Systems Analysis Group

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Research Activities in Systems Analysis Group

The Systems Analysis Group aims to provide valuable information about response measures to global warming and energy issues through systematic approaches and analyses. This article presents the outcomes of the analyses that our group has been conducting for future scenarios with regard to the countermeasure strategies for decarbonization.

1. Role of CCU for realizing Carbon Neutrality

The direction of the measures for realizing carbon neutrality and the role of Direct Air Carbon Capture and Storage (DACCS) as a negative emission technology are explained in the featured article about Beyond EXPO. In this chapter, we introduce the role of Carbon Capture Utilization (CCU) for pursuing carbon neutrality with the analyses by our global energy and climate change mitigation assessment model, DNE21+.

1.1. Overview and Focal points of CCU

There are several forms of CCU, such as Enhanced Oil Recovery (EOR) as a form of CO_2 storage, and the use for fuels, chemicals and promoting mineralization, and so on. CO_2 is chemically stable thus additional energy with synthesized hydrogen etc. is necessary to utilize it for energy or chemicals. On the other hand, the promotion of mineralization, such as mineralization of cement, does not require additional energy during the process.

It should be noted that the fuel use, for instance, does not have CO_2 emission reduction effect since CO_2 captured and used for synthesis is emitted at combustion. In that case, CO_2 plays a role as an intermediary for hydrogen transport to enhance the convenience of hydrogen. CO_2 can be reduced by replacing fossil energy with carbon-free hydrogen energy. The CO_2 emission reduction effect by the alternative is the same as the amount of CO_2 used for synthesis.

In principle, there is no difference in the CO_2 used for synthetic fuels regardless of its source, even if the CO_2 from fossil fuel combustion is captured and used. However, in that case, fossil fuel combustion is performed separately, and gross zero emission cannot be achieved. Therefore, in order to achieve net zero emission, negative emission technologies (NETs) should be conducted somewhere in the world to cancel out the CO_2 emission from the fossil fuel combustion. There are some arguments on one hand that the CO_2 used for synthetic fuels should be limited to the CO_2 captured by DAC or from bioenergy emission, however, it is necessary to evaluate in terms of economic efficiency for the whole system. Although the evaluation of CCU is difficult, which may lead to both overevaluation and under-evaluation, it is important to make a better assessment in the whole system considering the current status.

1.2. Evaluation of the role of synthetic fuel, a representative example of CCU by DNE21+

This section shows the example of the analyses on the countermeasures for global carbon neutrality by global energy and climate change mitigation model, DNE21+. The DNE21+ can make an assessment until 2100, with 54 regions, in which around 500 technologies can be assessed. Here, we introduce the analysis results about synthetic fuels for which systematic analysis is considered particularly important. For detailed assessment of synthetic methane and synthetic oil, please refer to Reference 1) and 2), respectively. Reference 1) indicates that applying synthetic methane would be economically efficient in the case that there are large differences in the marginal abatement cost (MAC) of emission reduction target among nations, as it would be economically rational that methanation is conducted in the country where MAC is relatively low and the methane is exported to and used in the country where MAC is relatively high. The result of the scenario where the globally equalized MAC is assumed, which tends to show slightly conservative result for synthetic fuels, is introduced in this article.

Table 1 shows the assumed scenarios for model analysis.

The production and consumption of hydrogen which is an energy source of synthetic fuels are shown in Fig. 1. The major production method will be gasification from coal and lignite with CCS (blue hydrogen) in the standard cost case of PV (2DS_1 scenario) and water electrolysis by solar PV (green hydrogen) in the low-cost case of PV (scenarios other than 2DS_1). As for consumption, hydrogen will be used as itself in various ways, including power generation, hydrogen direct reduction steelmaking, and transportation, and also the use for synthetic fuels with captured CO_2, such as synthetic methane and synthetic oil, is evaluated as an economically efficient measure. Fig. 2 shows the global CO_2 consumption for synthetic fuels. This amount is equal to CO_2 reduction effect caused by replacing fossil fuels with use of synthetic fuels (carbon-free hydrogen). The result shows that the CO_2 used for synthetic fuels is not limited only to captured CO_2 by DAC or from biomass combustion but mainly captured CO_2 from fossil fuel combustion, even under B1.5D_3_DAC, where DAC is assumed available.

