The economic impacts of climate policies under the shared socioeconomic pathways

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Abstract

This paper discusses economic impacts of climate policies under the shared socioeconomic pathways (SSPs) on population, GDP and technology. The concepts and storylines on the SSPs have been discussed by the international communities on integrated assessment model (IAM) and impact, adaptation, and vulnerability (IAV). This economic analysis, focusing on climate mitigation, is conducted by using an energy-economic model, DEARS (Dynamic Energy-economic Analysis model with multi-Regions and multi-Sectors) having economic and energy modules. We assume the climate policy cases as the CO2 emission pathways with the radiative forcings of 4.5, 3.7 and 3.0W/m^2 in 2100. The results reveal that the industrial structure changes from energy-intensive to service sectors in all the cases. To compare the results of SSP4 (inequality world) to those of SSP5 (conventional development), the adverse economic impacts in SSP4 with the high prices of fossil fuels are relatively small. On the other hand, the adverse impacts in SSP5 with the low prices are high because the baseline CO2 emission levels are relatively high and the amounts of emission reductions in the policy cases are relatively large. These results are consistent with the SSPs storylines in which SSP4 and SSP5 have low and high challenges for climate mitigation, respectively.

Keywords: Climate Change; Shared socioeconomic pathway; Mitigation

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1. Introduction

In order to assess future changes in various factors such as socio-economy, technology, land use and GHG emissions, scenarios on socio-economy and emissions have been used for climate policy researches. Those scenarios were used as inputs datasets for climate models and then the outputs by climate models were used as analyses of climate impacts, mitigations and the relevant costs. The IPCC has developed Integrated Scenarios 1992 (IS92) on GHG emission scenarios, and then Special Report on Emission Scenarios (SRES). Currently, international research communities have developed Representative Concentration Pathways (RCPs) on GHG emissions and Shared Scio-economic Pathways (SSPs) on socio-economic factors, which will be utilized as common baseline for climate researches.

The concepts and storylines on the five types of the SSPs have been discussed by the international communities on integrated assessment model (IAM) and impact, adaptation, and vulnerability (IAV). Currently, the SSPs include SSP1 (sustainability), SSP2 (middle of the road), SSP3 (fragmentation), SSP4 (inequality) and SSP5 (conventional development). Figure 1 shows SSP scenario matrix. The SSPs are based on the concepts representing the socioeconomic challenges for climate mitigation and adaptation. High and low socio-economic challenges for mitigation, corresponding to upper and lower areas in Figure 1, represent having high and low costs on climate mitigation, respectively. High and low challenges for adaptation, corresponding to right- and left-hand areas, represent having the large and small amounts of vulnerabilities, respectively. The concepts and theoretical frameworks of SSP scenarios are summarized in the special issue of Climatic Change journal (2014, vol.122, issue3).

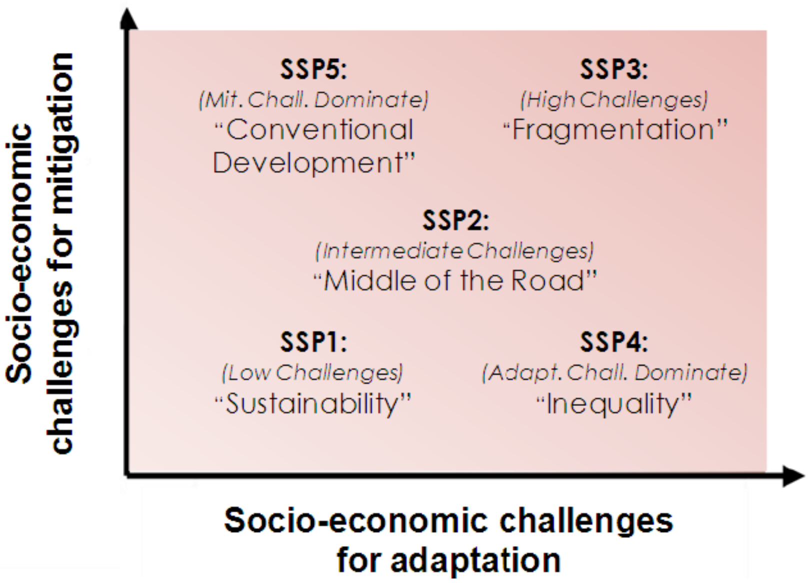


Figure 1 Schematic representation of the SSPs (O'Neill et al. (2012))

Previous works have mainly focused on the macro factors like GDP and population on socio-economy. There remains a need for scenarios on industrial structures corresponding to the macro frameworks. The purpose of this study is to analyze industrial economic impacts of climate policies under the scenarios assumed for representing the concepts of the individual SPPs. The paper focuses on climate mitigation on the SSPs.

