only way to find a solution is to involve people with various positions and specialties in the discussion and utilize the popular knowledge that arises from them. [2]

However, since these discussions tend to diverge, tools are needed to help them converge. To achieve this, it is necessary to provide consistent quantitative solutions to the various "what if questions" that participants have about global warming, so that discussions can proceed based on these solutions. Incidentally, giving a consistent calculated solution to "what if questions" is called "counterfactual simulation" [3]. Here, the participants in the discussion will set various hypotheses, and quantitative solutions to them will be obtained using this simulator. This enables a back-and-forth between hypotheses and possible solutions, and is expected to advance the discussion of "troublesome problems.

The "what if questions" regarding the global warming issue for the Japanese economy include, for example, can the Japanese economy grow and CO2 emissions decline at the same time, can Japan's CO2 emissions decline without relying on nuclear power, and can electricity and gas companies overcome the diseconomies of scale in the face of ongoing IT innovation and sluggish demand? The purpose of this simulator is to provide a consistent solution to these questions and to help the discussion progress.

3. Characteristics and Mechanism of EYE_2040

3.1 Its characteristics

This simulator has the following characteristics.

(1) Comprehensiveness: Rather than calculating only energy supply and demand, it is possible to calculate the macroeconomy and industrial structure, which are the environment surrounding them, and to obtain energy solutions based on them. Until now, energy forecasts have made rather simple assumptions about the macroeconomy and industrial structure (e.g., economic growth rate and crude steel production), and have used only energy models based on these assumptions to obtain solutions. Here, we explore the possibility of new solutions by including macro and industrial structure as part of the calculation, instead of using them

＊Shonan Econometrics Co.
2-24-11-1008, Shimotani, Taito-ku, Tokyo 110-0004, Japan
E-mail: yosokupro@gmail.com

as given conditions.

(2) High speed: To use the simulator as a discussion board, it is necessary to provide instantaneous answers (quantitative solutions) to the various questions posed. The computation time to obtain the solution of this simulator is almost instantaneous, and it can be used as a tool for facilitating discussions.

(3) Ease of access: This simulator is a tool for solving "tricky problems. For this purpose, it is important that the participants themselves can follow up the calculation results by themselves. Since this simulator is provided as a software, users can follow up the results if they use a Windows PC.

3.2 Simulation as a computational method

Usually, the solution to the global warming problem is obtained by a constrained optimization type model (e.g. Nordhaus[4)]). The original model was the Ramsey model, which was later mathematically organized by Koopmans to form the prototype of the current model[5)]. The impetus for this type of model to become standardized as a model for dealing with global warming was probably the introduction of this type of analysis in the IPCC's Second Assessment Report on Climate Change 1995 [6)].

However, in order to apply this type of model to the global warming problem, we have to make some unrealistic assumptions. The following three assumptions must be made: (1) perfect foresight, (2) the existence of a "representative individual" as an optimizing agent, and (3) the assumption of a single equilibrium.

First, the issue of global warming is fraught with uncertainty, and this uncertainty about the future is intrinsic to human society[7)]. Moreover, there are various actors involved in this problem (countries, companies, NPOs, etc.), and there is no single decision-making entity[8)]. Furthermore, without a single equilibrium, the search for an equilibrium solution through optimization itself becomes meaningless[9)].

The application of such constrained optimization methods to the analysis of economic phenomena has been subject to serious criticism regarding its effectiveness, especially since the 2008 financial crisis. For example, Nobel Prize winner Solow stated that "the Ramsey model is not a sound micro-foundation for macroeconomics"[10)].

On the other hand, path-finding computer models that assume uncertainty about the future have been proposed in fields other than economics. For example, the forward reasoning method proposed by political scientist Bernstein is one of them.[11)] In this paper, we refer to this method and conduct a simulation based on a what if question, and search for a future path by using the quantitative solution. Since this method can take into account path dependence and other factors related to future paths, it opens up the possibility of using the not-a-real option instead of npv (net present value method) as a policy evaluation. [12)]

3.3Configuration of this simulator

It consists of a Japan macro model, an industrial structure model, and an energy supply-demand model, and the calculation period is up to 2040. When the user sets the main exogenous values, the calculation is performed and the solution is obtained instantly. The calculation is performed in one direction, from macroeconomy to industrial structure to energy supply and demand (however, since the macro model and energy model are non-linear simultaneous equations, the respective solutions are obtained by convergence calculation). Therefore, the impact of energy conservation measures on the macroeconomy and industrial structure (e.g., employment effects) cannot be obtained. Since the macro effects of such energy conservation measures are two orders of magnitude smaller (several billions to several tens of billions of yen) than the usual macro calculations (in trillions of yen), it is necessary to calculate them in a separate routine. This is an issue to be addressed in the future.