Table 1　Model analysis scenarios

Scenario name	Global emission scenarios	[Supply side] PV cost	[Demand side] Fully autonomous cars and Share mobilities acceleration	[NETs] DAC
2DS_1	Below 2 °C (>50%): Corresponding to IEA ETP2017 [2DS]	Standard cost reduction	w.o. consideration	w.o. consideration
2DS_2		Low cost particularly in Middle-East & N. Africa		
2DS_3			Share mobilities acceleration (Fully autonomous cars)	
B2DS_2	Below 2 °C (>66%): Corresponding to IEA ETP2017 [B2DS]	Low cost particularly in Middle-East & N. Africa	w.o. consideration	w.o. consideration
B2DS_3			Share mobilities acceleration (Fully autonomous cars)	
B1.5D_3_DAC	Below 1.5 °C in 2100 (>66%): overshoot of temperature	Low cost particularly in Middle-East & N. Africa	Share mobilities acceleration (Fully autonomous cars)	Available (Low cost) No feasible solution if DAC not available

Note) 1: The assumed PV costs in the standard scenario are below 60$/MWh accounting for about 6% of the global PV potential and 60-80$/MWh for about 24% in 2050. Those in the low cost scenarios are below 30$/MWh accounting for 15% of the global PV potential and 30-40$/MWh for about 14%. 2: It is assumed that fully autonomous cars are available in 2030 and ride-/car-sharing is accelerated in the fully autonomous cars and share mobilities acceleration scenarios. 3: The assumed necessary energy for DAC is 4.7GJ/tCO2 in 2050.

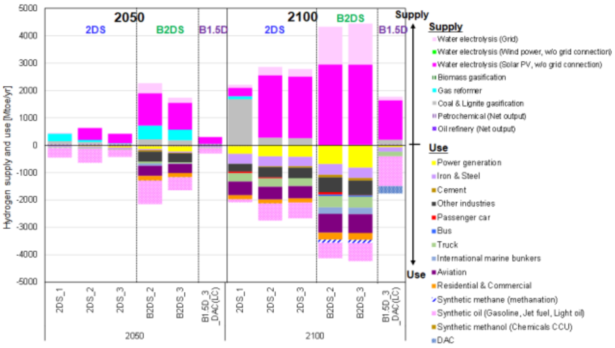

Fig.1　Global hydrogen balances

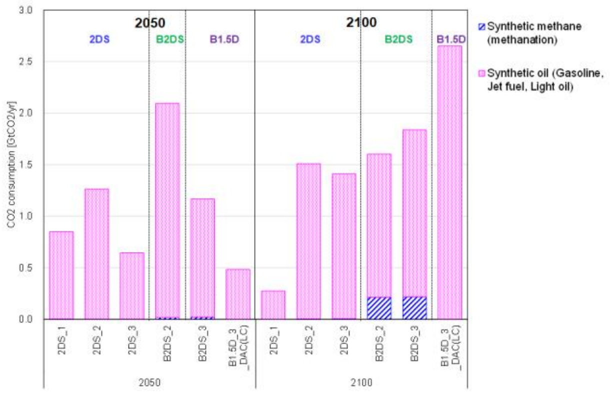

Fig. 2 Global CO_2 consumption for synthesis fuels

The use of synthetic methane can contribute to realizing carbon neutrality with utilizing existing infrastructure and gas appliances by use of piped gas. As for synthetic oil, it will be possible to achieve carbon neutrality while utilizing existing infrastructure and technologies, such as hybrid vehicles, in the road transport sector. Also, the use of those synthesis fuels will be effective for the measures which are difficult to replace with electricity or hydrogen in the aviation, marine bunkers, industry, and other sectors. The role of synthetic fuel as CCU should be evaluated integrally with hydrogen supply, and the evaluation is not simple. However, our analyses suggest that it can be an important piece of measures for achieving carbon neutrality.

