Socio-economic factors and future challenges of 1.5°C goal

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Abstract

The Paris Agreement has confirmed that the ultimate climate policy goal aims to hold the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the increase to 1.5 °C In this study, we evaluated the role of socio-economic factors (e.g. technological cost and energy demand assumption) to change mitigation costs and achieving 1.5°C and 2°C goals using AIM/CGE (Asian-pacific Integrated Model/Computable General Equilibrium). In addition, we identified the affecting channels of the socio-economic factors on the mitigation cost. The results show that technology improvement in low-carbon energy supply technologies is the largest factor that reduces the mitigation cost. In 2100, the GDP loss associated with mitigation of 1.5 °C case in the technology improvement in low-carbon energy supply scenario is 1.8% which is more than a half of that in reference scenarios (without additional technological change case was 4.0%). Energy end-use efficiency and lifestyle change help to reduce the baseline emissions, and they also contribute to reduce the mitigation cost. Lifestyle change shows more power on the emissions reduction of transportation sector. Among the socio-economic scenarios, the biomass technology promotion has the largest negative emissions sources resulting from the expansion of BECCS (bioenergy combined with Carbon Capture and Storage). These socioeconomic factor change effects are slightly different between 1.5 and 2 °C scenarios but we can expect almost similar trend. Our findings indicate the importance of technological improvement for realizing very low temperature stabilization. How to realize the technological progress particularly in low carbon energy supply technologies should be more heighted for the decision makers.

Keywords: Socio-economic factors, 1.5°C goal, Paris Agreement, SSPs, Computable general equilibrium (CGE) model

1 Introduction

The Paris Agreement has confirmed that the ultimate climate policy goal aims to hold the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the increase to 1.5 °C. The 1.5°C climate change mitigation goal has been paid attention for its significant role in reducing the risks and impacts of climate change. Meanwhile moving from 2°C to 1.5°C also represents much larger efforts, challenges and costs.

There are few papers that have studied the mitigation effort that is consistent with 1.5°C goal. Rogelj at al.[1] found that the energy-system transformations in 1.5°C and 2°C consistent scenarios are similar in many ways. Additional CO2 emission reduction is mostly needed from 2°C moving to 1.5°C. Energy efficacy and early action are important to achieve 1.5°C goal.

Socio-economic factors, such as economic growth, population, demographic factors, technological change, lifestyle change, policies and so on, are the driving forces for future emissions. Mitigation challenges and costs of achieving stringent climate goal is strongly related with the socio-economic conditions. For example, recently developed Shared Socioeconomic Pathways (SSPs) quantitatively distinct various socioeconomic factors into five representatives including energy system[2], land use[3] and they clearly indicate the importance and future diversity in various socioeconomic aspects and climate mitigation cost [4]. However, SSPs change many of the factors at once and cannot identify what factors are important for the climate change mitigation cost. To overcome that weakness of such aspects, Marangoni et al. [5] explored the sensitivity of CO2 emissions projections to key drivers of the uncertainty in the SSPs, and found out that the income and energy efficiency are the most important drivers and found out that the income and energy efficiency are the most important drivers.

Besides of SSPs related studies, there are numbers of articles studying on the impacts of societal change on the climate change mitigation. For example, some focused on the technological change[6, 7], lifestyle change[8-12], energy efficiency and biomass role and so on. EMF27 study employs scenarios focusing on technology variations including energy intensity improvement, technology availability and constraints[13]. Several papers in EMF27 studied the results of mitigation cost and found that it could be dramatically reduced by the technology innovation[14-16].

Despite of the above literature, no studies have clearly answered what socioeconomic factors are critical to change the mitigation cost to achieve 1.5°C goal although identifying such elements would be meaningful for the decision makers in the way that they can realize where to invest. According to such background, this study aims to answer to the following questions 1) what socio-economic factors are most essential for the mitigation cost of stringent climate goals? 2) Through which channels do they affect the mitigation cost of stringent mitigation? 3) What is the uniqueness of 1.5°C comparing to 2°C?

The sections are ordered as follows. Section 2 demonstrate the methodology and scenario assumptions. Section 3 shows the results. Section 4 provide discussion and policy implications.