An explanation of each part is given below (Fig. 1).

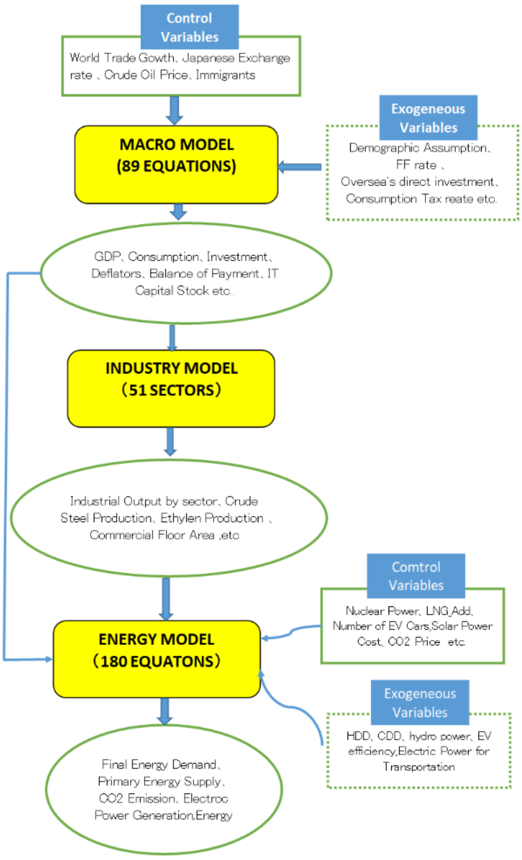


Fig１ EYE_2040 Simulator Flow Chart(Overall)

(1) Japan Macro Model

It consists of 89 equations and calculates the economic growth rate, expenditure-side GDP (consumption, investment, imports and exports, etc.), potential GDP, unemployment rate, national income, prices, public finance, etc. For example, for trade-related issues, imports and exports of goods and services are determined from the macro structure, and the current account balance is obtained by adding factor incomes from abroad to them.

There are five exogenous variables tat can be set by the user (world trade, exchange rate, oil price, public investment, and immigration). These can be set to any value within upper and lower bounds. For example, the exchange rate can be set to any value between 75 yen/$ and 180 yen/$ in 2040. The price of crude oil can be set to any value between $32/bbl and $112/bbl in 2040. The system is set up at two points in time, 2025 and 2040, and the complementary value is used for the intermediate point. Other variables assumed by the system include population (excluding immigration), the US Fed interest rate, the consumption tax rate, and foreign direct investment balances.) These assumptions are defined as upper and lower bounds, taking into account past movements in each variable. For example, between 2000 and 2016, the maximum value of the exchange rate is ¥125/$ and the minimum value is ¥79/$. The maximum value for the crude oil price is 110 dollars per barrel and the minimum value is 25 dollars per barrel, indicating that the assumed range is large enough to consider the future path.

The population assumptions (excluding immigrants) are based on the projections of the National Institute of Population and Social Security Research[13)] . The standard solution for immigrants is assumed to be 340,000 in 2040, and their share of the labor force is less than 1%.

(2) Industrial structure model

It incorporates input-output tables including forecast table (2025 and 2040) consisting of 51 sectors. These forecast tables are based on the actual tables (Ministry of Internal Affairs and Communications, 2000-2005-2011).

Table 1 Induced coefficients in the input-output and performance tables

		Private Consumption	Government Consumption	Government Investment	Private Investment	Export	Total
actual	2000	1.514	1.507	1.803	1.890	2.306	1.673
	2005	1.512	1.532	1.767	1.803	2.225	1.666
	2011	1.540	1.551	1.787	1.755	2.156	1.661
forecast	2025	1.523	1.555	1.730	1.629	2.018	1.626
	2040	1.538	1.575	1.669	1.540	1.942	1.619

This shows that the total inducement coefficient, as well as

we estimated forecasting tables by using the EU method[14)].

The characteristics of the forecast table are shown in terms of the evolution of the induced coefficient (Table-1). It can be seen that the coefficient of fixed capital formation has been gradually decreasing. This is an indication of the shift of industrial structure to services. And export and gross domestic product coefficients, are higher than the total inducement coefficients.

From the industrial structure model, the output value, employment, major production (crude steel, ethylene, cement, and paper pulp) and business floor space by industry to 2040 are obtained. These values are obtained by multiplying the production value of each sector by the intensity. The trend of past results is used for the intensity assumption. For major commodities, the effect of energy price elasticity is included in the intensity change.

