The IEEJ Outlook and the Technology Selection Model

The Differences and Implications of the Analyses Using Two Modelling Frameworks

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1. Introduction

In February 2025, the Japanese government received Cabinet approval for the 7th Strategic Energy Plan. In the formulation process for that Plan, six organizations, including the Institute of Energy Economics, Japan (IEEJ), submitted scenario analysis for 2040 and 2050 to the Strategic Policy Committee (December 2024). Additionally, separate from that analysis, the IEEJ also publishes global long-term energy supply and demand projections in its annual IEEJ Outlook. These two analyses, which serve different purposes, do not necessarily present the same solution and therefore rely on different analytical frameworks. In this paper, these two analytical frameworks and their results are compared to show the challenges toward achieving net zero in 2050 and the points to keep in mind when interpreting the results.

2. Comparing the two models' analyses:

2.1 Analytical methods

Table 1 compares the two analytical frameworks' differences. The IEEJ-NE (technology selection model) that was used for the Strategic Energy Plan is a backcast-type model for calculating "What should be done?" with cost minimization through linear programming. In contrast, the IEEJ Outlook is a forecast-type model that uses an econometric approach to predict "What if ~?" When the two are compared, their scenario categories are contrastive, and significant differences in how they handle CO_2 emissions and the determining factors of the energy mix can be viewed in the background to that.

Table 1 Characteristics of the Analytical Frameworks

	Technology Selection Model IEEJ-NE	**IEEJ Outlook Model**
Coverage of analysis	**Overall energy supply and demand up to 2050 (primary supply, transition, end use)**	
Category of scenario	**Backcast-type scenario**	**Forecast-type scenario**
Character of scenario	**What should be done** in order for ~?	**What** if ~?
Model used	Technology selection model (cost minimization through linear programming)	Cohort of models centered on an econometric-type model

Handling of CO_2 emissions	Is a constraint of the model analysis, and its attainment is taken as a given. (70-71% reduction in 2040 and net zero in 2050)	The result of estimates that are calculated for a case that envisages the maximum countermeasures in each sector. (In the case of the Advanced Technologies Scenario[1])
Energy demand	Service demand (crude steel production, volume of goods transported) is **given**. Calculates the energy supply volume that satisfies this.	Demand is **the estimation result** from economic assumptions for GDP, population, etc., and assumed energy prices and energy intensity.
Determining factors of the energy mix	Cost minimization based on conditions such as technology costs and upper limits for the introduction of technologies.	Time trends, energy price elasticity values + assumptions, collectively

To begin with, for CO_2 emissions, the analysis submitted for the debate on the Strategic Energy Plan utilized a technology selection model known as the IEEJ-NE Japan model. This analysis can be described as a backcast-type analysis that asks: "What sort of energy mix should be selected in order to realize reduction targets for the smallest cost?" On the other hand, the Advanced Technologies Scenario in the IEEJ Outlook, which is the main IEEJ Outlook scenario taken up in this paper, is a forecast-type analysis that asks: "In a case in which each country implements conceivably realistic emission reduction measures to the maximum extent, what sort of energy mix will it give rise to, and to what extent will CO_2 emissions reduction progress?" An important difference between this and the technology selection model is the fact that the attainment of reduction targets is not taken as a given.