2 Methodology

2.1 AIM/CGE

We used AIM/CGE (Asia-Pacific Integrated Model/Computable General Equilibrium), which has been widely used in climate mitigation and impact assessment [17-21]. AIM/CGE is a recursive dynamic general equilibrium model that includes 17 regions and 42 industrial classifications. Energy sectors, including power sectors, are disaggregated in detail. Moreover, to assess bioenergy and land use competition appropriately, agricultural sectors are also highly disaggregated [22]. This CGE model was developed based on the “Standard CGE model” [23], and details of the model structure and mathematical formulas are described in the AIM/CGE basic manual [24].

The production sectors are assumed to maximize profits under multi-nested Constant Elasticity Substitution (CES) functions and each input price. Energy transformation sectors input energy and value added as fixed coefficients of output. They are treated in this manner to appropriately deal with energy conversion efficiency in the energy transformation sectors. Power generation values from several energy sources are combined with a Logit function. This method is adopted in consideration of energy balance because the CES function does not guarantee a material balance. Household expenditures on each commodity are described by a Linear Expenditure System (LES) function. The saving ratio is endogenously determined to balance saving and investment, and capital formation for each good is determined by a fixed coefficient. The Armington assumption is used for trade, and the current account is assumed to be balanced.

In addition to energy-related CO_2 emissions, CO_2 from other sources, CH_4, and N_2O are treated as GHG emissions in this model. Non-energy related CO_2 emissions consist of land use change and industrial processes. CH_4 has various sources, but the main sources are the rice production, livestock, fossil fuel mining, and waste management sectors. N_2O is emitted by fertilizer applications and livestock manure management, as well as by the chemical industry. Energy-related emissions are associated with fossil fuel consumption and combustion. Non-energy-related emissions, other than land use change emissions, are assumed to be in proportion to the level of activities (i.e., output). Land use change emissions are derived from the difference of forest land area from that of the previous year multiplied by the carbon stock density.

The implementation of mitigation is reflected by a global emissions constraint. A globally uniform carbon tax is employed to meet the global emission constraints. The carbon tax makes the price of fossil fuel goods higher when emissions are constrained and promotes energy savings and the substitution of fossil fuels by lower emission energies and acts as an incentive to reduce the non-energy-related emissions. Gases other than CO_2 are weighted by global warming potential (CO_2=1, CH_4=25, N_2O=298, C2F6=12200, SF6=22800, CF4=7390) and summed as GHG emissions in CO_2 equivalents. The revenue from the carbon tax is assumed to be received by households.

2.2 Scenario settings

There are two dimensions of scenario design; namely 1) climate policy and 2) socio-economic factors. In climate policy dimension, there are three; baseline, 2.6W and 2.0W. The 2.0W scenario means that by the end of this century, the radiative forcing level is limited below 2.0W/m2 (1.9W/m2). The global mean temperature increase are well below 1.5°C (peaking in 2040 and end up with 1.3°C in 2100). The 2.6W scenario, similarly, is consistent with 2°C goal (global mean temperature change in 2100 is 1.7°C). Those climate related indicators are derived from MAGICC6. In this dimension, global uniform carbon price is applied as a cost-effective tool to achieve certain level of emission reduction each year from 2005 to 2100. In socio-economic dimension, the way of implementation of socioeconomic factors’ changes is to change some of the parameters which is related to the SSP settings.

Among the five SSPs domains, SSP2 is seen to be the continuing of the current social, economic and technological trend, leaving the world face moderate challenges to mitigation and adaptation. Therefore, we begin with the SSP2 assumption as reference (Ref) used by Fujimori et al. [25]. Then, there are four other assumptions which differentiate individual factors; namely HighTech, AEEI, Lifestyle and Bio (table 1). The basic idea of how to change the assumptions is using SSP1 assumption for each case. For example, SupTech changes renewable, nuclear and CCS technological cost as SSP1 while others are kept as SSP2. SSP1 depicts the sustainable growth pathway, with lower challenges to both mitigation and adaptation[26] and here, using SSP1 assumption allows us to see how much the mitigation cost is reduced by the corresponding factors direct to the SSP1 world. There could be an alternative way to use SSP3 which is the opposite representation in terms of the mitigation challenge. However, that treatment had a possibility to make the 1.5°C stabilization infeasible because SSP3 had no feasible solution even for 2.6W equivalent mitigation[27] and therefore, we took that approach.