The impact of the products of IT innovation, such as the shift to electric vehicles, is not included in the input coefficients of the input-output table. This is because it is assumed that demand for the products of IT innovation will be met not by domestic production but by imports. This assumption is not so strange in view of the hollowing out of the electronics industry and the case of smartphones.

In addition, energy demand is often calculated by multiplying each element of the input-output table by the energy intensity in LCA (Life Cycle Analysis) and so on. However, this paper does not take this approach, but constructs an energy model based on the energy balance table, and then determines energy supply and demand by inputting the outputs of the input-output table (output by industry, crude steel production, business floor space, etc.) into it. This is because the method of obtaining energy supply and demand by multiplying the input-output by the input-output in the input-output table is difficult to use for forecasting, let alone for empirical purposes, and because it is difficult to construct a model in which the macroeconomy is reflected in the industrial structure and the energy supply and demand is affected by changes in the macroeconomy, and therefore, it is difficult to use this method for forecasting. It is also because it is easier for the user of this simulator to follow the logical process of the calculation.

(3) Energy supply and demand model

It consists of 184 equations, where final demand (e.g. industry, household, business, transportation), energy conversion (e.g. power generation, energy refining) and primary supply (e.g. supply by energy source, imports) are calculated using macro models (e.g. GDP, consumption, oil prices) and industry models (e.g. output by industry, output of energy intensive industries, business floor area) results.

Specifically, the following process determines energy supply and demand.

(1) From the Japan macro model, GDP (calculated value), corporate prices (calculated value), exchange rate (assumed value), crude oil price (assumed value), etc. are given. (2) From the industrial structure model, production output (e.g. crude steel), manufacturing output, and business floor space in energy-intensive industries are given (calculated values) by multiplying the output of each sector (calculated values) by the intensity (assumed values).

The energy model assumes the above and calculates energy prices (gasoline price, kerosene price, and price of electric power). Kerosene price, total unit price of electric power) is calculated. Next, energy supply and demand are calculated in the order of final demand, conversion sector, and primary supply. The specifics are as follows.

*Final demand is calculated for the industrial, residential, commercial, and transportation sectors by energy source, based on the level of activity (e.g., private consumption and number of households for residential use) and price (electric power price/private consumption deflator for residential electricity use). Energy savings (e.g., residential solar power generation) are deducted.

*For power generation in the conversion sector, electricity input is determined from final electricity demand, and hydroelectric, nuclear, and new energy are first deducted as assumed values. Next, the input of petroleum and gas is calculated, and coal power generation is obtained as the residual after subtracting the above from the total input.

*In other conversion sectors, such as coke and city gas, the primary input is calculated from the demand obtained in the final demand sector.

*The sum of these is the primary supply. Then imports are calculated .

The exogenous variables used as input for the calculations are 10 inputs from the macro model (GDP, private consumption, investment on plant & equipment, capital stock, IT investment, exchange rate, oil price, consumption deflator, domestic corporate prices, total population, population over 65, households), 7 inputs from the industry model (industrial production index, crude steel production, ethylene production, pulp production, cement production, commercial floor space, and transport ton-kilometers), and 43 for which the simulator automatically sets assumptions (heating degree days:HDD, cooling degree days:CDD, average fuel consumption of passenger cars, power generation efficiency, hydroelectric power, agricultural heat demand, and new energy for steam generation).

There are six variables that can be set by the user. Their assumed ranges are as follows (for simplicity, only the 2040 values or the assumed values for 2025-2040 are shown).

*Nuclear power (minimum 300 PJ and maximum 1000 PJ in 2040).

*Addition of LNG in power generation (minimum value of 100 PJ and maximum value of 600 PJ in 2040). This is a realistic CO2 reduction measure in the period up to 2040.

*EV passenger car growth (average annual growth rate over 2025-2040, min 10%, max 25%).

*Home solar (off-grid): price assumptions (average annual decline over 2025-2040, min 2%, max 4%). Diffusion (average annual growth rate over 2025-2040, min 5%, max 30%).

*CO2 price (minimum value of $25/tCO2 and maximum value of

$50/tCO2 in 2040). For the CO2 price, we used the value calculated by the U.S. government (Interagency Working Group on Social Cost of Greenhouse Gases).[15]

Results of Calculation

4.1 standard solution

The reference solution is the calculated value when the user-settable exogenous variables are set to the median value (e.g., for the exchange rate, 2040 value = (min 75 + max 180)/2 ≈ ¥127/$). This is to check the reality validity of this simulator. The results (major values only) are shown in Table 2.

