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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 at both national and international levels.

This article reports research status for the international collaborative model comparison project, commonly called "EDITS" (Energy Demand changes Induced by Technological and Social innovation, commissioned project entrusted by the Ministry of Economy, Trade and Industry), which has been developing scenarios to support achieving of a society with low energy demand through technological and social innovation. For further EDITS project information, refer to RITE Today vol. 17 (2022).

1. Introduction

Inducing social changes toward the low energy demand society to achieve the 2°C and 1.5°C goals not only on the energy supply side but also on the energy demand side is crucial. Moreover, it is not just a reduction in demand but a society that brings about a "virtuous cycle between the economy and the environment," in other words, the actualization of a society that increases wellbeing along with lowering demand is consequential. Separately, while developing models under the ALPS (Alternative Pathways toward Sustainable Development and Climate Stabilization) project, we developed quantitative scenarios that are consistent globally, across energy supply and demand sides, and between demand side sectors by following the scenario protocol in the EDITS project and harmonizing with other research institutes.

1.1. Importance of energy demand side measures and scenario trends

The Intergovernmental Panel on Climate Change (IPCC) released its 1.5°C Special Report (SR15)[1)] in 2018. In the report, various emission pathways to achieve 1.5°C were presented, and in particular, the Low Energy Demand (LED) scenario[2)] was the focus of attention. This shows a much smaller picture of energy consumption than the final energy demand, as would normally be shown in model analysis. Also, this could contribute not only to combating climate change, but also to the simultaneous achievement of the Sustainable Development Goals (SDGs). The study in Ref. 3) also points out the fast technological progress of small-scale technologies, which are often found on the demand side. It points out that the distributed small-scale technologies have been increasingly utilized in recent years due to the energy liberalization market, technological innovation and digitalization. The IPCC Sixth Assessment Report (AR6)[4] includes a new chapter dedicated to demand-side measures, with a survey of current papers and other information, and states that "Demand-side measures and new ways of end-use service provision can reduce global GHG emissions in end-use sectors by 40-70% by 2050 compared to baseline scenarios.", and "Demand-side mitigation response options are consistent with improving basic well-being for all." (Summary for Policymakers: SPM, C.10).

Figure 1 shows the overall picture of global warming measures. Traditionally, social structural and lifestyle changes have been mostly analyzed as exogenous scenarios. In such cases, however, it was unclear what measures would achieve low energy demand. Lifestyle change is mostly discussed in the context of education, and while the importance of education is understandable, there has not been enough analytical research on the subject due to the long-time scale and uncertainty of the effects to be shown as a major global effect. This study is novel in that it attempts to quantitatively analyze the possibility that technological changes, such as digitalization, will trigger changes in social structure and lifestyles. Unless there is a change in the baseline emissions themselves to a lower level due to advances in energy demand side technologies, it will be very difficult to achieve carbon neutrality in 2050 or significant emission reductions.

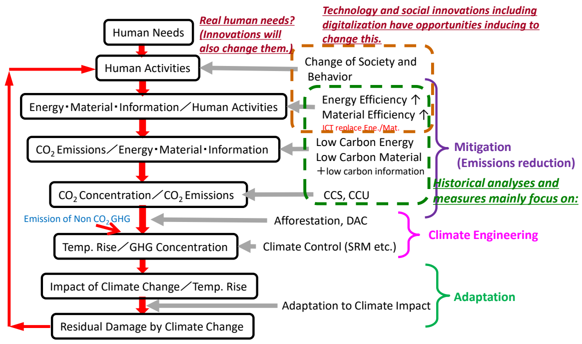


Figure 1 Basic structure of global warming countermeasures and changes in social structure and lifestyles