Here we explain why we adopt four scenarios in this study. Among the socio-economic factors, results of EMF27 projects show that technology innovation is important for the long-term global climate stabilization goals and the associated mitigation cost. Energy efficiency improvement is also indicated as important factors by literature. Biomass is gaining more and more attention for its role in producing negative emissions combining CCS and as an essential alternative energy sources. The general citizens' behavior would also change the requirements for the achievement of climate goals by climate policies. To represent these factors, we change parameters shown in table 1. Detailed description can be found in SI.

Because those elements changes several parameters for each (e.g. Tech changes renewables, nuclear and CCS), to identify further detailed factors, we also carried out another set of scenarios in which factors in HighTech are decomposed. We call these cases as a set of decomposition cases while the cases in table 1 are a set of core sensitivity cases. In HighTech decomposition scenarios, namely, Solar, Wind, Nuclear, CCS, Biomass. one-by-one technology improvement is assumed.

Table1 Core sensitivity cases[1]

case names	Socioeconomic factor's description
Ref	SSP2 parameters settings
HighTech	low cost for renewables, CCS, nuclear as in SSP1
Lifestyle	low preference for meat, industrial, transportation as in SSP1
AEEI	higher Autonomous Energy Efficiency Improvement as in SSP1
Bio	lower bioenergy tech cost and higher social preference as in SSP1

[1] Technology improvement in nuclear, CCS and bioenergy supply in SSP1 is no higher than SSP2. Here we assume the improvement rate is assumed 25% higher than SSP2, which is not consistent with SSP1. Similarly, the social acceptance of modern biomass in Bio scenario is assumed higher than SSP2 scenario, while in SSP1 it is assumed lower than SSP2. We didn't set these assumptions following SSP1 is because that our hope to develop scenarios representing more sustainable world against climate change. To do that, we neglect some other concerns such as technology risks which are reflected in SSP1.

3 Results

In this section, we conduct the results analysis with three steps. First, we demonstrate and compare the mitigation cost in mitigation scenarios. Second, we analyze the role of the most important socio-economic factor. Third, we trace the affecting channels of the socio-economic factors influencing mitigation cost. The difference between 2.6W and 2.0W are compared where appropriate.

3. 1 Mitigation cost

Figure 1 illustrates GDP loss rates, consumption loss rates and carbon prices overtime for all the main scenarios in comparison with Ref scenario. Among the three, GDP loss rates are seen as the main indicator of the mitigation cost in this paper. GDP loss rates in Core sensitivity cases are significantly lower than Ref case. The GDP loss rate in HighTech scenario is reduced by 62% from Ref in 2.6W and 45% in 2.0W in 2100 year. The effect is larger than other core sensitivity cases, implying that technological improvement in the Hightech has the largest potential to reduce the mitigation cost. Bio scenario shows decreased GDP loss rate with time while Lifestyle and AEEI scenarios show increased GDP loss rate. And GDP loss rate reductions end up in 2100 around 14% from Ref scenario similarly in the AEEI, Lifestyle and Bio scenarios in both 2.6W and 2.0W. Except for AEEI scenario, HighTech, Lifestyle and Bio scenario depressed the sharp increase of carbon price especially in the latter half of century in 2.0W. The consumption loss rate shows similar trend with GDP loss rate in all scenarios but larger magnitude.

The results of decomposition scenarios in HighTech scenario (SI) show the differences between individual technologies. In 2.6W nuclear technology improvement is the largest GDP loss rate reduction contributor (23% reduction from Ref scenario in 2100 in high_nuclear scenario), followed by CCS (15%). However, in 2.0W the contributions of each technology converge. The impacts of nuclear and CCS decline while the solar, wind, and biomass increase its impacts.