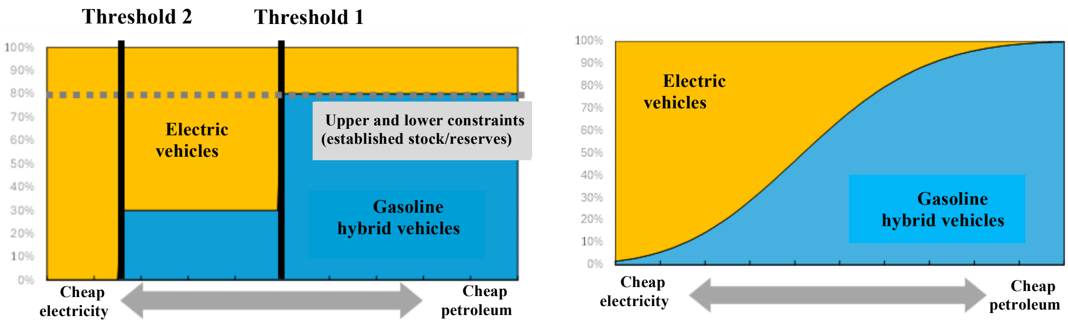
In addition, there is also an important difference in the method that the two models use to calculate the energy mix. Here, I will explain the example of the competitive relationship between gasoline hybrid vehicles and electric vehicles (Fig. 1). The technology selection model is a model that calculates the technology mix with the lowest cost, and in a case where a difference in cost between competing technologies arises, it is possible that the optimal solution in terms of technology share **will change suddenly at a certain threshold**. On the other hand, in the IEEJ Outlook, by taking into consideration assumptions for empirical price elasticity values, the pace of technology switches that account for time trends, etc., and other factors, it utilizes an analytical model[2] structured so that in a case where the costs when using a certain technology decline, that technology's share **gradually rises**. A technology structure is estimated that simulates the intensity and pace at which users undertake the energy transition, after taking into consideration also information such as technology cost changes, and furthermore, in the case of the Advanced Technologies Scenario, experts' views on various policy measures and the volume of the technologies introduced.

This difference is also one of the factors that makes the two analyses "backcast" and "forecast".

[1] Please bear in mind that although a scenario with the same name is presented in the supporting material for the 7th Strategic Energy Plan, its positioning differs considerably. In contrast to the IEEJ Outlook, where the Advanced Technologies Scenario is a scenario that assumes the maximum advances in climate change measures, in the 7th Strategic Energy Plan it is a scenario that assumes delays in progress with decarbonization technologies.

[2] Founded on a logit model. This is a method for estimating selection probability on the basis of relative costs and benefits between technologies, and is commonly used for estimating share in a diverse range of fields, such as the selection of fuels and transport modes.

The technology selection model is a model that poses "What should be done?" and calculates the cost-optimal energy mix in regard to conditions. On the other hand, the IEEJ Outlook can be described as an analysis for estimating a technology structure that simulates users' responses to changes in conditions such as technology costs; it is an analysis that asks "What if?", in other words.



Technology selection model (IEEJ-NE) IEEJ Outlook Model

Fig. 1 Schematic diagram of energy mix determining factors

2.2 Analysis results (1)CO_2 emissions (by sector)

Fig. 2 shows Japan's energy-related CO_2 emissions and their breakdown by sector, according to the two models' calculation results. Incidentally, the technology selection model analysis introduced here comprises four cases in which differences have been set for the degree of advancement of the respective technologies, and of those four cases, Fig. 2 displays the results for "Case 1: Advanced renewables" and "Case 3: Advanced CCS".

(a) Comparison of total CO_2 emissions (energy-related)

The technology selection model's analysis takes the attainment of the 2040 NDC[3] and net zero by 2050 as given constraints, and it comes up with an energy mix toward that. On the other hand, in the IEEJ Outlook, as a result of stacking up factors such as phenomena trends, maximum technological advances, and policy measures in each sector, and behavior changes among users accompanying that, the model's 2040 prediction aligns with the NDC, but a gap of around 6% (compared to 2013) remains at 2050. This unattained portion could be described as hinting at the limits of the maximum accumulation of technologies and policies that is currently conceivable, as well as the difficulty in attaining the net-zero target.

Incidentally, it is necessary to bear in mind that in the Outlook analysis and the analysis that utilized the technology selection model that are compared here, the assumed economic growth rates differ. Supposing a case in which the economic growth rate of 1.6%/year, which is assumed in the technology selection model's analysis, is utilized in place of the economic growth rate of 0.8%/year (2022-2040) on which the Outlook analysis is premised, the Outlook analysis's energy demand and CO_2 emissions would climb higher.