The remainder of this paper proceeds as follows. Section 2 outlines the methodology for economic analysis. This section includes an overview of the energy-economic model used in this study and the assumptions and simulation cases. Section 3 describes an analysis of economic impacts of the climate policies under the SSP scenarios.

2. Methodology

2.1. Overview of energy-economic model

In order to analyze economic impacts of mitigation policies, we utilize a world energy-economic model of DEARS (Dynamic Energy-economic Analysis model with multi-Regions and multi-Sectors), developed by Homma and Akimoto (2013). DEARS is a computable general equilibrium (CGE) model with an intertemporal optimization problem which maximizes global discounted consumption utilities up to the middle of this century with ten-year steps. The model evaluates the impacts of energy and CO_2 emissions reduction policies on economic systems with consideration of international industrial relationships.

DEARS has two modules. One is the economic module, which represents explicitly industrial structures of production, consumption, and trade by region and by sector in terms of monetary units, which are required for sectoral analysis on climate policies. The other is the simplified energy systems module, which represents explicitly energy flows in terms of physical units. The two modules are completely linked. The model includes 18 regions and 18 non-energy sectors, according to Tables 1 and 2.

The macro production functions for the whole economy are based on the Cobb-Douglas function, while the sectoral production functions for the non-energy sectors are based on the Leontief function. Figure 2 shows nested model structures in the non-energy sectors. The model also includes twelve energy sources with eight types of primary energy (coal, crude oil, natural gas, biomass, hydro power, wind power, nuclear power, and photovoltaics) and four types of secondary energy (solid, liquid, and gaseous fuels, and electricity). These various types of electricity generation and carbon dioxide capture and storage (CCS) technology are also modeled. The model has bottom-up modeling structures for these technologies. The energy-saving effects are evaluated using long-term price elasticity.

The main datasets of DEARS are based on the GTAP database (Hertel (1997), Dinaranan (2006), Alexander (2008)) for economic systems and on IEA energy balances and datasets of other models (Akimoto et al. (2010), RITE (2009)) for energy systems. Since the input-output table is based on GTAP, which is commonly used for international CGE model analysis, the international transfer of industry (leakage of industry) can be analyzed. Since the information on the energy supply and the power generation sector is not sufficient in the input-output table, we conduct bottom-up modeling taking relevant technologies into account and make adjustments to achieve consistency with IEA statistics, which allows consistent analyses and assessments of energy and the economy.

Table 1 Regional dimension of the DEARS model

Developed regions		Developing regions	
JPN	Japan	CAM	Central America
USA	U.S.A.	BRA	Brazil
CAN	Canada	SAM	Other Latin America
WEP	Western Europe	CHN	China
EEP	Eastern Europe	IND	India
FSU	Former Soviet Union	ASN	ASEAN
		TME	Middle East
		NAF	Northern Africa
		CAF	Central Africa
		SAF	Southern Africa
		ROW	Rest of the world

Table 2 Sectoral dimension (non-energy) of the DEARS model

I_S	Iron and steel	LUM	Lumber
CRP	Chemical	CNS	Construction
NFM	Non-ferrous metal	TWL	Textile
NMM	Non-metal mineral	OMF	Other manufacturing
PPP	Paper and pulp	AGR	Agriculture
TRN	Transport equipment	ATP	Aviation
OME	Machinery	T_T	Other transport
OMN	Mining	BSR	Business service
FRP	Food processing	SSR	Social service