1.1. Example of evaluation of the feasibility of low energy demand by DX

Digital transformation (DX) and other innovations have created potentials to reduce implicit costs and induce the circular and sharing economy through relatively low costs (e.g., Ref. 5)). The IPCC Sixth Assessment Report (AR6)[4] also presents Figures 2 and 3 as a result of reports on the effects of each measure on reducing energy demand and CO_2 emissions from various studies, including the Ref. 5). Although there is a large range of estimates, it has been shown that fairly large reductions in energy demand and CO_2 emissions can also be expected. On the other hand, these analyses evaluate reduction rates for each measure and do not show consistent and quantitative energy reductions or CO_2 emission reductions across sectors. Also, as noted above, the IPCC AR6 states that "Demand-side measures and new ways of delivering end-use services could reduce global GHG emissions in the end-use sector by 40 to 70 percent by 2050 compared to the baseline scenario." However, each measure is evaluated by cumulating each of the measures and is not necessarily estimated across sectors using a consistent and quantitative model, including the cost of the measures.

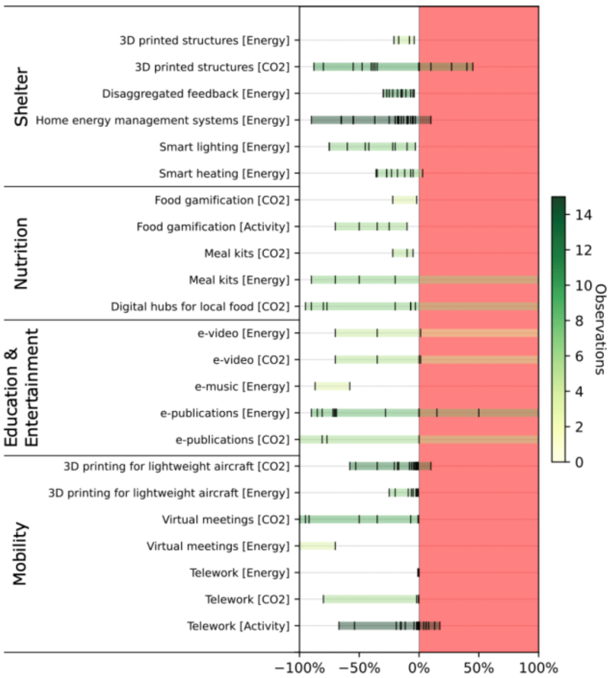


Figure 2 Impact of digitalization on energy consumption and CO_2 emissions (Source: Ref. 4))

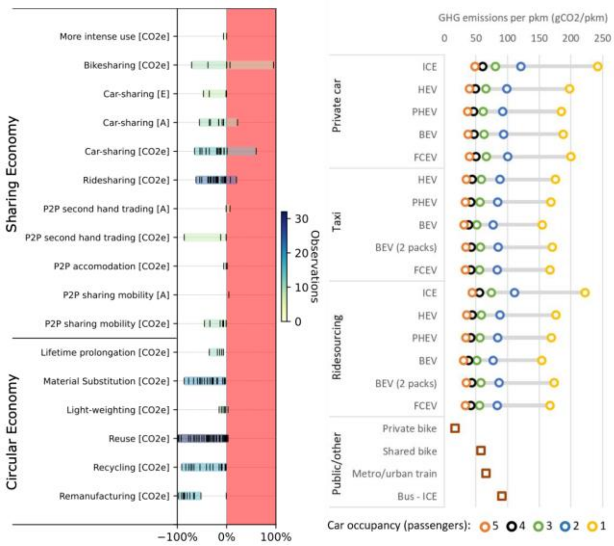


Figure 3 Impact of the sharing and circular economy on energy consumption and CO_2 emissions (Source: Ref. 4))

2. Assumptions on analysis scenarios

Comprehensive and quantitative analysis of complex systems and clarification of their usefulness and challenges will be a powerful driving force for society as a whole to promote a society with low energy demand, such as a circular and sharing economy, induced by DX. What the EDITS project will explore and attempt to present as a quantitative scenario is not simply a demand reduction, but a scenario that will bring about "the Virtuous Cycle of Environment and Economy," i.e., a society in which demand is reduced while wellbeing is improved.

