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An Integrated Scenario Analysis for Future Zero-Carbon Energy System

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Abstract

An integrated scenario analysis methodology has been proposed for zero-carbon energy system in perspectives of social-economy, environment and technology. In the methodology, firstly various service demands were estimated based on social-economic data, and best technology and energy mixes were obtained using the optimization model to meet the service demand. The methodology has been applied to Japan toward zero-carbon energy system out to 2100. The results show that, in the end user side, zero-carbon energy scenario was obtained based on 75% on electricity and three power generation scenarios were proposed, 30% renewable and 70% gas-CCS in scenario 1, respective one third nuclear, renewable and gas-CCS in scenario 2, and 60% nuclear power, 20% renewable and 10% gas-CCS in scenario 3. Finally, the scenario 2 with balanced diversity in nuclear, renewable and gas-CCS was recommended based on comprehensive inter-comparisons. The feasibility of the proposed methodology has been demonstrated.

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Keywords: Zero-carbon, scenario analysis, renewable energy, nuclear power, Fukushima Accident

1. Introduction

Rising carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions largely resulting from fossil fuel combustion are contributing to higher global mean temperatures and to climate change. Humanity has to decide if business as usual will continue or if concerted action is to be taken in reducing CO_2 emissions. To do this, Japanese policy makers need to clearly understand the level of the commitment required. The CO_2 emission reductions required could be achieved mainly in three different ways: by a reduction in energy demand, an expansion in nuclear power and the increase in renewable energy. Increasing the share of electricity utilization in the end-user side is considered to be the most effective way to reduce demand through technology substitution and energy saving, and increase the penetrations of nuclear power and renewable energy simultaneously. Therefore, the philosophy adopted in the energy scenario planning for Japan considers that the future society toward to 2100 is becoming more reliant on electricity, and thus

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further highlights the need to move to a zero-carbon electricity system based on zero-carbon power sources including nuclear power and renewable energy [1-2]. This research aims to develop an integrated scenario analysis methodology for future zero-carbon energy system, and it will be applied to Japan to assess the role of energy efficiency, structural change in industry, and new supply options for transitioning Japan's economy to a lower-GHG trajectory in the longer term.

2. Methodology

An integrated energy scenario analysis model has been proposed as shown in Fig.2 [3-7]. It is composed of three parts: (i) a bottom-up simulation model for estimating final energy demand based on the information of macro-economy, lifestyle, industrial structure and technology improvement; (ii) a optimization model for conducting power generation planning for meeting electricity demand subject to various constraints including natural resources, economic, environmental, geographic, natural conditions, etc. (iii) an hour-by-hour simulation model for testing the reliability of the obtained power generation best mix considering renewable energy and smart grid strategy integration.

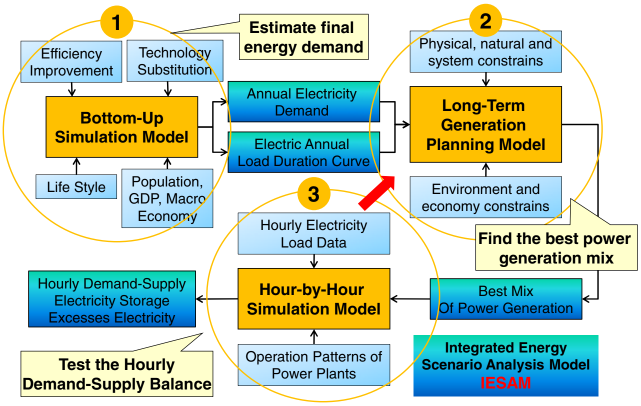


Figure 1 Proposed integrated scenario analysis model

3. Scenario Analysis

The methodology proposed previously was applied to Japan toward 2100. The key technologies in residential, commercial, transportation and industry sectors are shown in Figure 2. It is obvious that, at end-user side, more and more electricity will be used to reduce CO_2 emission; on the other hand, renewable, nuclear and clean thermal power will be used to provide zero-carbon generations. In some parts of industry, biomass and hydrogen will be used as rural material and heat source. Therefore, an electricity based future zero-carbon electricity system is designed as illustrated in Fig. 2.

A scenario analysis of zero-carbon energy system toward 2100 using a developed integrated analysis model was shown in Fig. 3. The result in Fig.3 shows that with the help of all electrification in residential and commercial sectors, electric vehicles, bio-fuel airplane etc. technologies in the transportation sector and hydrogen steel making, bio-refinery for new material, eco-cement making, paperless office, etc. technologies in the industrial sector, in the end-user side, zero-carbon energy scenario was obtained. The obtained final energy mix show that zero-carbon electricity generation system is of vital importance to the achievement of a zero-carbon emissions energy system in the future, with the society becoming reliant on electricity more and more. The electricity demand is expected to keep at the same level of 1000TWh from 2010 to 2100, but the electrification ratio will be increased from 25% to 75%.