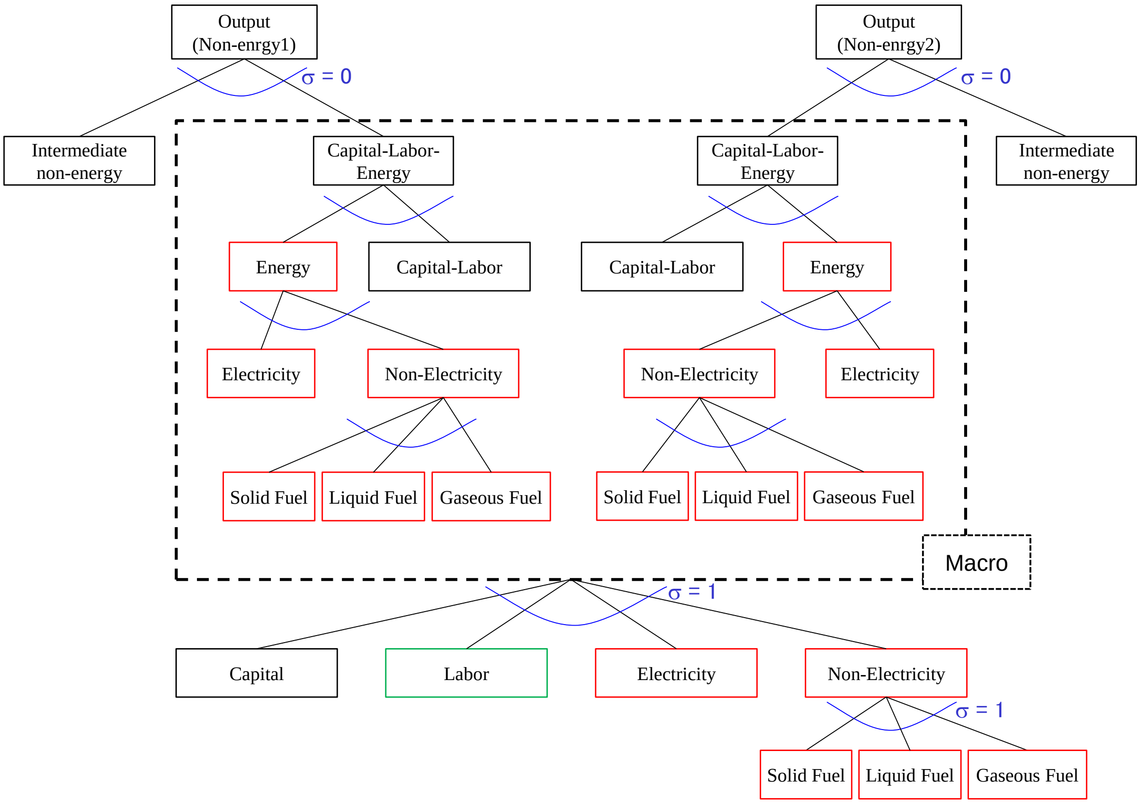


Figure 2 Structure of non-energy sector in DEARS

Note: For simplicity, only 2 non-energy sectors are depicted in the figure. The 18 non-energy sectors are practically modeled. Labor is exogenous variable.

2.2. Assumptions and simulation cases

At present quantitative interpretations and methodology for representing SSPs differ among researchers. In this study, the population scenarios, which are exogenously determined in the model, correspond to the IIASA scenarios[5)] for the five types of SSPs. We assume that annual growth rates of global population for 2000-2050 in SSP2, SSP4 and SSP5 are 0.8%, 0.8% and 0.7%, respectively (RITE, 2014). Because the GDPs are endogenously determined in the model, the GDP-relevant parameters such as total factor productivity (TFP) parameters are harmonized with the baseline GDP scenarios for the SSPs. We assume that annual growth rates of global GDP for 2000-2050 in SSP2, SSP4 and SSP5 are 2.5%, 2.3% and 2.8%, respectively (RITE, 2014).

Other assumptions are also needed for representing the concepts of the SSPs. We assume substantial differences in fossil fuels technology (e.g., mining) among SSP2, SSP4 and SSP5. The future supply prices of fossil fuels depend on the level of the supply technologies and differ among scenarios. We consider the price scenarios in which the technology levels are low, middle and high, respectively and thus the price projections of SSP4, SSP2 and SSP5 are high, middle and low (RITE, 2014). Because the prices are endogenously determined in the DEARS model, the relevant parameters are harmonized with the corresponding supply functions.

In this study, the three types of CO_2 emission pathways are assumed in the climate policy cases. The emission pathways assume the radiative forcings of $4.5W/m^2$, $3.7W/m^2$ and $3.0W/m^2$ in 2100. These pathways mainly covers lower levels focused in the original RCPs and IPCC-AR5 (IPCC, 2014). In this paper, we focus on economic impacts of the emission pathways under SSP2, SSP4 and SSP5 scenarios.