2.1. Narrative scenario

In the EDITS project, the Narrative WG presented a qualitative “high wellbeing with low resource use (High-with-Low)” scenario that considers the drivers shown in Figure 4[6].

This scenario is a worldview that combines the advancement of digitalization, innovation through new combinations, and decent living standards (DLS), and assumes that low demand (in energy and various materials and products, etc.) can be achieved while increasing wellbeing. The relationship between the elements is shown in Figure 5.

In previous Integrated Assessment Model (IAM) analyses, final energy consumption is often given exogenously based on population and GDP scenarios, and elasticities are used to estimate final energy consumption under climate change measures. However, industrial and other demands are only a result of consumption behavior that enhances wellbeing. Energy demand is only a derived demand to obtain products and services. The method is highly novel in that it focuses on changes in consumption behavior to obtain products and services, estimates the resulting reduction in demand for material products and energy, and then estimates the overall energy supply and demand, as well as the resulting CO_2 emissions. Through this, the effects of demand-side measures will be visualized and used as an incentive for social change toward the realization of “the Virtuous Cycle of Environment and Economy”.

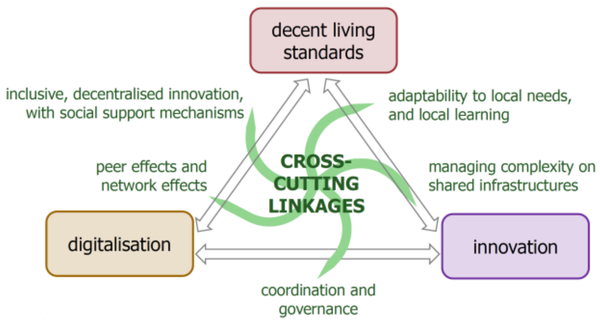


Figure 4 Assumed drivers for qualitative scenario 'High-with-Low' (Source: Ref. 6))

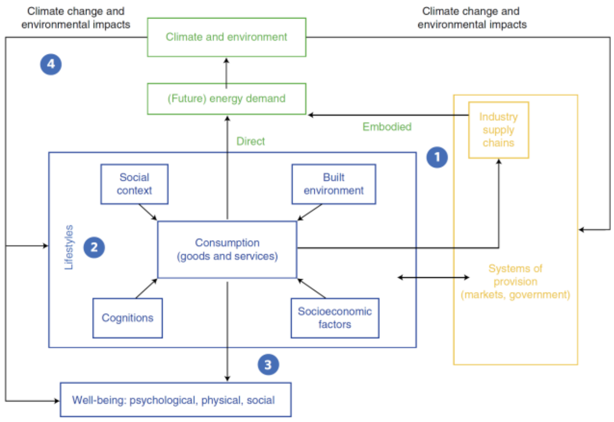


Figure 5 Relationship among the elements in qualitative scenario 'High-with-Low' (Source: Ref. 6))

2.2 Assumptions in quantitative scenario analysis

The potential for achieving a low-energy demand society as well as the impact on emission reduction of GHG realized by the circular and sharing economy mainly induced by DX, are quantitatively estimated using the global energy assessment model DNE21+. It is noted that currently only a fraction of spillover effects is considered for estimates due to the limited availability of quantitative data. In addition to that, large uncertainties exist in the assumed precondition for the model, leaving us with issues of acquiring and reflecting better data. DNE21+ conducts a bottom-up assessment of carbon-intensive products such as iron and steel, cement, or chemical products, enabling us to consistently analyze the effects of the circular and sharing economy such as a decrease in basic material production or accompanying reduction in energy consumption.