2. Assessing impacts of border carbon adjustment using global energy-economic model

2.1. Background of border carbon adjustment (BCA)

The goal of achieving net zero emissions by 2050 has been set by countries around the world. If the cost of burden of reducing GHG emissions in one country is greater than that in other countries, it will affect the international competitiveness of energy intensive countries in that country and will lead to leakage of CO_2 emissions to other countries (substitution of domestic products by overseas products and transfer of production bases overseas). Border Carbon Adjustment (hereinafter referred to as BCA) is being discussed as one of the options to deal with this problem. In general, the BCA is a border measure that imposes the same burden on imported products from countries with insufficient emission reduction efforts as domestic products.

In December 2019, Ursula von der Leyen, the president of the European Commission, announced the European Green Deal (see Reference 3), that contains a goal of net zero greenhouse gas emissions by 2050. It also includes a roadmap for the carbon border adjustment mechanism (CBAM). At the European Council meeting in July 2020, it was agreed that the institutional design would be completed in the first semester of 2021 with a view to its introduction at the beginning of 2023. It should be noted that introduction of BCA involves challenging issues, regarding such as compatibility with World Trade Organization (WTO) rules, the methodology for assessing the carbon content of products and how the tax rate is adjusted.

2.2. Methodology

We examine the impacts of BCA by using the global energy-economic model that we have developed, called the DEARS model[4]. The model is an integrated model of a top-down economic module (general equilibrium type) whose objective function is to maximize the global utility of consumption, and a simplified bottom-up energy system module. In the economic module, 16 non-energy industries are assumed, and the input-output (IO) structure based on the GTAP (global IO table), is explicitly modeled. Regarding trade, the Armington structure with the substitution between imported and domestic products is formulated.

This study focuses on steel products as a case study and shows the economic impacts and CO_2 emissions under multiple cases, by assuming two types of tariff methods for border adjustment as follows.

I. BCA tariff

In general, the BCA tariff rate is determined by the average CO_2 intensity embodied in the imported products made in the country of origin. In this case, heterogeneity within the same products is not considered.

II. CSTR (Cooperative Sectoral Tariff Reduction) tariff

The CSTR tariff, proposed by Banks and Fitzgerald (2020)[5], is based on the differentiated CO_2 intensity embodied in the imported products, taking into account the heterogeneity within the same ones. The CSTR tariff will encourage a shift to the products with relatively low intensity, which leads to more reduction in CO_2 emissions. However, because of the considerable difficulty involved in estimating the distribution of energy intensity of steel production within each country, the following assumptions were made for this analysis. First, steel products are classified into three product groups (universal grouping) according to their energy intensity: (i) Good (0.10[GJ/$]), (ii) Middle (0.80), and (iii) Poor (1.50) (hereinafter referred to as Good, Mid., and Poor, respectively). Then, the ratios belonging to each product group by region are assumed to be consistent with the statistical data of regional average energy intensity in steel production.

Following previous studies[6)7)], we assume substitutability between demand of imported products and that of domestic ones by using a CES-type function with the elasticity of substitution (δ) that is assumed to be 1.5 in the standard case. Furthermore, we assume an elasticity of substitution of 2.0 for the demand between the product groups.

Table 2 shows the simulation cases in this study. We examine the impact of BCA and retaliatory measures based on a simplified scenario in which Japan, the US and the EU cooperate in implementing domestic emission reduction measures while the rest of the world (ROW) do not take any measures. Two types of carbon tariff are assumed as mentioned above, and we explore the impact of favorable treatment for the product group with the lowest intensity.

Table 2 Simulation cases

Case name	Regions with domestic carbon tax: 32$/tCO₂	Carbon tariffs: 32$/tCO₂	Favorable treatment for good performer [w/o tax and tariff] (-G)	Retaliatory tariffs by ROW (-R)
(1) TRI	[US, EU, JPN]	×	×	×
(2) WLD	All regions	×	×	×
(3) TRI-BCA	[US, EU, JPN]	BCA	×	×
(4) TRI-BCA-R	[US, EU, JPN]	BCA	×	○
(5) TRI-CSTR	[US, EU, JPN]	CSTR	×	×
(6) TRI-CSTR-R	[US, EU, JPN]	CSTR	×	○
(7) TRI-CSTR-G	[US, EU, JPN]	CSTR	○	×
(8) TRI-CSTR-G-R	[US, EU, JPN]	CSTR	○	○