3. Results and discussion

Firstly, we conduct analysis on the baselines of SSPs under the assumptions. The GDPs (sum of value-added) in SSP5 are highest while those in SSP4 are lowest. Figure 3 shows global sectoral value-added in the baseline of SSPs. The main contributions to GDP growths are service sectors in all the scenarios. Regardless of SSPs, the service sector is expected to grow steadily over time.

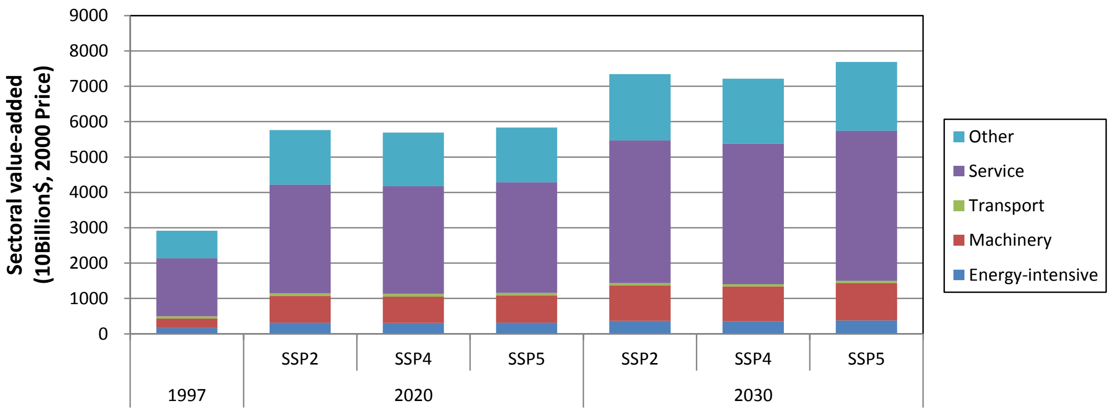


Figure 3 Global sectoral value-added in the baselines

Next, we conduct analysis on the climate policies under the SSPs. Figure 4 shows the global CO_2 emissions in the baselines of SSPs and three types of emission reductions in climate policies in 2030. The CO_2 emissions in the SSP5 baseline are the highest because SSP5 assumes low price on fossil fuels, as a result, the SSP5 has the largest emission reductions relative to the baseline. On the other hand, the CO_2 emissions in the SSP4 baseline are the lowest due to assuming the high fuel prices. The SSP4 in the climate policies has the smallest amounts of emission reductions. The levels of emission reductions in SSP2 lie between SSP4 and SSP5.

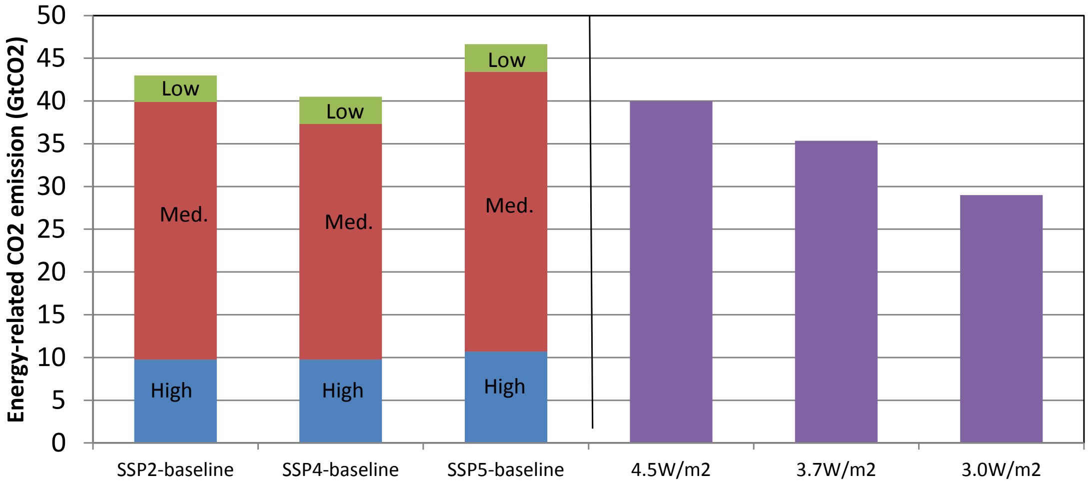


Figure4 Global CO2 emissions in the SSP baselines and the assumed climate policies in 2030

