15. Household energy security under stringent climate change mitigation goals of the Paris Agreement

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We examined the impact of climate change mitigation policies in line with the 2℃ and 1.5℃ temperature goals on household energy security in a global scale household model soft-linked to a computable general equilibrium model. We concluded that although the 1.5℃ mitigation pathway would not increase the regional gap in residential energy use, it could compromise residents' living standards unevenly. Future attention on the energy transition should focus on supporting improved energy efficiency in the global south.

Key Words: *climate change mitigation, the Paris Agreement, household energy security, equity*

1. INTRODUCTION

To tackle the threats from climate change, the Paris Agreement (PA) declared a long-term climate goal of a global average temperature increase well below 2°C and even below 1.5°C above pre-industrial levels 1). This requires urgent deep transitions by all actors, like energy system decarbonization, improved land-use development, and demand-side management 2), and will significantly affect households via production, prices, and income.

Explicit attention to poverty and equity is salient to fair and effective policymaking for climate change mitigation. Radical decarbonization of the energy system could induce drastic increases in energy prices, changes in the availability of carbon-intensive energy carriers, and an unstable energy service supply 3), which is essential in SDG17. Disadvantaged lower-income people are more exposed and vulnerable to such changes and their energy security could be threatened under such circumstances because the combination of high energy prices, low income, which is often followed by poor energy efficiencies, would prevent them from satisfying their energy service need 2). Here, household energy security is defined as the availability of an assured and regular supply of clean energy fuels at an affordable price for various household activities 4).

At the same time, the revenues from climate policies, for example, the carbon tax revenues could be used to finance clean energy infrastructure which could help provide universal access to modern energy and thusly enhance household energy security. On the other hand, improved equity and energy poverty alleviation are known to be effective enablers of demand-side management and other climate change mitigation actions 5), but the current climate change mitigation modeling often failed to take into consideration of such interactions.

This study examined the impacts of climate change mitigation policies in line with the 2°C and 1.5°C temperature goals on poverty and household energy security and compare the different implications by country. We hope to reflect on the achievement of an equitable distribution of the mitigation responsibilities and an optimal way of carbon pricing and revenue distribution.

2. MATERIALS AND METHODS

2.1 Methodology overview

We used an integrated assessment modeling framework to make global projections from 2010 to 2050. Mitigation pathways needed to meet the 2°C and 1.5°C temperature goals were determined using AIM/Hub [3], a recursive dynamic computable general equilibrium (CGE) model. The impact of the climate targets on households was computed in a Poverty, Household, and Income distribution model (AIM/PHI) [6] with a flexible demand system and a household consumption database.

2.2 Models

AIM/Hub covers 17 regions, with 43 industrial sectors and four institutions, including a representative household. The carbon price is an innate driver of mitigation and is determined endogenously to meet the emissions budget. The GDP loss and price changes are then passed on to the AIM/PHI model as impacts on the income and expenditure sides.

The AIM/PHI model distributes the household income following a lognormal income distribution function, which is one of the most commonly used distribution functions when it comes to poverty or hunger risk projections for its good performance at the lower tail of the distribution. Then, households decide their expenditures on 18 commodities in the AIDADS (An Implicitly Direct Additive Demand system) [7], supported by global household consumption databases, and national household surveys [8–12]. There are five energy commodities: solid (fuels); liquid (fuels); gases; biofuels; and electricity (and heat, geothermal, and others). Household energy expenditures and consumption were not available for all regions or the data quality was of concern. We complemented the household energy profile in the consumption database using the energy balance table and prices provided by International Energy Agency [13].

2.3 Data

We obtain the energy consumption for residential use from the IEA energy balance tables (EBTs) for 14 commodities in 190 countries and region aggregations and national energy enduse prices for 6 commodities in 139 countries (See **Table 1**).

The energy enduse prices are provided in PPP$ per unit and are converted into PPP$ per toe net calorific value (NCV) using the OECD average conversion factors to match with the energy consumption in the EBTs. Missing values were filled in with the national or regional or global median in all time periods.

Special attention to biomass and biofuels is need for future research. The IEA accounted for the biofuels blends in transportation fuels and the biomass in electricity generation, but does not explicitly provide the enduse prices for the biomass and biofuels directly consumed by the households. This part of biomass is typically collected freely or bought in local markets in a low price. A simple way of imputation is to use the price of a similar products instead. Here we took the price of Steam coal. We would like to have a more mature simulation on the biomass combustion in household.

2.4 Scenario

The business as usual (BaU) scenario was the middle-of-the-road Shared Socioeconomic Pathway 2 (SSP2) baseline in which no climate policies were adopted. The 2°C and 1.5°C scenarios followed the SSP2 narratives and global CO_2 emissions constraints to achieve the long-term goals of the PA. The national mitigation pathway was determined by the globally uniform carbon price to achieve the global temperature goals. The projections were from 2020 to 2050. In this report, we presented the emission reductions shouldered by the main contributors and the corresponding macroeconomic loss, as well as the poverty and energy poverty related indicators.