Table 2: Reference solutions for EYE2040

1) key results from Macro Model

		actual	forecast	
	unit	2015	2025	2040
GDP(real)	10^12yen,chained(2011)	517	555	655
private consumption (real)	〃	295	323	396
government consumption(real)	〃	105	112	129
investment of plant & equipment(real)	〃	80	88	105
export(real)	〃	83	109	179
import(real)	〃	90	121	199
GDP (nominal)	10^12yen	532	576	797
private consumpton deflator	2011=100	101.6	105.6	125.8
world trade	bill.$(2000)	11,366	14,198	22,121
crude oil price	$/bbl	49	66	72
exchange rate	yen/$	121	115	127

2) key results from industry model

		actual	forecast	
	unit	2011	2025	2040
total production	10^12yen(2011)	930	1,016	1,231
manufacturing	〃	287	275	303
construction & civil engineering	〃	53	57	60
transportation	〃	38	37	43
communication	〃	48	96	154
business service	〃	169	199	256
public service	〃	140	166	214
peronal service	〃	59	52	56
crude steel production	10^6T	108	102	94
ethylen production	〃	6.7	6.3	5.7
commercial floor area	10^6m^2	1,827	1,954	2,161

3)key results from energy model(1)

		actual	forecast	
	unit	2015	2025	2040
fnal demand total	PJ	13,745	13,329	12,858
industry	〃	6,157	5,596	5,178
household	〃	2,028	2,239	2,475
commercial	〃	2,389	2,184	1,948
transportion	〃	3,171	3,311	3,257
oil	〃	3,108	3,247	3,188
electric power	〃	63	64	69
electric power demand	10^8kwh	9,944	9,707	9,805
electric poewr generation input	PJ	9,102	8,691	8,498
coal	〃	3,189	2,466	1,510
oil	〃	1,059	889	631
gas	〃	3,651	3,802	4,239
renewable	〃	510	610	760
hydro	〃	691	698	709
nuclear	〃	2	225	650
power generation efficiency	original	0.42	0.42	0.43

3)key results from energy model(2)

primary supply	PJ	20,334	19,619	19,026
coal	〃	5,274	4,396	3,223
oil	〃	8,354	7,849	6,987
gas	〃	5,145	5,453	6,255
renewable	〃	868	1,000	1,203
hydro	〃	691	698	709
nuclear	〃	2	225	650
import pf oil	KTOE	224,758	215,585	199,610
CO2 emmision (energy oriented)	Mt-c	332	303	269
cud oil import price	yen/10^3kcal	4.32	5.69	7.38
electric price	yen/KWH	28.4	36.1	48

Table 2: Reference solutions for EYE2040(continued)

Comparison with the Government's projection

	unit	Government	ours
GDP	10^12yen,chaned(2011)	711	652
crude steel production	10^8T	1.2	1
ethylen production	10^6t	5.7	6.3
commercial floor area	10^6m^2	1971	1954
energy final demand	PJ	12453	13329
electric power demand	10^8kwh	9808	9707
CO2 emission(energy oriented)	MT-C	253	303
exchange rate	yen/$	105	115
crude oil price	$.bbl	128	66

*govarnment projetion is for 2030,ours is for 2025.
**govarnment projection(energy conservation case)

(1) Macro model results

We assume world trade growth of 2.3% per year from 2015 to 2025 and 3.0% from 2025 to 2040, exchange rates of ¥115/$ in 2025 and ¥127/$ in 2040, and oil prices of $66/barrel in 2025 and $72/barrel in 2040.

At this time, economic growth will be around 0.7% per annum from 2015 to 2025 and 1.1% from 2025 to 2040. Prices (private consumption deflator) will grow at a slightly faster rate of 1.2% per annum between 2025 and 2040. The current balance of payment will be slightly in deficit in 2040 because the deficit in the goods and services account cannot be fully offset by the surplus in the income account.

(2) Industry model results

The growth rate of total output is almost equal to the growth rate of GDP, and the output value in 2040 will be 1,231 trillion yen (2015 price). By industry, the share of manufacturing will decline (from 31% in 2011 to 25% in 2040), while the share of telecommunications will increase (from 5% in 2011 to 13% in 2040). The proportion of business services will also increase slightly. In other words, there is a noticeable de-manufacturing of the industrial structure and growth of IT services. At this time, crude steel production in 2040 will be 94 million tons, ethylene 5.7 million tons, business floor space 2.16 billion square meters, etc.