We assume that the carbon price and carbon tariff are 32$/t$CO_2$ referring to the EUA price of EU-ETS (July 2019), and the tax revenue is used for government consumption (the general account). The carbon price and carbon tariff are assumed to be levied on emissions after allocating electricity and heat. Export tax rebate, the refund of carbon tax paid on exported products, is also considered. Although various types of retaliatory measures can be considered, we assume that the same rate as carbon tariff is levied on the steel products as a retaliatory tariff. The baseline (without additional climate policies) socio-economic scenario in this study is assumed to be the median scenario (SSP2)[8)].

2.3. Results

(1) Impacts of different carbon tariffs

In the BCA (Cases 3 and 4) and CSTR (Cases 5 through 8) implemented by the US, the EU and Japan, the steel production values have turned positive, respectively, relative to Case 1, therefore, both types of carbon tariffs will reduce the decline in international competitiveness (Fig. 3). Also, the introduction of BCA and CSTR has the effect of reducing carbon leakage when compared to Case 1 (Fig. 4).

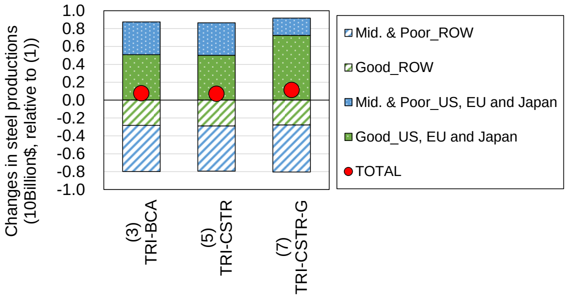

Fig. 3 Impact of BCA and CSTR on steel production (2020)

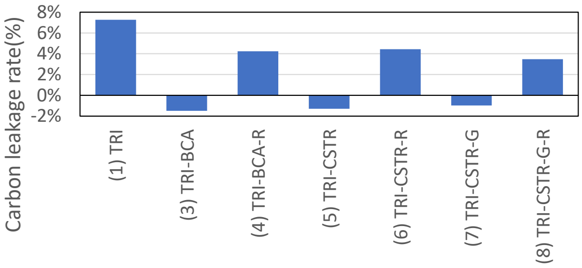

Fig. 4 Carbon leakage (2020)

Note) Carbon leakage is expressed as increase in CO_2 emissions (for steel productions) in the rest of the world (ROW) over CO_2 reductions in the US, the EU and Japan relative to the baseline.

It is estimated that both BCA and CSTR will promote the production shift to steel products with the lowest intensity (classified as "Good"), however, the impact of differences in tariff methods is not significant. Similarly, with regard to the global CO_2 reduction effect, the difference caused by the differentiated tariff methods is not large, such as from the comparison between Case 3 and Case 5 in Fig. 4. Rather, the exemption for products "Good" has a large impact on the production shift to products "Good", but the impact on the global emission reduction is limited.

(2) Impacts of retaliation

In the case of retaliatory measures by ROW in response to the border adjustments by the US, the EU and Japan, the relative price of import from the US, the EU and Japan in ROW relative to the cases without retaliation will increase, resulting in a shift of steel production from the US, the EU and Japan to ROW (Fig.5). In addition, retaliatory tariffs will reduce the international competitiveness of the US, the EU and Japan, and worsen leakage (Fig. 4). The impact on global emission, however, is also estimated to be very small.

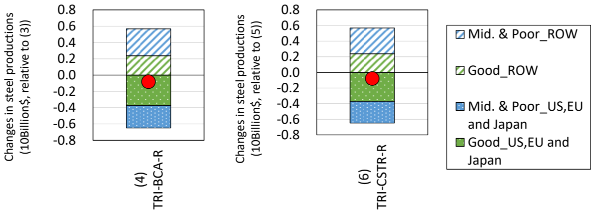

Fig. 5 Impact of retaliatory tariffs on steel production (2020)

(3) Impacts of international cooperation

In Case 2, which assumes all countries cooperate to reduce emissions and impose the same rate of carbon price on domestic production of steel in all countries, the steel production of "Mid" and "Poor" in ROW decreases compared to Case 1, while the production by the US, the EU and Japan increases (Fig. 6).