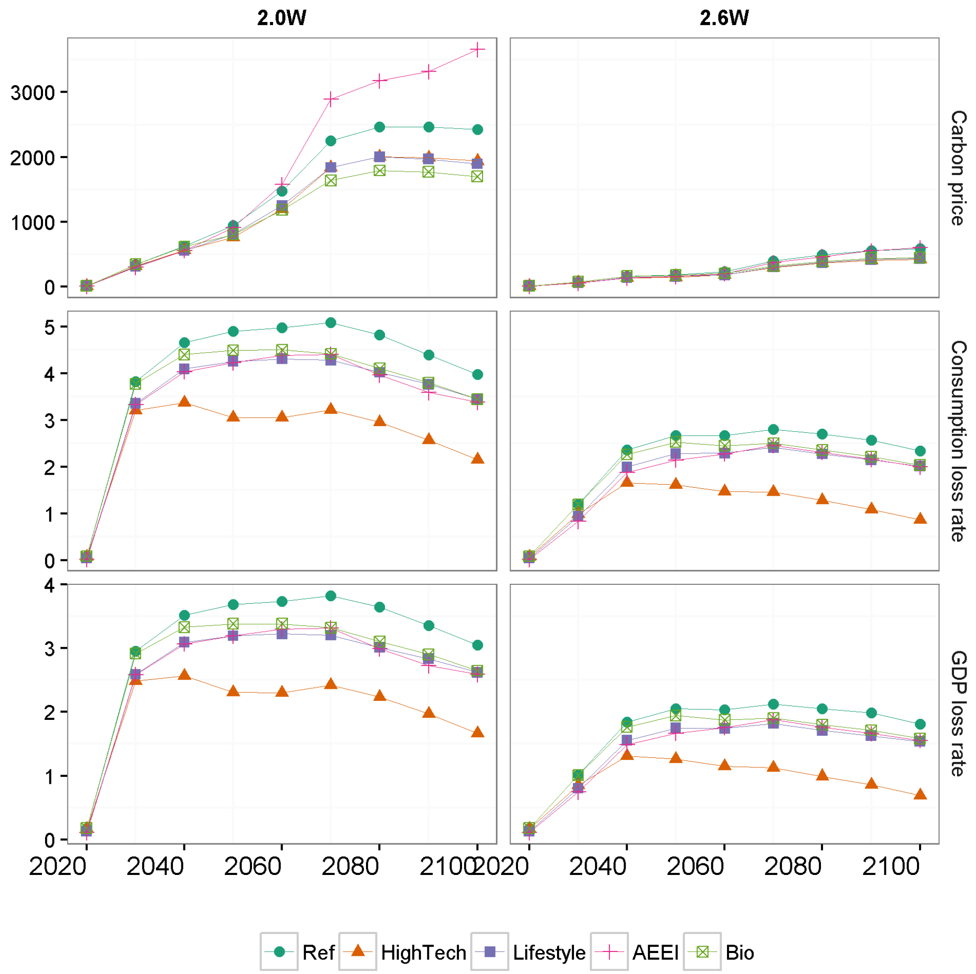

Figure 1 Mitigation cost for all the socio-economic scenarios in 2.6W, 2.0W policy dimensions[2] (Unit: Carbon Price USD2005/tCO2; Consumption loss rate and GDP loss rate: %)

3.2 Role of technology improvement in the energy supply sector

The cost reduction effect of the technological change in HighTech scenario is transmitted to the final energy price. The electricity price in HighTech is much lower than other scenarios (Figure 2) due to the reduction in investment cost, management and operation cost and other associated cost in low-carbon energy supply sector triggered by technological change. The electricity price in 2.6W for HighTech scenario is even close to the energy price in other socio-economic scenarios in Baseline. The electrification rate in HighTech scenario are the highest among the socio-economic scenarios due to the low cost of electricity, but the electrification rate growth from Ref scenario is still limited, by 4.37% in 2.6W and 3.04% in 2.0W. The low cost of electricity in combination with high electrification rate lead to the large reduction of the GDP loss.

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[2] AEEI scenario in 2.0W shows substantial increase in carbon price compared with SSP2. AEEI rapids the phrase-out of fossil fuel plants in the near term and CCS installation is thus limited to certain level. After 2060, the emissions are below zero and larger BECCS and CO2 plantation are needed. By that time the CCS is still expensive thus the CO2 plantation plays the important role in keeping negative emissions. It pushes higher carbon price. However, the GDP loss rate is not influenced in AEEI scenario.