(3) Energy model results

Energy final demand falls slightly from 13,330 PJ in 2015 to 12,900 PJ in 2040. By sector, the share of industry declines (from 45% in 2015 to 40% in 2040) and business also declines (from 17% in 2015 to 15% in 2040), while that of households increases (from 15% in 2015 to 19% in 2040) and transport also increases slightly (from 23% in 2015 to 25% in 2040). The decline in the share of industry is due to changes in the industrial structure, in particular the maturation of energy-intensive industries.

Commercial energy has been in a gradual decline since the mid-2000s. The main reason for this is the progress of IT innovation. The following equation (Figure 2) shows that the increase in IT capital stock has a negative impact (elasticity -0.6) on commercial energy demand, along with electricity prices (elasticity -0.4).

```
estimation period(1990-2014)
LOG(CMTL) = -8.8 +1.90*LOG(FLOOR) -0.45*LOG(PELEC/CGPI) -0.62*LOG(IT_STOCK(1)/KP(1))
                 (-3.0)     (6.2)                (-2.9)           (-3.3)
 Adj.R^2= 0.9498  S.E.= 0.033  D.W.ratio= 1.7

CMTL:commercial energy demand
FLOOR：commercial floor area
PELEC:electric power price
CGPI:Producer Price Index
IT_STOCK:IT capital stock
KP:private capital stock total
```

Figure 2: Commercial energy demand estimation formula

Demand for electric light and power will be around 980 billion KWH in 2040. This is roughly the same level as the 2016 result (990 billion KWH). Looking at the composition of power sources, coal and oil will decline significantly, while natural gas will grow. The share of renewable energy will be 9% in 2040, while that of nuclear power will be 8%.

Primary supply declines slightly from 19,620 PJ in 2015 to 19,030 PJ in 2040. This is characterized by a decline in the share of coal (from 26% in 2015 to 17% in 2040) and an increase in the share of natural gas (from 25% in 2015 to 33% in 2040). Nuclear energy will have a share of 650 PJ in 2040, which is only 3% of the total. Renewable energy will account for 1,200 PJ in 2040, or about 6% of the total.

CO2 emissions (energy origin) will be 332 MT-C in 2015, 303 MT-C in 2025 and 269 MT-C in 2040.
Energy prices will be as follows in 2040: crude oil import price 7.4 yen/thousand KCAL, electric light overall unit price 48 yen/KWH, etc.

In addition, we compare our standard solution with the Long-Term Energy Outlook of the Agency for Natural Resources and Energy16) . Looking at this, the Long-Term Outlook assumes a slightly larger GDP and higher oil prices than ours. As for energy supply and demand and CO2 emissions, the Long-Term Outlook is slightly lower than our calculations. This is probably because the figures in the Long-Term Outlook are based on a solution that includes energy conservation to the maximum extent possible. It should also be noted that the comparison here is based on the Long-Term Outlook's figures for 2030 and our calculations for 2025.

(4) Energy-saving measures adopted here

In this section, we focus only on residential solar power (off-grid) and electric passenger vehicles (EVs) as energy-saving measures. These two are closely related to IT innovations, as is the case with Tesla in the United States, and it will be interesting to see what happens in these two areas.

Of course, CO2 reduction measures are not limited to these, but include hydrogen economy and CO2 capture and storage. The inclusion of such measures will be a future issue, based on the technological maturity of such measures.

i) Residential solar power generation (off-grid)

Here, we assume an off-grid system, rather than the current system in which the power company purchases the surplus. In other words, supply and demand will be adjusted at home using batteries. Therefore, it will have nothing to do with the feed-in tariff (FIT) system.

Assume a panel capacity of 4KW per unit and 1,150 hours of operation per year. Battery capacity is assumed to be 14 KWH, and the price including panels is assumed to be 1.96 million yen in 2015 (by the way, the battery price of Tesla's Power Pack 2 is 600,000 yen), and it shall decrease every year.

Battery prices are beginning to be put to practical use not only for EVs but also as a storage method to reduce peak demand for electricity (e.g., 80 MWH (20,000 KW) battery system for Southern California electricity peak demand measures, Mira Loma substation, in operation January 2017). Such increased use will drive down battery prices and pave the way for residential electricity storage.

Battery storage systems are being increasingly introduced, especially as a peak power plant measure, and the think tank HIS expects it to reach 52 GW worldwide by 2025.17) In the standard solution, it is assumed that 730,000 households will be installed with a system price of 1.01 million yen in 2040 (household penetration rate is 1.3%). At that time, the amount of electricity generated will be 2.9 million KWH. At that time, the amount of electricity generated per household will be 4,600 KWH/year, etc.

ii) EV (electric vehicle)

According to McKinsey, global EV sales will reach 4.5 million units in 202018). Furthermore, in relation to the global warming issue, there are headwinds for the use of internal combustion engines in cars. The UK is likely to ban the sale of internal combustion engine vehicles (including hybrids such as Prius) by 2040. California is moving in the same direction as the UK.