For energy poverty, we assessed three commonly used indicators. They are the 2M indicator, Low Income High Cost (LIHC), and the Hidden Energy Poverty (HEP) extent [14]. The 2M indicator measures the percentage in the total population of those whose proportion of energy expenditure in the total disposable income is higher than twice the national average. The LIHC indicator gives the percentage in the total population of those whose budget on commodity and services other than energy services is lower than the poverty threshold while the share of energy budget in the disposable income is lower than the national median. The HEP extent shows the percentage in the total population of those whose energy expenditure is lower than half the national average.

Table 1 Energy commodities

AIM/PHI	EBT	Price database
Solid	Coal and coal products	Steam coal
	Peat and peat products	
	Primary biomass and waste	
Liquid	Crude, NGL and feedstocks	Kerosene
	Oil products	
Gas	Liquefied petroleum gases	Liquefied petroleum gases
	Natural gas	Natural gas
Biofuels	Other biofuels	Kerosene
Electricity	Electricity	Electricity
	Geothermal	
	Heat	
	Solar/wind/other	

3. RESULTS

3.1 Greenhouse gas emissions and economic losses

Figure 1 showed the greenhouse gas (GHG) emission reductions by each country to fulfill the 1.5℃ scenario in 2050. In 2050, 71.4 Gt CO_2eq would be emitted in the BaU scenario, while the 1.5°C target required a nearly "net zero" scenario (4.02 Gt CO_2eq). The six regions with the largest reductions contributed two thirds of all reductions. China alone needs to reduce 17.4 Gt CO_2eq in 2050. India and Southeast Asia are expected to achieve a significant reduction despite their large populations and economic development. The large reductions caused significant GDP loss in the Former Soviet Union, India, and China, compared to that in the United States and European Union (EU), indicating the uneven mitigation responsibility suggested by a uniform carbon price.

3.2 Total energy consumption by households

Figure 2 showed the per capita annual final energy demand in the residential sector. The Former Soviet Union, India, and Southeast Asia were where the most radical reductions should occur to achieve the PA temperature goal. Heat was the major energy commodity for end-use in the Former Soviet Union, where the winter was long and the average temperature was low, while biofuel dominated in India and Southeast Asia, where the average temperature was higher and there is an abundance of biomass easily available. It is not hard to see that this variance is alargely relevant to the geographic features, which have not yet been addressed in our model.

Large variation in energy services demand could lead to very different distributional outcomes of climate policies, based on our previous study (under review). Regional gaps narrowed in the 1.5°C scenario, but the per capita final energy demand and electrification rate in India and Southeast Asia suggested difficulties in improving the living standard along with climate change mitigation.

3.3 Energy consumption by poor households

Figure 3 showed the average energy consumption in households living below the poverty line of $3.2 per capita per day in Southeast Asia and the EU, with similar GDP loss per ton of GHG emission reduction, but in different stages of development. Regardless of the low-income elasticity of the poor and their already low energy consumption and living standards, they would still need to cut their daily energy consumption by around 1.5% in 2050 to achieve the 1.5°C temperature goal. Comparing **Figure 3** with **Figure 2**, there was a significant gap between the CGE and household model and narrowing the gap is a critical step to validate our projections.

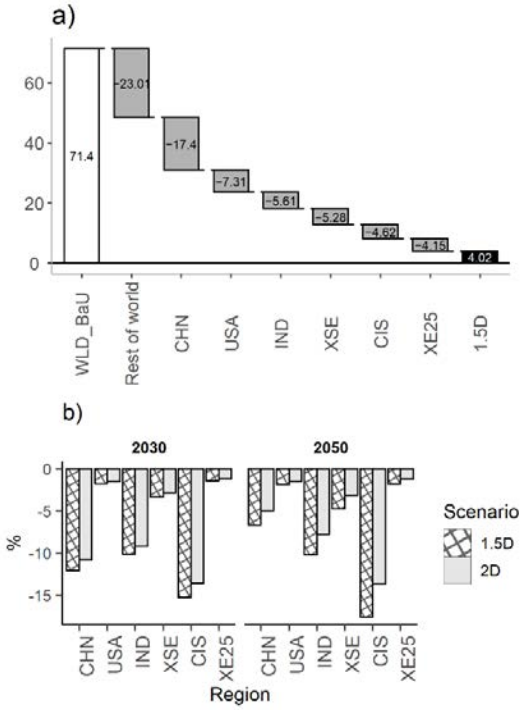

Figure 1 Distribution of the GHG reduction and GDP loss. a) Regional GHG reductions needed to achieve the 1.5°C temperature goal (Gt CO_2eq/yr). b) GDP loss (%) in each region compared to BaU.

3.4 Energy poverty by region

Figure 4 showed the energy poverty evaluated by the 2M indicator, HEP, and LIHC.