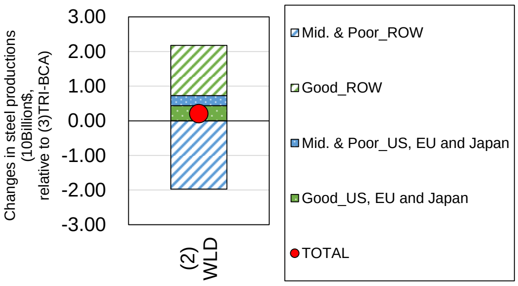

Fig. 6 Impact of international cooperation on steel production (2020)

(4) Comparison of impacts by region

When the US, the EU and Japan implement border adjustment measures, other countries such as China have higher incentives to implement retaliatory measures (Fig. 5). Under such circumstances, the impact on the US, the EU and Japan will differ, with the negative impact of retaliation being relatively large in Japan and small in the US (Fig. 7). The following two factors can be considered. First, although Japan has a lower intensity of both converter steel and electric furnace steel than that of other countries[9], Japan's superiority is not properly reflected in a framework that does not distinguish between converter steel and electric furnace steel. Therefore, the rate of increase in the price of steel products after tariffs are levied, is estimated to be in the order of "Japan (high ratio of converter steel) > the EU> the US (high ratio of electric furnace steel)". Second, the export-import ratio of steel products is also a factor in the different regional impacts of border adjustment and retaliatory measures. The ratio of steel product export to import in the baseline scenario in 2020 is estimated to be 5.0 for Japan, 0.9 for the US, 2.0 for the EU, and 1.5 for China. Japan's high ratio will result in small benefits of border measures and large negative impacts of retaliatory measures.

Conversely, the US has a high import ratio, suggesting that the benefits of border measures are large and the negative impacts of retaliatory measures are small. In addition, under the framework that does not distinguish between converter steel and electric furnace steel, the US with its high ratio of electric furnaces, is estimated to be superior in terms of intensity. Therefore, in this framework, the US has a high incentive to implement border adjustment measures even with retaliation.

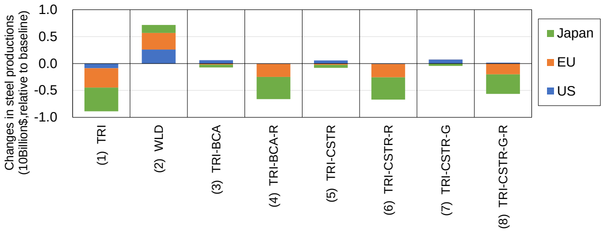

Fig. 7 Changes in steel production by region (2020)

(5) Sensitivity analysis on elasticity of substitution between domestic and imported products

When the elasticity of substitution between domestic and import products is large (δ=2.8)[10], the carbon leakage rate increases in Case 1 compared to the standard assumption (δ=1.5) due to a larger shift to other regions (Fig. 8). Moreover, while the border adjustment measures have the effect of reducing leakage, the retaliatory measures increase the leakage rate compared to the standard case.

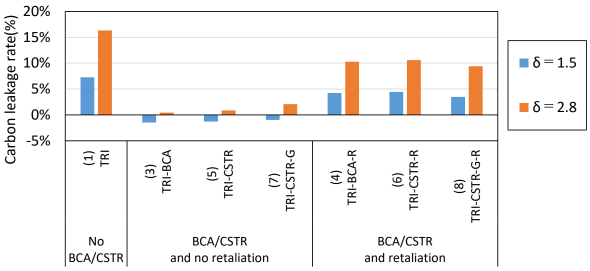

Fig. 8 Impact of change in elasticity of substitution on carbon leakage rate (2020)

2.4. Conclusion

The two types of carbon tariffs methods, a general BCA tariff based on the average product intensity and a CSTR tariff based on the intensity of each product, were estimated to reduce the loss of international competitiveness due to domestic reduction measures and to reduce carbon leakage, with little difference between the tariff methods.