Quantitative assumptions of scenarios based on qualitative scenario drivers shown in Figure 4 are conducted. Table 1 shows scenario assumptions of circular economy (CE) induced by DX (hereafter in this report, sharing economies shall be included in circular economy and thus described as "CE" as a whole). Table 2 presents the titles of the scenarios analyzed and their assumptions. For emissions scenarios, the Baseline scenario without any specific emissions scenario, and the B2DS scenario that assumes 2°C with >66% probability, are assumed. For B2DS, GHG neutrality by 2050 is assumed to be achieved within each major developed country including Japan.

As a potential impact of advanced digitalization and innovation on the demand side, in addition to the CE, the provision of flexibilities on the electricity demand side which contribute to increased consumption of variable renewable energies (VRE) is considered. More specifically, technologies such as BEV, PHEV, heat-pump water heaters, and cogeneration systems are assumed to be able to provide a capability of more flexible demand adjustment towards VRE (especially PV) supply within the electricity load curve of DNE21+, than the standard scenario ("FL" scenario). Grid integration costs are assumed to be able to reduce, considering the possibility of reducing battery storage size in the grid due to the reverse power flow from BEV and PHEV.

In many cases, the demand-side technologies are in smaller sizes, called granular technologies. The learning rates of these technologies tend to be observed as being higher in general, due to their quicker development cycles. Although DNE21+ has already assumed larger cost reductions for PV, wind power, or EV batteries, even in the standard scenario, we have assumed a scenario in which the learning rates of these relatively smaller-scale technologies are further higher ("GR" scenario) However, it is noted that this scenario is an exogenous assumption, and should be treated as a reference scenario to be compared with the results of other scenarios.

Table 1 Scenario assumptions of circular economy (CE) induced by DX

Changes due to digitalization	Direct impacts	Indirect impacts	Model assumptions (tentative)
1) Ride and car-sharing associated with fully autonomous cars	- Energy consumption reductions due to ride-sharing	- Reductions in consumption of basic materials, e.g., iron and steel, plastics, tire, glass, and concrete, due to reductions in number of cars associated with car-sharing - Reductions in freight shipping => 8)	- Iron and steel production: -4% (for cars and multi-story car park) - Plastic production: -1% - Tire production (for cars): -28% - Glass production (for cars): -28% (corresponding reductions in energy consumption is assumed.) - Cement production: -1% (only for multistory car park)
2) Virtual meeting and teleworking	- Reductions in travel service demand and the associated reductions in energy consumptions in transport sector	- Potential reductions in numbers of commercial building, and the resulting reductions in iron and steel, concrete, and others *[Not yet considered]*	- Reductions in person-km travel by passenger cars, buses, and aircraft by 10%
3) E-publication etc.	- Reductions in paper consumptions due to large deployment e-publications etc.	- Potential reductions in freight services for papers *[Not yet considered]*	- Reductions in paper/pulp by 20%
4) Recycling and reductions in apparels due to e-commerce and other digitalization	- Reductions in energy consumptions for apparel productions	- Potential reductions in energy consumption at shopping centers, and the reductions in iron and steel, concrete due to less building construction, etc. *[Not yet considered]*	- Reduction in new productions of apparels by 20% (No explicit modeling for apparels in DNE21+, and corresponding reductions in energy consumption is assumed.)
5) Loger life time of buildings due to improv. In city planning	- Potential reductions in cement and steel due to longer life time of buildings		- Longer lifetime of building: +40%; the related reductions in cement (-3%) and steel (-3%) productions
6) Reductions in food losses due to better demand projection	- Reductions in nitrogen fertilizer, plastics, etc. and the resulting energy consumption reductions - Potential reductions in energy consumption at supermarkets etc. - Red. In CH_4 and N_2O	- Reductions in freight shipping services => 8) - Potential reductions in construction for supermarkets etc., and the resulting reductions in iron and steel, concrete, and others. *[Not yet considered]* - Potential increases in afforestation due to increase in rooms of land area. *[Not yet considered]*	- Reduction in petrochemical products including ammonia by 1% - Reduction in plastics by 1% - Reduction in paper and pulp by 0.5% - Reduction in transport services by 1% and others (according to I/O analysis results) - Reduction in CH_4 and N_2O emissions: 493 $MtCO_2eq$/yr in 2050
7) AM (3D-printing) for applying aircraft	- Reduction in aluminum and steel production - Reduction in electricity for productions	- Energy efficiency improvements of aircraft and the energy consumption reductions - Energy efficiency improvements of cars and the energy consumption reductions *[Not yet considered]*	- Reduction in aluminum and steel productions by 1% and 0.02%, respectively - Reduction in electricity consumption by 1% - Increase in energy efficiency of aircraft by about 10%
8) Reductions in freight shipping services due to reductions in basic materials and products	- Energy consumption reductions in freight shipping		- Reduction in freight shipping demand by 1%