(b) Comparing the breakdown of CO_2 emissions by sector

In the energy mix for which the overall minimum cost is calculated through the technology selection model, a clear order of preference emerges in terms of CO_2 emissions by sector. To

[3] This is a target to reduce greenhouse gas emissions by 73% (compared to 2013 levels) by 2040, which the government set as Japan's "nationally determined contribution" in February 2025. A 70-71% reduction in energy-related CO_2 emissions, which is consistent with that target, is set as a premise.

begin with, the power generation sector approaches zero emissions rapidly, and in 2050, a picture emerges of significant declines in emissions in the buildings and transport sectors, also. On the other hand, because the industrial sector requires high-temperature heat that is difficult to attain with electrification, the need will emerge to rely on future technologies such as hydrogen reduction, synthetic fuels, and CCS. As a result of this, the pace of the sector's emissions reduction will be slow compared to other sectors, and the sector will account for around half the emissions in 2050.

On the other hand, in the Outlook model, the pace of reductions between sectors is nearly in line. Like the technology selection model, in the Outlook model, the industrial sector will account for the largest amount of emissions in 2050. However, in contrast to the technology selection model, in the Outlook model, a certain amount of emissions will persist even in the buildings and transport sectors. The Outlook model does not take it as a premise that decarbonization will necessarily occur in each sector; it simulates actual behavioral changes by stacking up price elasticity values and systems. In the determining factors of the energy mix that were shown earlier in Fig. 1 (right graph), the end portions represent groups of users that remain largely unresponsive to prices and policy incentives. And because strata such as this exist in every user sector, in the Outlook model, this means that a certain amount of emissions will persist in any sector.

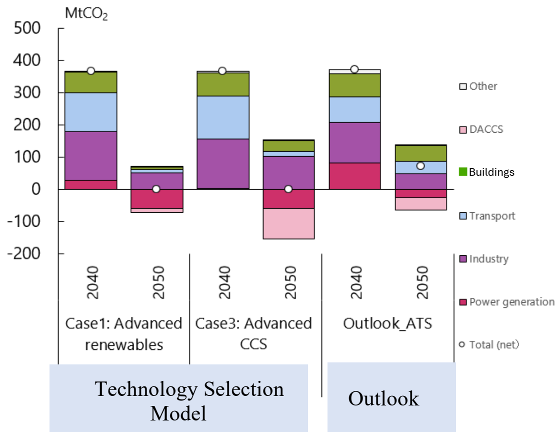


Fig 2. The models' calculation results (energy-related CO_2 emissions)

NOTE: BOTH MODELS COVER ENERGY-RELATED CO_2 EMISSIONS OVERALL, BUT THE DEFINITIONS OF THE SECTORS INTO WHICH THE EMISSIONS ARE BROKEN DOWN DO NOT MATCH COMPLETELY.

The differences in the calculation results of both models illustrate the gap between theoretical optimal solutions and moves toward fuel transition by actual users. Based on the results of both, it can be seen that: (1) **for decarbonizing the industrial sector, an acceleration in technological innovation, along with negative emissions technologies[4] that can offset the portion that cannot be fully reduced, will be particularly vital,** and (2) **even in other sectors, not all users are necessarily capable of fuel transition**. This suggests that in pursuing actual policy-making toward carbon neutrality, in order to move from the "upper limits of the collective assumptions that are conceivable now," as is presented in the Outlook model, and draw closer to the "theoretical optimal solutions" presented in the technology selection model, it will be particularly important to have measures in place to support strata in all user sectors that will struggle with fuel transition.

[4] Indicates technologies that collect and remove CO_2 from the atmosphere. In the two models explained in this paper, both take Direct Air Carbon Capture & Storage (DACCS) and Bioenergy with Carbon Capture and Storage (BECCS) into consideration.