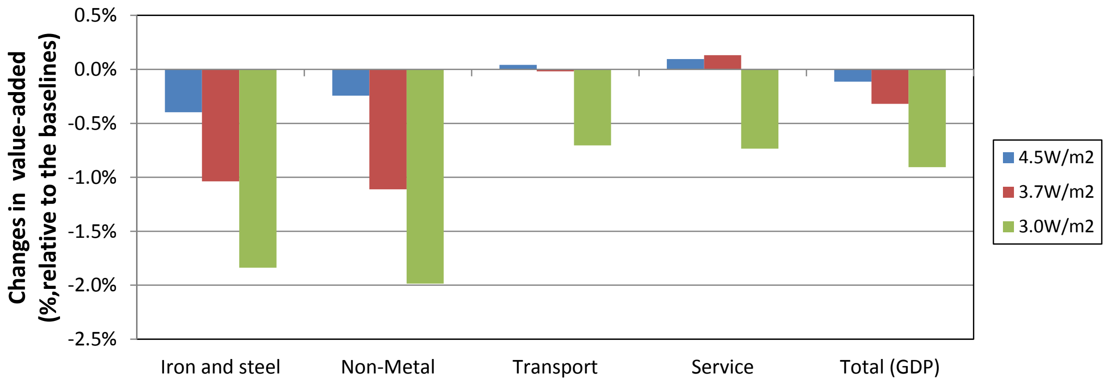
Note: High, Low, Med in the graphs represent country groups with high, low and medium income levels, respectively. High, Med, Low groups correspond to OECD90, sub-Sahara Africa and poor Asian countries, and others, respectively.

Iron and steel, and Non-metal sectors, that are energy-intensive sectors, have the largest adverse impacts (GDP losses to the baselines) because the sectors have the highest energy and CO2 intensities. In particular, the high levels on emission reductions result in the large amounts of adverse impacts. On the other hand, service sector with low intensities has low impacts. When the reduction levels are low (e.g., 4.5W/m2 in SSP2 and SSP4), the service sector has possibilities of positive impacts (negative GDP losses). These results indicate that the industrial structure changes from energy-intensive to service sectors in all the reduction cases.

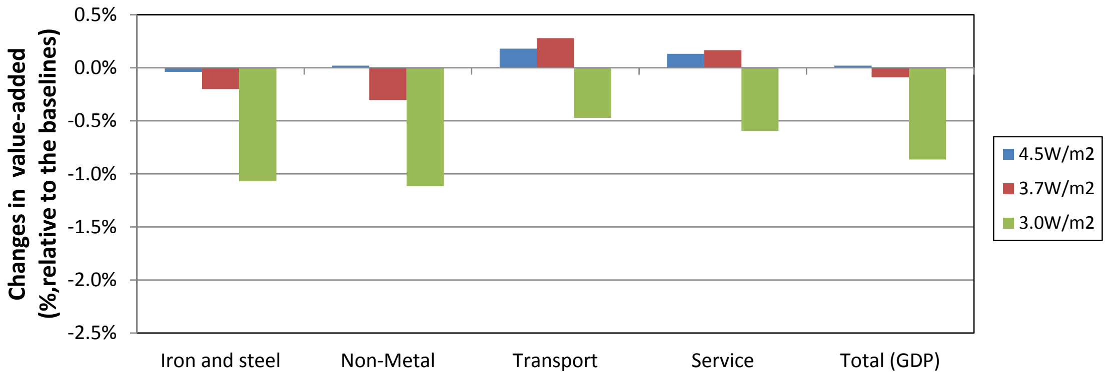
In order to evaluate consistencies of the assumptions on socio-economy and fuel prices for representing the concepts of SSPs, we compare the GDP losses among the SSPs. The adverse economic impacts in SSP4 with having the high prices on fossil fuels are relatively small. On the other hand, the adverse impacts in SSP5 with the low prices are high because the CO_2 emission reductions from the baselines are relatively large. These results under the assumptions are consistent with the SSPs storylines in which SSP4 and SSP5 have low and high challenges for mitigation options, respectively.