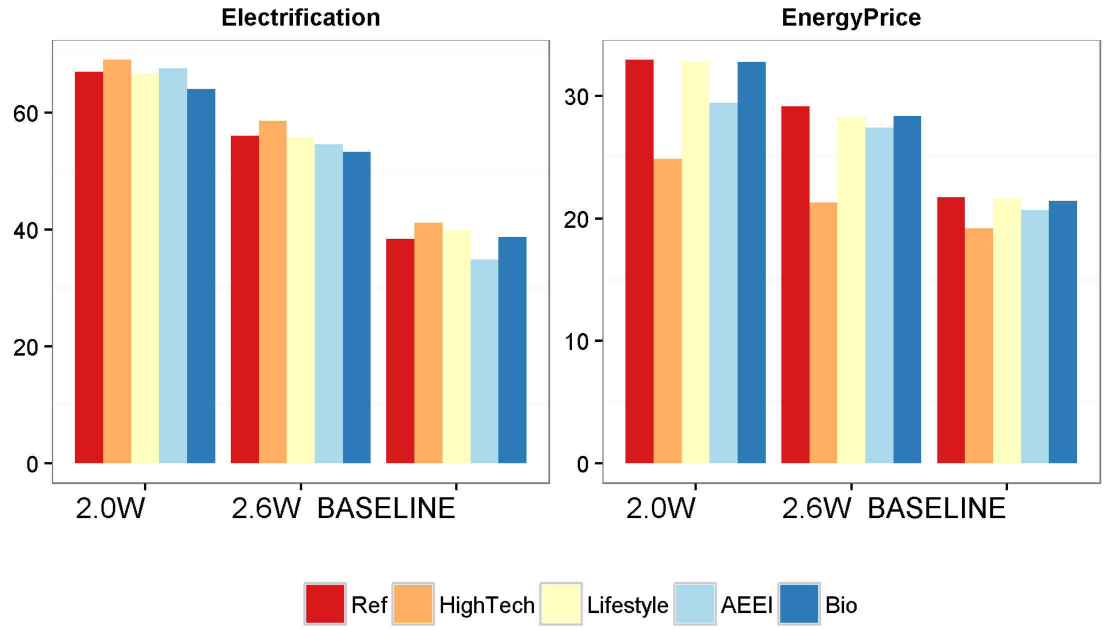

Figure 2 Electricity price and electrification in 2100 for all socio-economic scenarios in 2.6W, 2.0W and Baseline climate policy dimensions. (Unit: Electrification:%; Energy Price: USD2005/GJ)

3.3 Affecting channels of socio-economic factors

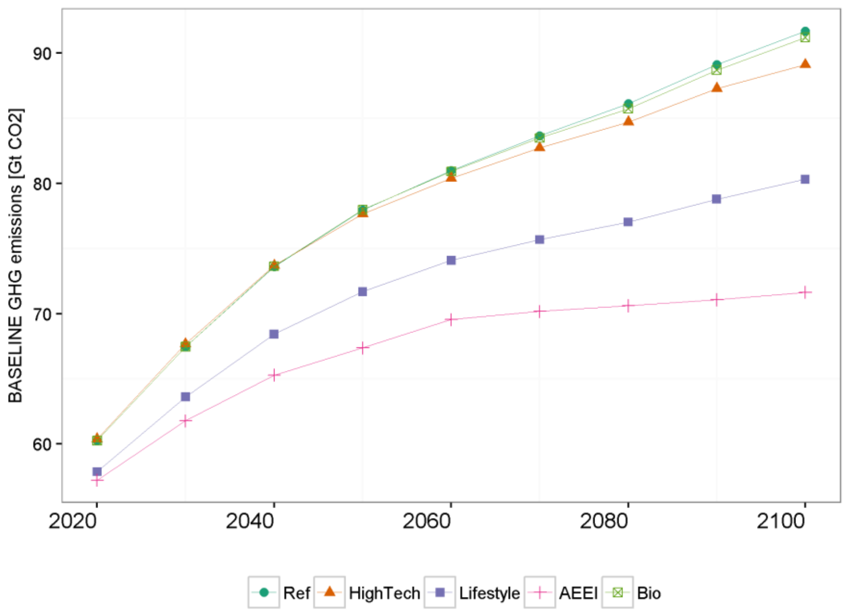

Figure 3 GHG emissions for all socio-economic scenarios in Baseline. (Unit: GtCO2eq)

Baseline GHG emissions are one of the factors that determines mitigation costs. Figure 3 shows Baseline emissions for all the socio-economic scenarios. AEEI and Lifestyle scenarios exhibit strong effects in Baseline while HighTech and Bio scenario barely change from Ref. AEEI and Lifestyle change would influence the mitigation challenges by the decreasing emissions reduction rates.

Sectoral features of final energy consumption are examined for AEEI and Lifestyle scenarios. Comparing Lifestyle with AEEI, the transportation sector includes different final energy use tendency (Figure 4). The final energy demand reduction from Ref in transportation sector is 32% and 12% in 2100, in Lifestyle and AEEI scenarios, respectively. While for industrial and residential and commercial sectors, the AEEI scenario seems more effective in reducing final energy demand and the reduction rate could be above 30% in 2100. It means that to lower the energy consumption in transportation sector, to reduce the transportation service demand as a lifestyle change could be a good way since it is relatively difficult to reduce the emissions by improving energy efficiency in transportation sectors.