Red: residential sector, **Green**: commercial sector, **Blue**: transport sector, **Purple**: industry sector, **Brown**: Non-CO_2 GHGs etc.

Table 2 Assumed scenarios for circular economy (CE) induced by DX

	Emissions reduction	Energy demand reductions due to mainly digitalization						Demand flexibilities in electricity (EV, HP, CGS)	Rapid cost red. in granular tech's, e.g., PV, Wind, EV
		Transport 1)	Residential 2, 3, 4)	Building 5)	Food 6)	Industry 7)	Spill over 8)		
BL-Std	Baseline (non specific climate policies)	—	—	—	—	—	—	—	—
BL-Mobil		X							
BL-Resid			X						
BL-Build				X					
BL-Food					X				
BL-Ind						X			
BL-All_CE		X	X	X	X	X	X		
BL-All_CE+FL		X	X	X	X	X	X	X	
BL-All_CE+FL+GR		X	X	X	X	X	X	X	X
B2DS-Std	B2DS (well below 2C; NDCs in 2030; CN by 2050 in G7 countries)	—	—	—	—	—	—	—	—
B2DS-Mobil		X							
B2DS-Resid			X						
B2DS-Build				X					
B2DS-Food					X				
B2DS-Ind						X			
B2DS-All_CE		X	X	X	X	X	X		
B2DS-All_CE+FL		X	X	X	X	X	X	X	
B2DS-All_CE+FL+GR		X	X	X	X	X	X	X	X

Note) For Shared Socioeconomic Pathways (SSPs), this study employed the SSP2, middle of the road scenario.
The rebound effects other than the ones associated with the reductions in carbon prices are not considered.

3. Results

Firstly, the results of the Baseline scenarios are presented. Figure 6 and 7 show the reductions in global final energy consumption and in global GHG emissions, respectively, from the standard scenario (Std) where CE progress is not assumed. Although it is in the analysis stage considering only limited spillover effects, it is indicated that considerable cross-sectoral energy-saving effects can be expected by realizing the assumed CE. The contribution of car sharing and ride sharing, induced by the realization of fully automated cars, to low energy demand is significant as the effects of DX assumed in this analysis, including the spillover effects on the industrial sector. Besides, large impacts can be expected by other changes such as virtual meetings. It is shown that reducing food loss has the potential to greatly promote the reduction of non-CO_2 GHGs in particular.

Similarly, for the B2DS scenarios, Figure 8 and 9 show the reductions in global final energy consumption and in global GHG emissions, respectively, from the standard scenario (Std) that does not assume CE progress. Even considering only the limited number of CE cases and spillover effects, it is indicated that about 6% of the world's current total final energy consumption and around half of the energy saving estimated to be economically efficient under the 2°C target could be additionally saved by CE in 2050. Under the condition where the emission reduction targets are defined, the assumed CE measures are relatively inexpensive, and the dependence on the technologies recognized as the measures with marginal costs, such as carbon dioxide removal (CDR) including bioenergy with CCS (BECCS) and CO_2 direct capture and storage (DACCS) can be reduced. Although the final energy consumption reduction effect is significant, the CO_2 reduction effect is not estimated as large as the energy consumption, because it includes a reduction in CO_2 intensity on the energy supply side. However, the cost reduction effect is huge.