Figure 6 shows the GDP losses (relative to the baselines) in 2030 by income level group. The stringent reduction cases result in large GDP losses in all the SSP scenarios and all the incomes groups. To compare between the incomes levels, the medium income level group like China and India has large adverse impacts. The group has the largest shares of emissions in 2030 (as shown in Figure 5), and their reductions from the baselines are relatively large.

i) SSP2



ii) SSP4



iii) SSP5

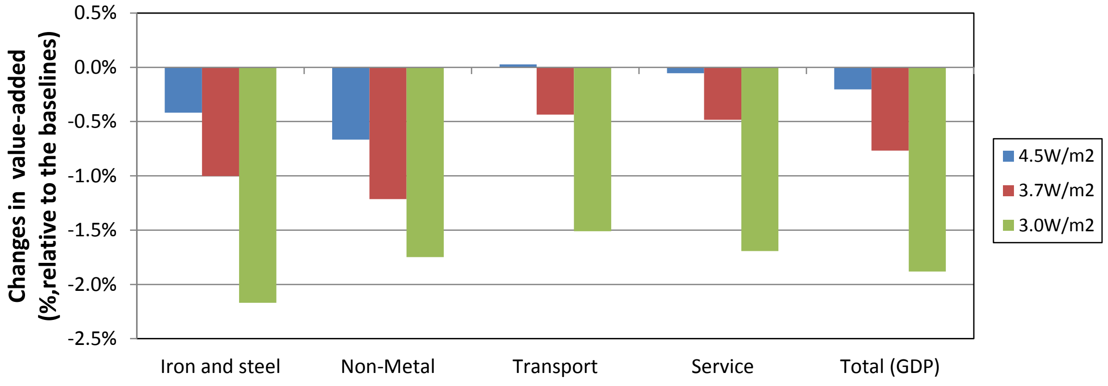


Figure 5 Changes in sectoral value-added in 2030 (relative to the individual SSP baselines)

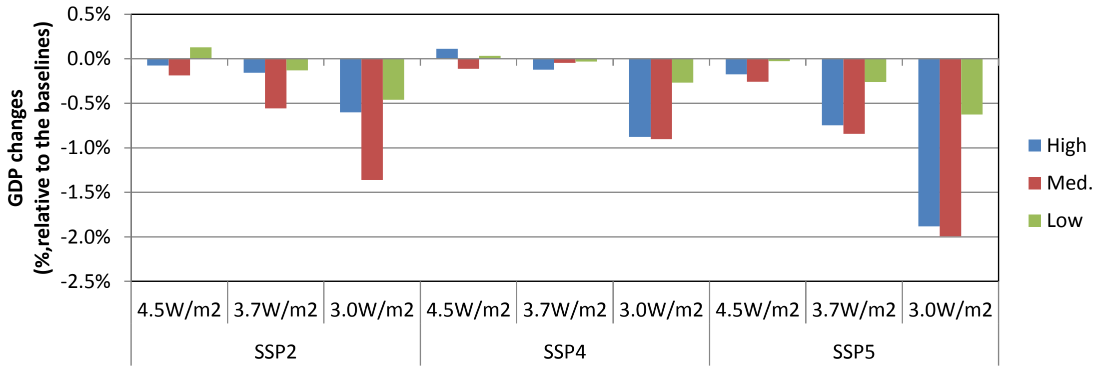


Figure 6 Changes in GDP by income groups in 2030 (relative to the individual SSP baselines)

4. Conclusion

This paper develops the quantitative scenarios on socio-economy based on the concepts of SSPs, and investigates the economic industrial impacts of climate policies in 2030 under the assumed SSPs. The results reveal that adverse economic impacts of the climate policies in the energy-intensive sectors such as iron and steel and non-metal sectors are relatively large. Service sectors have relatively low impacts in the stringent emission reduction case. These results reveal that the industrial structure changes from energy-intensive to service sectors in all the SSPs in the reduction cases.

The adverse economic impacts in SSP4 with the high prices on fossil fuels are smaller than SSP5 to implement all the assumed climate policies. On the other hand, the adverse impacts in SSP5 with the low prices are high because the baseline CO_2 emission levels are relatively high and the CO_2 emission reductions are relatively large. These results are consistent with the SSPs storylines in which SSP4 and SSP5 have low and high challenges in the terms of climate mitigation, respectively.

For future works, in order to develop more persuasive scenarios on SSPs, we need to additionally investigate the scenarios on industrial structures for the SSPs using cross-section and time-series analysis.

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