Lifestyle change could open another vital channel to reduce the effects of climate policies on the economy through reduction in non-CO2 emissions, mainly through dietary change towards low-meat consumption pattern (SI). CO2 emissions budget constraints thus loosened and energy and land scarcity impact less negatively on the economy. Other channels contributing to reducing the mitigation cost of Lifestyle scenario is through the lowered price of livestock (SI).

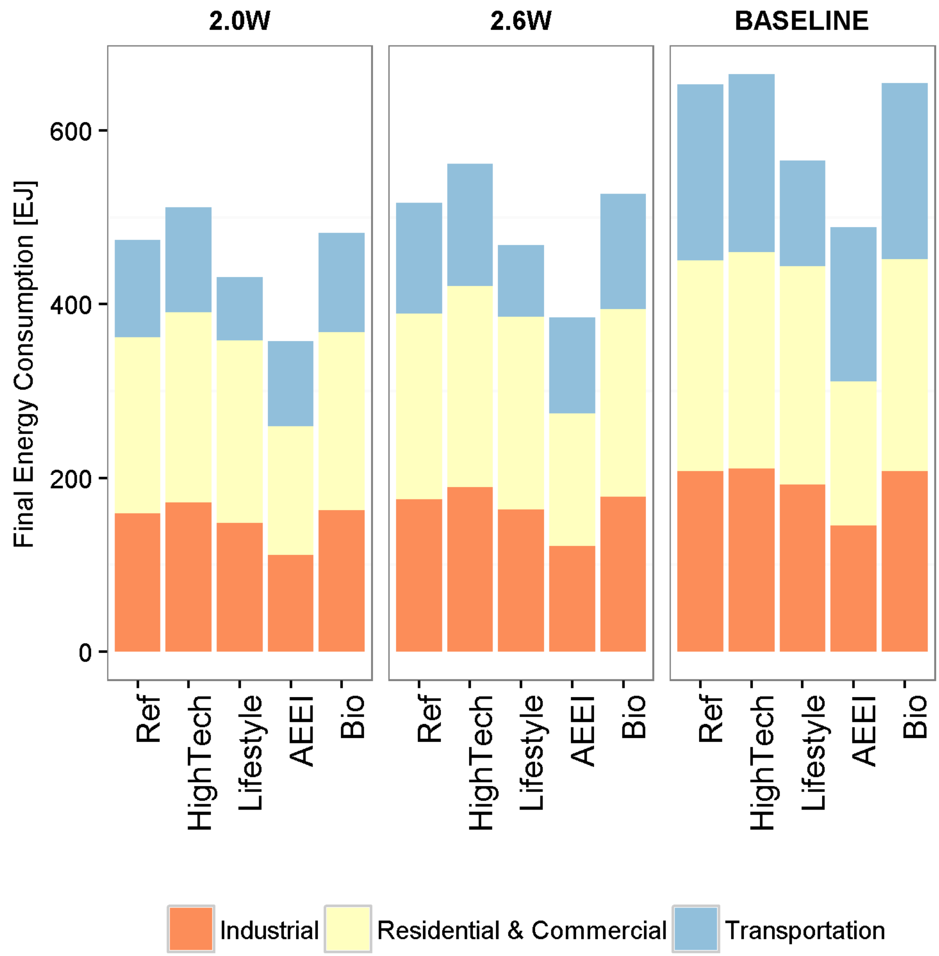

Figure 4 Sectoral energy consumption in 2100 for all socio-economic scenarios in 2.6W,

2.0W and Baseline climate policy dimensions.

Biomass is an important alternative of energy source for its carbon neutral feature and ability of producing negative emissions combined with CCS technology. Demand for primary bioenergy is increased substantially in climate stabilization scenarios (SI). It is even more so in Bio scenario. The carbon price in Bio scenario is the lowest among the socio-economic scenarios in 2.0W, particularly in the latter period of this century.