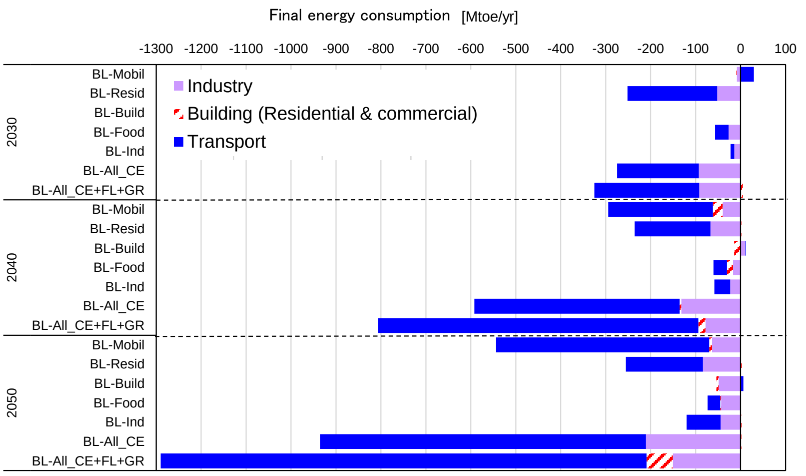


Figure 6 Changes in global final energy consumption under CE scenarios (Baseline)

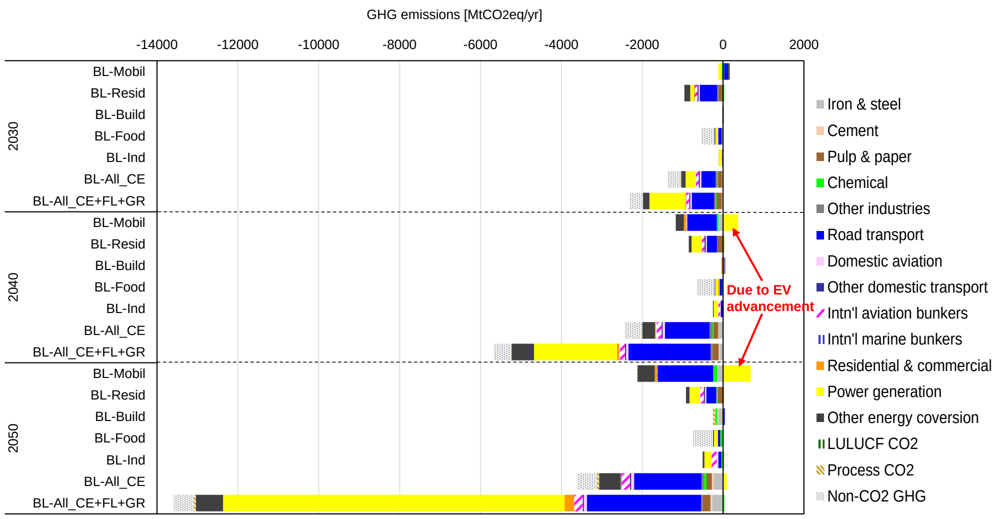


Figure 7 Changes in global GHG emissions under CE scenarios (Baseline)