Here, we assume that the electricity cost (which corresponds to the fuel consumption of internal combustion engines) will initially be 5.2 KM/KWH, which will increase year by year to 7.7 KM/KWH in 2040. Under the standard solution, the number of EVs in Japan in 2040 will be 2.14 million (slightly less than 3% of the total passenger car fleet), and electricity consumption will be 1.6 billion KWH. Note that even in 2040, the number of EVs will not reach 5% of the total number of vehicles owned, so the model does not include a choice routine between EVs and gasoline vehicles (including PHVs).

4.2 Monte Carlo solution

Using the high speed of this simulator, we ran 100 simulations. Since the future of the Japanese economy and energy situation is uncertain, it is useful to understand the future trend values and realistic fluctuation ranges. By "realistic range of fluctuation", I mean the potential fluctuation of the Japanese economy in the future (without assuming fundamental structural changes).

This meaning is easy to understand if we consider it in terms of GDP movement. The range of fluctuation in 2040 based on the simulator's calculation is 652±54 trillion yen (at 11-year prices) (Figure-3). The actual GDP since 2000 (2000-2016) is 492±18 trillion yen (the same period), indicating that the fluctuation range is smaller than expected. This is an indication that the growth rate did not increase much (an average growth rate of 0.7% from 2000 to 2016) even though Abenomics and other policy variables (such as increased public investment and negative interest rates) were fully mobilized. In other words, in the Japanese economy, changing policy variables does not significantly change GDP or other indicators. This phenomenon is known among economists as the "lost 20 years.

The impact of IT innovation on economic growth is assumed to be not so great, referring to the work of the American economic historian Gordon (The rise and fall of American Growth). In this sense, the growth rate of the Japanese economy is not expected to increase much in the future. 19)

The "realistic" range of change in CO2 emissions is also not very large (245 ± 12 MT-C in 2040), because the macro and industry exogenous conditions set here have both positive and negative effects on the change in CO2 emissions. This is because the exogenous conditions for macroeconomic and industrial factors that we set here have both positive and negative effects on the change in CO2 emissions. For example, consider the case of a weaker yen (devaluation of the exchange rate). In this case, the macro effect has a positive effect on GDP due to increased exports and increased profits of companies from overseas, and this has a positive effect on energy demand (income effect). On the other hand, the depreciation of the yen increases energy prices (in yen terms), which has a negative effect on energy demand (price effect). In other words, the impact of the yen's depreciation on CO2 emissions is the offset of the income effect and the price effect.

This result suggests a problem of estimating future CO2 emissions only by energy models with simple assumptions on macroeconomic and industrial structures (the calculation results tend to be too large). This is also known as the so-called efficiency gap problem.

For example, in a recent paper (Fowlie, Greenstone, and Wolfram [2018]), it was found that energy savings in the household sector were much lower than the energy model calculation results.20) In this sense, the calculations using this simulator, which incorporates macroeconomic and industrial structure changes, may serve as a reference when looking at future trends in CO2 emissions.

The upper and lower bounds that the simulator itself can take are much higher than the "trend range" mentioned above. In the upper case, which assumes high economic growth and low energy prices, CO2 emissions in 2040 are 382 MT-C (energy origin). On the other hand, in the lower limit case, where the economy is stagnant and energy prices are assumed to be high, CO2 emissions are 178 MT-C in 2040. In other words, the simulator's computable range is 178-382 MT-C (2040), which indicates that the model has a sufficient search range.

Such a solution can be obtained by the user himself by changing the assumed values. Therefore, if you are considering a large reduction in CO2 emissions, for example, you can get some suggestions by taking a closer look at the contents of this lower bound solution (macroeconomy, industrial structure, energy supply and demand).

Table 3 Assumed values for Monte Carlo calculations (main variables)

		mean	S.E
exchange rate (yen/$)	2014act	105.9	0.0
	2025Assum	110.9	19.5
	2040Assum	124.0	28.9
crude oil price ($/bbl)	2014act	89.2	0.0
	2025Assum	62.7	11.0
	2040Assum	71.6	16.5
World Trade (bill $(2000))	2014act	11,235	0
	2014-2025growth rate	2.41	0.42
	2025-2040 gowth rate	2.86	0.68
public investment (bill.yen(2011))	2014act	26,057	0
	2014-2025growth rate	-0.6	0.6
	2025-2040 gowth rate	-0.1	0.8
nuclear power generation (PJ)	2014act	0	0
	2025Assum	230.5	49.7
	2040Assum	680.9	146.8
LNG additon (PJ)	2014act	0	0
	2025Assum	103.6	16.9
	2040Assum	362.5	59.3

In the calculations, the mean and standard deviation of each assumed value (crude oil price, etc.) were given, and the corresponding normal distribution was generated using random numbers, which were used as the assumed values for each calculation. The movements of each variable are assumed to be independent. The Box-Mueller method was used to convert the uniform distribution to a normal distribution.