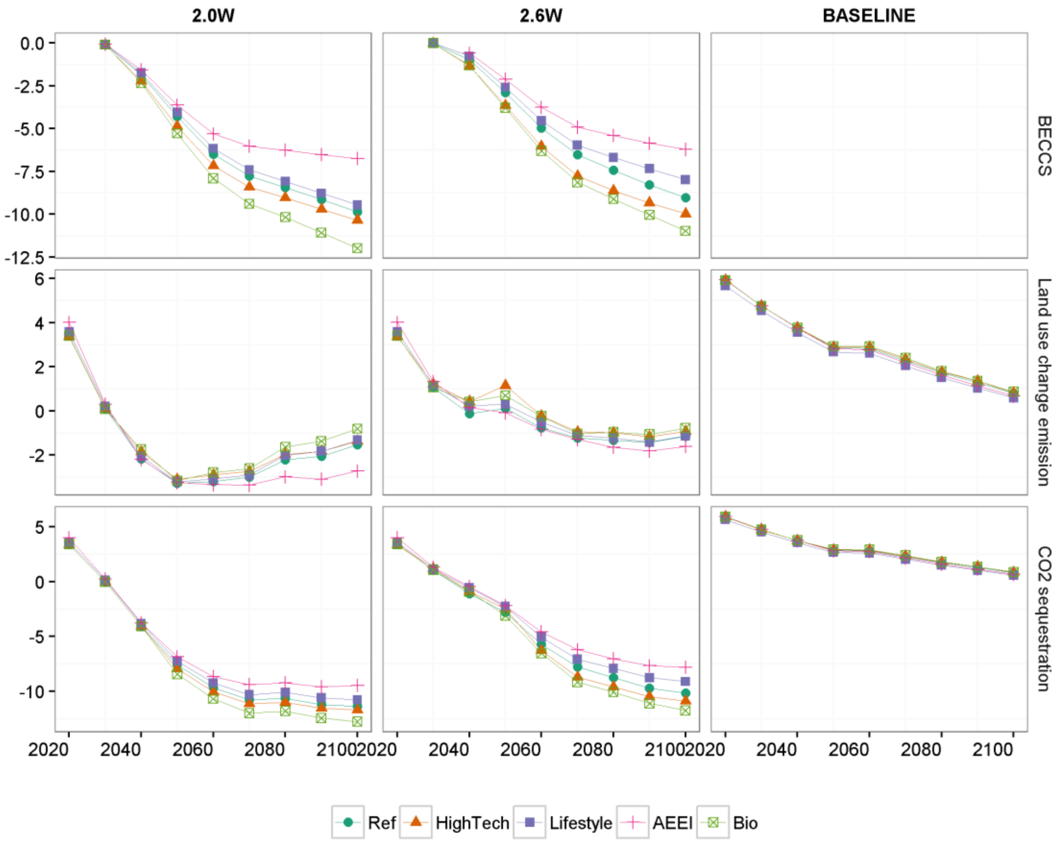

Figure 5 CO2 sequestration for all socio-economic scenarios in 2.6W, 2.0W and Baseline climate policy dimensions. (Unit: GtCO2)

Figure 5 illustrates the CO2 sequestration including emissions removed through BECCS and land use change. CO2 absorption from land use change is basically greater in 2.0W than 2.6W in all socio-economic scenarios, though the volume is decelerating in the latter century in 2.0W due to the competition between bioenergy crop and forest land under high carbon price. The total CO2 sequestration is thus stay stable since 2070 in 2.0W. Among the socio-economic scenarios, the Bio scenario achieved the largest negative emissions sources without higher carbon price, resulting from the expansion of BECCS.

4 Discussions and implications

Scenarios	Channels to reduce the mitigation cost	GDP loss rate reduction in 2.0W	Other principle features
HighTech	Energy Price/ electrification/ investment cost	Largest potential, weaker than 2.6W	Low-carbon technology converged contribution
AEEI	Baseline/Energy intensity	As effective as 2.6W	
Lifestyle	Baseline/energy intensity/non-CO2	As effective as 2.6W	Limiting transportation sector emissions
Bio	CO2 sequestration/ carbon price	As effective as 2.6W	