Conversely, retaliatory measures were estimated to reduce the international competitiveness of Japan, the US and the EU and to worsen carbon leakage, although the impact on global emissions was very small. Under the framework we examined, the results implied that the incentives to introduce border adjustments would differ depending on the regional structures of production and trade.

For future work, it will be important to consider the extension of the classification of converter steel and electric furnace steel with respect to steel products, as well as the extension to other energy-intensive and major trade products.

3. Overview of Research Project (EDITS) on Low Energy Demand Society Affected by Technological Innovation and Social change

In 2020, RITE started a new research project, EDITS (Energy Demand changes Induced by Technological and Social innovations), which includes international model comparisons of analyses on energy demand changes and their impacts. The project is supported by Ministry of Economy, Trade and Industry (METI).

3.1. Background

We do not consume energy because we want to. We consume its embodied energy for obtaining services. A lot of energy is wasted to obtain that service, especially near the final demand (Fig. 9).

The energy required for the final services is estimated to be around 5% of the total primary energy consumption. However, the over consumption will be basically rational if we consider the "hidden costs" that hinder our convenience, and the energy supplies and demands in the current society was determined with over energy consumptions. Although having said that, it is being changed along with technological progress. For example, lighting has been practical use which turns off automatically when there are no people around and air conditioners can also cool a specific area where people are intensively. These technologies led to energy savings while suppressing service degradation. On the other hand, there is still a lot of waste as a social system.

The progress of information and communication technology (ICT) has the potential to induce social innovation on the final energy demand side and to leads to triggering: (1) from independent technology to connection between technologies, (2) from possession to use, and (3) inducing sharing economy and circular economy.

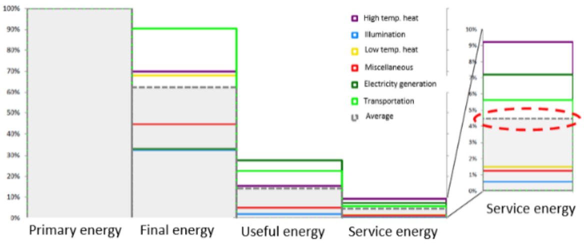

Fig. 9 Global Energy Consumption by Usage

(when primary energy consumption is 100%)[11]

For example, advances in ICT can have a significant impact on mobility. A change called Connected; Autonomous; Service & Shared; Electric (CASE) is happening. The utilization rate of private cars is estimated to be about 4-5%, and private cars are not used for many hours.

However, if a fully autonomous vehicle is realized, even with ride sharing or car sharing, it will not impair convenience significantly and likely to be used at a low cost because of an increase of operation rate. Ride sharing can directly reduce the energy consumption of automobiles, and car sharing can reduce the number of automobiles, reduce the use of materials such as iron and plastic as well as the energy consumption required for the manufacture. These reductions can contribute to the simultaneous achievement of the SDGs. Excessive production is being carried out not only in automobiles but also in apparel, food systems, etc., and there is a possibility that these can be reduced by the progress of ICT. It is important to control total energy demand of society by not only directly reducing energy but also reducing the energy embodied in services and products. On the other hand, ICT can increase energy consumption in data centers and other various rebound effects, so comprehensive analysis including behavioral changes is required.

3.2. Overview of EDITS

Under these circumstances, the EDITS project has just started the following research:

- Building a research community: Promoting better understanding through interaction between research and policy analysis with sharing new data, new concepts, methodologies, and policy analysis focused on the demand side.
- Improvement of state-of-the-art demand side model: Further refinement of environmental and climate policy analysis by mutual comparison and sharing of methodologies and models across disciplines and environmental fields.
- Model-to-model comparative analysis: Conduct model analysis and simulation to assess synergies and trade-offs, potential impacts and barriers to SDGs from demand-side policies while particularly focusing on digitization, sharing economy, and policy design with synergies from the integration of SDGs and climate goals

Many domestic and foreign research institutes and researchers will work together to tackle this important and difficult analytical tasks. RITE and the Institute for International Applied Systems Analysis (IIASA) playing a central role and collaborate with Tokyo University, Osaka University, Lawrence Berkeley National Laboratory (LBNL), Stanford University, Wisconsin University, Tsinghua University of China, and other institutes in South Korea, Italy, Germany, Thailand, Brazil, etc.

Reference

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