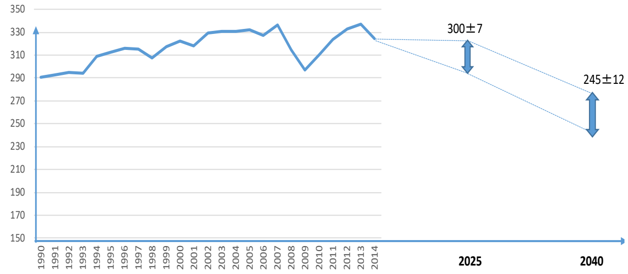
The main assumed values are shown in Table 3.

For example, the exchange rate was ¥105.9/$ in 2015, but in 2025 this is assumed to be a normal random number with an average of ¥110.9/$ and a standard deviation of ¥19.5/$, and in 2040 an average of ¥124/$ and a standard deviation of ¥28.9/$ (intermediate years use complementary values).

The main calculation results are shown in Figure 3.

This shows a realistic range of possibilities for one of the "what if questions" (the relationship between GDP and CO2 emissions). Figure 3.1) shows the movement of CO2 emissions up to 2040, and Figure 3.2) shows the movement of GDP.

1)Monte Carlo calculations(CO2 emission(MT_C))



2)Monte Carlo calculations(GDP,10^12yen chaned(2011))

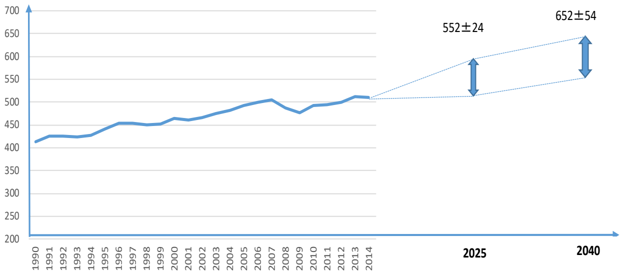


Fig. 3 Monte Carlo solution (main variables)

It can be seen that GDP will continue to grow , while CO2 emissions will continue to decline . In other words, the relationship between GDP and CO2 emissions is becoming increasingly disconnected. In this case, the amount of nuclear power generation will not increase as much as it has in the past (see the nuclear power generation assumptions in Table 3).

The causes of the disconnect between GDP and CO2 include the overseas transfer of energy-intensive industries in industry, the progress of off-grid in households, the decline in energy demand due to IT innovation in commercial sector, and the decline in car use due to aging in the transportation sector.

Let us look at this in terms of the GDP elasticity of CO2 emissions (the so-called Kuznets curve). The trend value of CO2 emissions in this calculation (2014-2040) is -1.1. This is considerably larger than the historical value (2000-2016) of -0.2. It is also large compared to the elasticity (-0.3) at per capita income above $10,000 in the classic study of Schmalensee (1998)[21) . From this perspective, the present calculations seem to indicate one possibility for the decoupling argument.

As a trend value, the economic growth rate will be slightly higher in the second half of the period 2025-2040 than in the first half of the period 2015-2025. This may be due to the fact that the latter half of the period incorporates the recovery trend of the global economy and the increase in the number of immigrants domestically.

If sales of electric power companies are determined bby the product of the amount of electricity sold and tthe price of electricity, then the future growth in ssales of electric power companies will depend on the pprice of electricity. Here, we use 48 yen/kwh as the ccentral value, but if prices do not rise by this amount, electric power company sales will face a slump.

5. conclusion

The global warming issue is a "tricky problem," and different people have different positions and opinions. Under these circumstances, we have developed simulation software to help advance the debate when discussing future global warming countermeasures. This software is expected to be useful in convergence of discussions by making counterfactual calculations for various questions on the global warming issue, and by enabling a back-and-forth between hypotheses and quantitative solutions. As a tool for discussion, the simulator is useful because of its high speed (answers are given instantly) and comprehensive nature (it covers from macro economy to energy demand).