2.3 Analysis results (2) Power generation mix

Next, the power generation mix is shown in Fig. 3. Incidentally, the amount of power generated differs significantly as a result of differences in the economic growth assumptions of both models. Note that a comparison was carried out using generation mix ratios in Fig. 3.

In both analyses, common points in the energy mix from 2040 are that there is substantial transition progress, renewable energy is adopted in large quantities (around 55-63% in 2050), nuclear power supports the baseload, and thermal power remains (20-30% of the mix).

The models differ, however, in how that thermal power is made up. In the technology selection model, ammonia is the mainstay in Case 1, and gas CCS and ammonia are the mainstays in Case 3, with limited use of coal-fired thermal power in both Cases, but in contrast, in the Outlook model, coal, gas, and ammonia are in balance, being employed in comparatively close amounts. This is because the technology selection model optimizes the energy mix by evaluating the merit order across a year's 8,760 hours (365 days x 24 hours), making it likely that the energy mix will converge on the most competitive fuels.

Results such as this provide a large number of hints as theoretical cost-optimal solutions, but there is no guarantee that facilities that are inferior in terms of the merit order will, in fact, necessarily cease operating. That is because in the real world, each region's supply and demand gap, operators' investment strategies, system responses, and other factors work in combination, and so things will not necessarily move toward optimal solutions in a straight line. The IEEJ Outlook can be said to be presenting a balance after incorporating elements such as this (strictly as macroscopic elasticity values), while also taking differences in generation cost into consideration. However, when it comes to a desirable power generation mix that actually covers these points at issue, a more detailed bottom-up analysis will be needed.

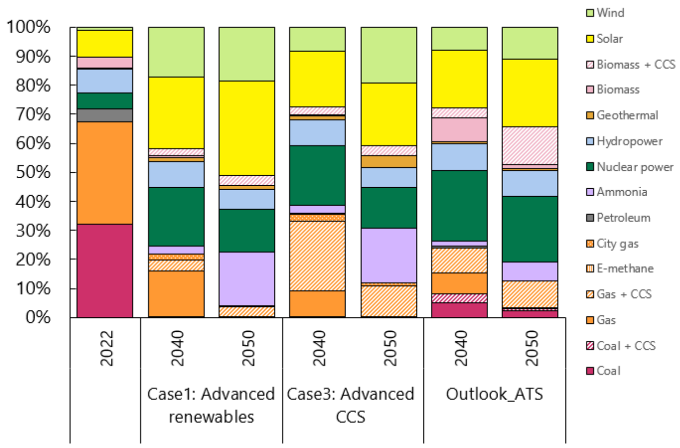


Fig. 3 The models' calculation results (power generation mix)

NOTE: THE DEFINITIONS OF TECHNOLOGY CATEGORIES IN THE TWO MODELS DO NOT MATCH COMPLETELY.

3. Conclusion

Currently, a large number of organizations are announcing quantitative scenarios. Attention needs to be given to the fact that the implications of those figures will change greatly depending on which of the questions they are based on: "What should occur?" or "What will occur?"

The supporting material for the 7th Strategic Energy Plan only mentions that thermal power will account for "30-40%" of the energy mix in 2040, and the fact that the omission of a breakdown by fuel suggests a deliberate decision, reflecting both the characteristic features of the analytical frameworks and the uncertainty of future developments. In the analysis by the six organizations at the Strategic Policy Committee, what was presented were "theoretical optimal solutions" based on their respective assumptions, and since their assumed conditions are accompanied by many uncertainties, the analysis is some distance away from predictions as "forecasts."

In addition, the recent Strategic Energy Plan presents an overall image of energy supply and demand, but in the process, from here on, there are expected to be discussions on specific ways forward in each sector. The authors also intend to continue providing analysis that contributes to the energy transition, while appropriately combining the two analytical frameworks discussed in this paper.

3. References:

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