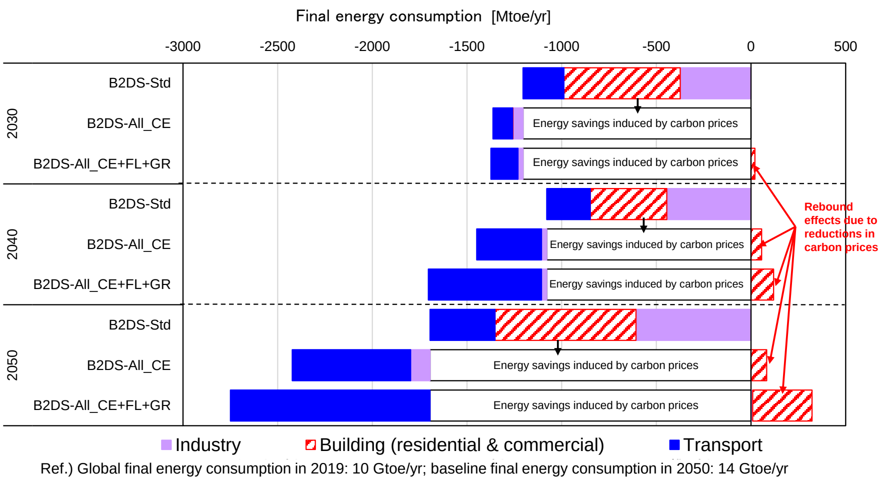
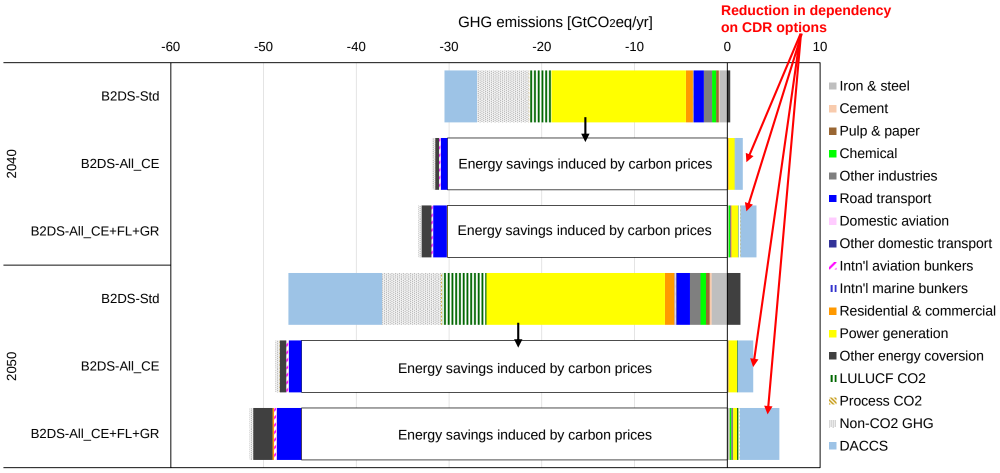


Figure 8 Changes in global final energy consumption under CE scenarios (B2DS)



Ref.) Global GHG emissions in 2019: 59 $GtCO_2eq./yr$; baseline GHG emissions in 2050: 73 $GtCO_2eq./yr$

Figure 9 Changes in global GHG emissions under CE scenarios (B2DS)

Figure 10 shows global final energy consumption per capita by region. Developed countries are consuming more energy than needed especially on the demand side, and the realization of low energy demand is induced and the international disparities of energy consumption per capita is reduced in 'High-with-Low' scenario.

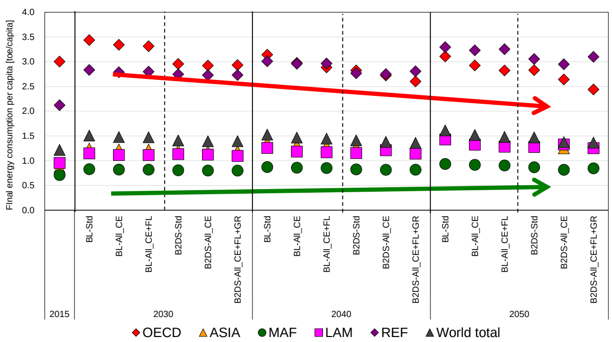


Figure 10 Final energy consumption per capita by region

Table 3 shows the changes in the total energy systems costs under the CE scenarios compared to those in the standard scenarios, and Figure 4 shows the CO_2 marginal abatement costs in B2DS. It is estimated that the promotion of CE induced by DX will lead to a significant reduction in energy systems costs. In particular, a significant cost reduction in the whole society induced by ride-sharing and car-sharing using fully automated cars can be expected, and also the changes in the residential sector, such as teleworking, and the reduction of food loss would have relatively high potential to reduce energy systems costs.