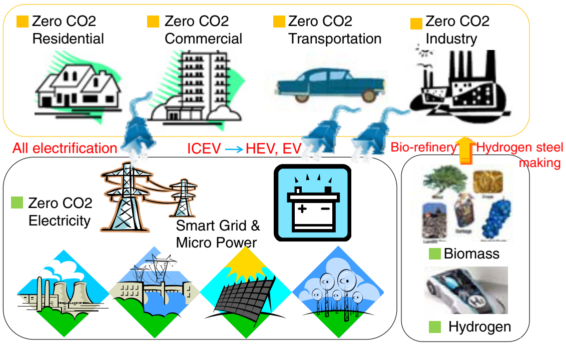


Fig.2 Electricity-based future zero-carbon energy system

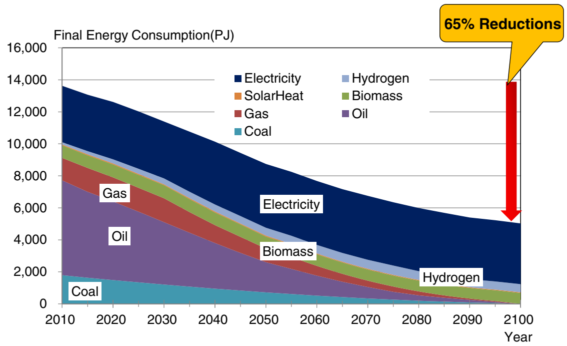
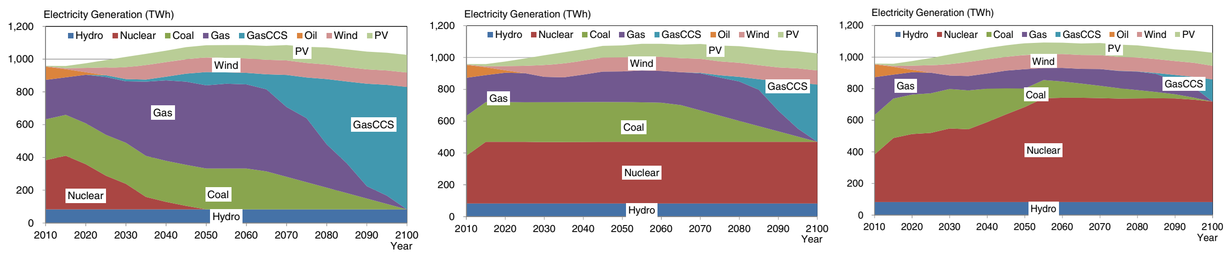


Fig.3 Final energy demand in the design scenario

Three power generation mix scenarios and their comparisons are shown in Fig.4. In the first scenario, no new nuclear power plant is built since 2010, on the other hand, in the second scenario, new nuclear power plant is permitted but the maximum capacity is limited to 50GWe, and no any constraints are used for nuclear power. The results show that compared with 70% dependent on gas or 60% on nuclear in the first and third scenario respectively, on the contrary, renewable energy, nuclear power and gas-CCS provide 30% respectively in the second scenario.



2100 Scenario 1 (No New Nuclear since 2010)

2100 Scenario 2 (Max 50 GWe Nuclear Power)

2100 Scenario 3 (No Constraints on Nuclear Power)

Fig.4 Electricity generation mixes in three scenarios with different nuclear power policies

The inter-comparison of the three different scenarios was conducted by an integrated perspective by using a radar chart as shown in Fig.5. Three scenarios are evaluated from versatile aspects of economy, environment, risk and diversity aspects, by using total cost, accumulated CO_2 emission, Herfindahl-Hirschman Index (HHI) and immediate fatality rates. The risk is calculated based on the published data of fatality rate per GWe times operating year for various types of power generation technologies [8]. All the data of the four indexes are standardized as normalized from 0 to 1, where lower number value of HHI for example means higher diversity. Therefore, for all the four indexes the smaller value the better performance. Therefore, Scenario 1 is the worst among the three. The scenario 3 is better than the Scenario 2 in both risk and CO_2 emission with equal in cost. The Scenario 2 is better than the Scenario 3 in HHI, diversity of energy source. Therefore, the second scenario can be recommended based on the comprehensive comparisons of the three scenarios.

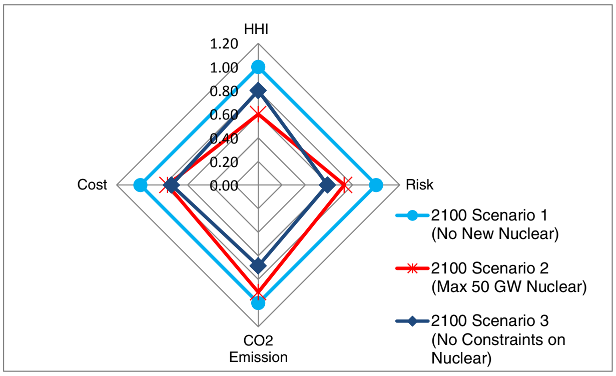


Fig. 5. Comprehensive comparisons of three different scenarios to 2100

4. Conclusion

An integrated scenario analysis model has been proposed for future zero-carbon energy system, and it has been applied to Japan. Scenario analysis has been conducted on energy system in Japan out of 2100 in perspectives of social-economy, environment, technology and security. Firstly various service demands were estimated based on social-economic data, and the best technology and energy mixes were obtained using the optimization model. The results suggest that, in 2100, electricity will provide more than 75% final energy and electricity is generated by different scenarios based on different nuclear power policies. Finally, the second scenario with a balanced diversity of nuclear, renewable and gas-CCS was recommended. The feasibility of the proposed methodology has been proven through the case study.

5. Acknowledgements

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