Table 2 Summary of the key findings

In summary, this paper explores the most essential socio-economic factors for mitigation cost under 1.5°C climate goal as well as their affecting channels. The comparison between 2°C scenario and 1.5°C scenario is made. Table 2 provides an overview of the affecting channels and differences between 1.5 and 2 °C. The novelty of this study is summarized in the following new findings with respect to the initial three research questions. First, we found that technology improvement in low-carbon energy supply sectors shows the largest potential to reduce the mitigation cost. Second, our analysis shows that the socio-economic factors reduce the mitigation cost through different channels. The low energy supply cost leads to the direct energy supply cost reduction together with facilitation of electrifications which is the fundamental element to decarbonize energy system or make it negative one eventually. Energy efficiency and lifestyle change help to shape the baseline trajectory with its strong effects on the demand side. AEEI is remarkably effective in suppressing industrial and residential sectors emissions through energy efficiency improvement, with less but also significant impacts on the transportation sector. In contrast, lifestyle change shows more power on the emissions reduction of transportation sector. Among the factors, the Bio scenario has the largest negative emissions sources resulting from the expansion of BECCS. Third, we found that the role of technology improvement is slightly weaker in 1.5°C scenario than 2 °C scenario, but effective similarly. The contribution of individual technologies is converged in 1.5°C scenario, with solar, wind and biomass gaining more importance.

Here we have three points to make. First, the supply-side technological change touches upon the nature of GDP loss caused by climate policies. Firstly, the overall energy cost of the economic activity is thus reduced due to lowered electricity price associated with higher electrification rate. Secondly the investments are lead to the sectors where the expense is less expensive without climate policy and reduce the “deadweight losses” [30]. The other socio-economic factors also influence through the above channels but do not show as strong linkages. Meanwhile, it should be noted that these results depend on the assumption of the degree of technological improvement and other end-use side life style and efficiency changes. Second, Solar, wind and biomass are gaining importance in lowering the macro-economic cost of climate actions in 1.5°C scenario, while nuclear and CCS are more influential in 2°C scenario. It is in line with the energy supply structure since the renewables account for larger share in 1.5°C case compared with 2°C scenario It should be noted that though their roles are declining, technological change in nuclear and CCS remain a large contributor to the mitigation cost improvement and their technology development should not be neglected. Third, since the supply side technological improvement is not as effective in achieving 1.5°C goal as 2°C case, other socio-economic factors are seen more important and should be considered as alternative solutions, such as energy efficiency, lifestyle change and biomass related technology promotion, since the latter three appear as effective as in the 2°C scenario.

Based on the above results and discussion, we make four suggestions for policy makers. First, technological improvement in low-carbon energy supply sectors should be prioritized. More input in R&D investment towards low-carbon energy supply technologies could be beneficial. We could focus more on renewables if we aim at more stringent climate stabilization level like 1.5°C. Second, we should not underweight policies targeting at energy efficiency improvement of end-use, greener lifestyle change and biomass energy technology related promotion. For example, energy efficiency standards and regulations could be set by the governments on the sectoral end-use equipment and appliances. The information sharing of climate change and education could be further improved for shaping people's behavior in energy-saving and conservation, greener transportation mode choice, low-carbon diet and so on. The social acceptance of biomass use should be improved and associated policies could be implemented to deal with public concerns such as food security and deforestation.

The study has some limitations. First, it does not consider the interactions among the factors. We can conclude this trend from the sub-scenario results that the effects of factors are interactive thus not cumulative in all. Marangoni[5] incorporated the interaction among factors in his sensitivity analysis from the view point of emission decomposition under the same carbon price. However, it remains unknown interaction effects on the macro-economic cost in achieving curtain forcing level such as 2.0W. Similarly, the SSP2 socio-economic background is essential assumptions in this study. It would be interesting to consider the socio-economic uncertainty from other domains such as SSP1 as the start point. Second, the technological change could be driven by most fundamental socio-economic drivers such as R&D investment in energy supply sector and energy efficiency improvement for energy end-use[31-36] and sometimes that could be cost-effective. Here in this study, we run the HighTech scenario by assuming the reduction in investment cost indicates the investment efficiency improvement as a result of the technological change. We run AEEI scenario by simply changing one parameter indicative of efficiency change in energy end-use. More realistic policy implications could be made if we step further for incorporating drivers such as R&D investment in the modelling and analyze their impacts on the mitigation cost of stringent climate goals.

5 Conclusions

This study investigated the role of socio-economic factors in reducing mitigation cost under 1.5°C and 2°C climate goals. Using AIM/CGE model, we examined four families of socio-economic factors, namely, low-carbon energy supply technologies, end-use energy efficiency improvement, lifestyle change and biomass technology promotion. We found that the low-carbon energy supply technologies progress is the strongest factor to reduce mitigation cost and that would play a key role to achieve 1.5°C climate stabilization.

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