In addition, as Table 4 indicates, a reduction in marginal CO_2 abatement costs (about 20-30 %) can be expected in achieving long-term targets such as 2°C goal.

Table 3 Reductions in energy systems costs: under CE scenarios (unit: Billion USD/yr)

	Scenarios	Mobil	Resid	Build	Food	Ind	All CE	All CE +FL	All CE +FL+GR
Annual average in 2030-2040	Baseline	▲547	▲339	▲1	▲57	▲4	▲894	▲894	▲963
	B2DS	▲556	▲352	▲0	▲64	▲5	▲926	▲928	▲1038
Annual average in 2040-2050	Baseline	▲1601	▲459	▲1	▲74	▲7	▲1971	▲1971	▲2085
	B2DS	▲1635	▲477	▲6	▲90	▲14	▲2037	▲2038	▲2266

Note) The changes in the costs compared those in the standard scenarios for each emissions reduction target.

Table 4 CO_2 marginal abatement costs in B2DS (unit: USD/tCO_2eq)

	B2DS-Std	B2DS All-CE	B2DS All-CE+FL	B2DS All-CE+FL+GR
2040	68–310	57–238	57–240	50–195
2050	146–739	123–524	122–522	60–364

Note) The cost ranges are those due to the differences in emissions targets across countries

4. Summary

This fiscal year, as a consistent and quantitative scenario across regions/countries and sectors, modeling and preliminary calculations were performed in the DNE21+, the global energy assessment model, lining with the qualitative scenario "high wellbeing with low resource use (High-with-Low)" presented by the Narrative Group. We modeled, analyzed, and evaluated only CE that some DX can induce due to the difficulty of quantitative estimation. In addition, as for the spillover effects, only limited effects were considered due to the difficulty of quantitatively estimating. Despite these, the corresponding energy reduction and GHG emission reduction effects were evaluated. Additionally, a reduction in energy system costs and in CO_2 marginal abatement costs in the B2DS scenario (below 2°C, >66% probability) were estimated. This can be said to be a scenario that indicates the possibility of a "virtuous cycle between the economy and the environment" or "high wellbeing with low resource use."

However, the estimate of final energy consumption in the Low Energy Demand (LED) scenario addressed in IPCC SR1.5 is far below the estimate in this analysis. Thus, it is necessary to quantitatively model various measures which could be induced by DX, as well as social changes, such as CE that can be influenced derivatively, and conduct quantitative scenario evaluations. On the other hand, it is also essential to deepen our understanding of the reasons why the gaps occur with the LED scenarios. Further progress in quantitative and comprehensive analysis, and on the contrary, if gaps still exist, deepening understanding of those gaps will be indispensable for the evaluation in the next IPCC reports. In addition, it is essential to assess the energy reduction side, proceed with the analysis, including the rebound effect, and conduct a more comprehensive evaluation.

Reference

1) IPCC Special Report on Global Warming of 1.5℃ (2018)

2) A. Grubler et al., A low energy demand scenario for meeting the 1.5°C target and sustainable

development goals without negative emission technologies. Nat. Energy, 3(6), 515–527 (2018)

3) C. Wilson et al., Granular technologies to accelerate decarbonization. Science, 368(6486), 36–39 (2020)

4) IPCC WG3 AR6: Climate Change 2022: Mitigation of Climate Change (2022)

5) C. Wilson, L. Kerr, F. Sprei, E. Vrain, M. Wilson, Potential Climate Benefits of Digital Consumer Innovations. Annu. Rev. Environ. Resour., 45(1) (2020)

6) EDITS WG3 Narratives group (Arnulf Grubler, Greg Nemet, Shonali Pachauri, Charlie Wilson), The 'High-with-Low' Scenario Narrative (2022)