Using this simulator, we estimated CO2 emissions consistent with the macroeconomic and industrial structure up to 2040. In the base solution (2025), it is almost comparable to the figures in the Long-Term Energy Demand and Supply Outlook. According to the Monte Carlo calculation, which was set up to obtain a realistic trend value based on the past movements of the Japanese economy and CO2 emissions, the relationship between economic growth and CO2 emissions seems to be gradually decoupled, as suggested by the Kuznets curve. In this case, it is not as dependent on nuclear power generation as it was at its historical peak.

We also found that the sales of electric power companies will depend on the price of electricity in the future, as long as demand growth is not expected. Of course, this is only one possibility. However, the simulation software can be run by anyone with a Windows PC22) . Therefore, the results can be verified even by non-energy specialists, and it is expected that new arguments will emerge from such work.

Future issues include: (1) Although only household off-grid and EVs are treated here as energy conservation measures, other CO2 control measures (hydrogen economy, CO2 capture and storage, etc.) should be included in the assumptions, while taking into account the technological maturity level, and (2) although the calculations here are made in one direction (macroeconomy → industrial structure → energy supply and demand), the macro effects of energy conservation measures should be included.

We would like to thank the reviewers for their helpful comments in the preparation of this paper. We also thank Professor Emeritus Shuzo Murakami of the University of Tokyo for various suggestions in the early stages of the development of this software.

references

1) H.W. Rittel and M. M. Webber ; Dilemmas of a General Theory of Planning,Policy Sciences, 4 ,(1973), 155-169

2) Lu Hong and S.E. Page; Groups of diverse problem solvers can outperform groups of high-ability solvers,PNAS,Nov,16,(2004),Vol.101,No.46

3) Judia Pearl and Dana Mackenzie ;The Book of Why (2018), Allen Lane

4) W. Nordhaus; Economics of Global Warming, Yasuhiro Murota and Yukari Yamashita, translated by Kae Takase (2002), Toyo Keizai Inc.

5) T.C.Koopmans ;On the concept of optimal economic growth, Pontifica Acadeia Scientarvm, The Econometric Approach to Development Planning,Oct 7-13,1963, (1965) 223-287,North-Holland

6) IPCC Working Group III ; Climate Change 1995, Cambridge Univ. Press,1996
Chapter 4 Intertemporal Equity, Discounting, and Economic Efficiency

7) Karl Popper; The Open Universe, translated by Makoto Ogawara and Yasuyuki Kageyama (1999), Iwanami Shoten, p73

8) A.P.Kirman; "Whom or what does the representative individual represent ? ", Journal of Economic Perspectives, (1992) Vol.6.No2

9） M.Morishima;Comment on Koopmans' paper, p295
Pontifica Acadeia Scientarvm, The Econometric Approach to Development Planning,Oct 7-13,1963,(1965) North-Holland

10)R.M.Solow; Comments, Journal of Economic Perspectives, (2008) Vol.22,No.1,Winter

11) S.Bernstein , R.Lebow,J.Stein. andS.Webere, "God Gave Physics the Easy Problems: Adapting Social Science to an Unpredictable World", European Journal of International Relations, (2000) Vol.6(1),pp43-76

12) R.Adner and D. Levinthal ; "What is not a real option: considering boundaries for the application of real opions to business strategy", Academy of Management Review, 2004,Vol.29,No.1

13) National Institute of Population and Social Security Research, "Population Projections for Japan (January 2012 Estimates).
In Japanse
(14) Kohei Yoshinaga, "The Input-Output Table of the EU as a Whole and Its Economic Structure", Input-Output, (1997) Vol.7,No.4
In Japanese
15) Interagency Working Group on Social Cost of Greenhouse Gases;Technical Support Document:Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis UnderExecutive Order 12866, (2016) United States Government
(16) Agency for Natural Resources and Energy, "Long-Term Energy Supply and Demand Outlook, Related Materials," July 2015.
In Japanese
17) Henry Sanderson ;Grid storage batteries help electric vehicles go truly green,(2018) Financial Times, Sept 5,2018
18) Mckinzey & Company; The Global electric-vehicle market is amped up and on the rise, (2018)
19) R.Gordon; Rise and Fall of American Growth,Princeton Univ.Press,2016
(The End of Growth: The American Economy, translated by Hiroko Takato and Yumi Yamaoka, Nikkei BP,2018
20) M.Fowlie, M.Greenstone,C.Wolfram, "Do Energy Efficiency Investments Deliver?Evidence from the Weatherization Assistance Program",QJE,Vo.133,1 August 2018,pp1597-1644
21) R. Schmalensee and T. M. Stoker, "World Energy Consumption and Carbon Dioxide Emissions:1950-2050",R.E.Stat.
(22) A free version can be downloaded from www.e1yosoku.com (not available now). A list of model equations will be published on the website.