The HEP showed the highest energy pvoerty rate and the 2M indicator showed the lowest in the BaU scenario. While LIHC and HEP indicated the trend of decreasing energy poverty from 2020 to 2050 in all scenarios, the 2M indicator increased slightly in the 1.5D and 2D scenarios but nearly disappeared in BaU.

Comparing the mitigation scenarios to BaU, the HEP showed decline in energy poverty by climate policies while the other two indicated an the worsening in energy poverty by climate policies.

The distinct outcomes by the three different indicators implied not only the different nature of the indicators but also the limitations of our current methodology. The 2M indicator puts emphasis on the abnormally large share of energy expenditures, indicating the difficulties in satisfying the energy service need. It was largely subject to the income elasticity of energy goods. The HEP focused on the low total energy expenditure, which reflected the low consumption. It was hard to judge whether the decreasing budget or the income elasticity was more important. The LIHC indicated the vulnerability of people falling into poverty due to energy-related shocks. And it might be a

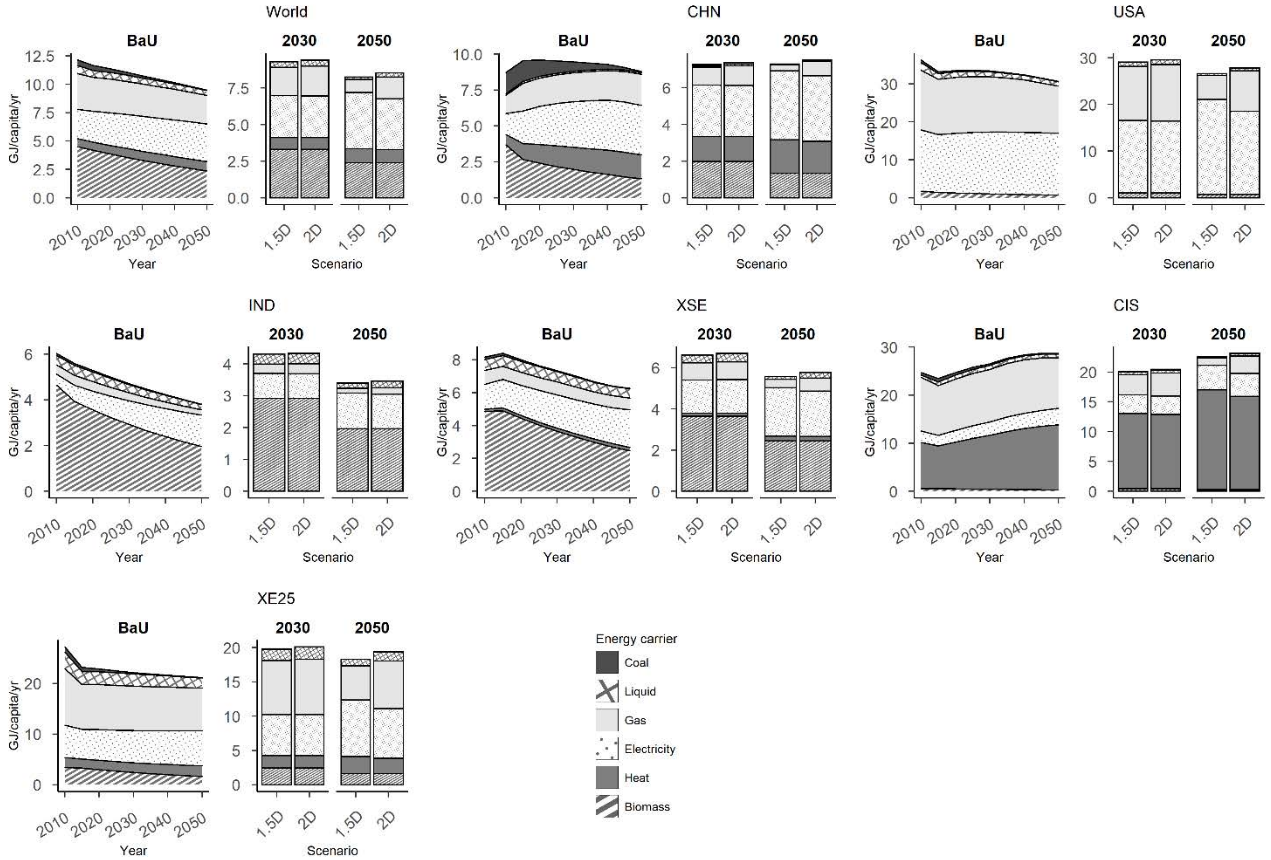

Figure 2 The per capita final energy demand for residential use worldwide and in the six regions with the greatest reductions. This result came from AIM/Hub and the category wwas slightly different from the what we showed in **Table 1**. Biomass refers to the traditional biomass. The sum of biomass and coal equals the "Solid" fuel in AIM/PHI. Biofuel is included in Liquids here.

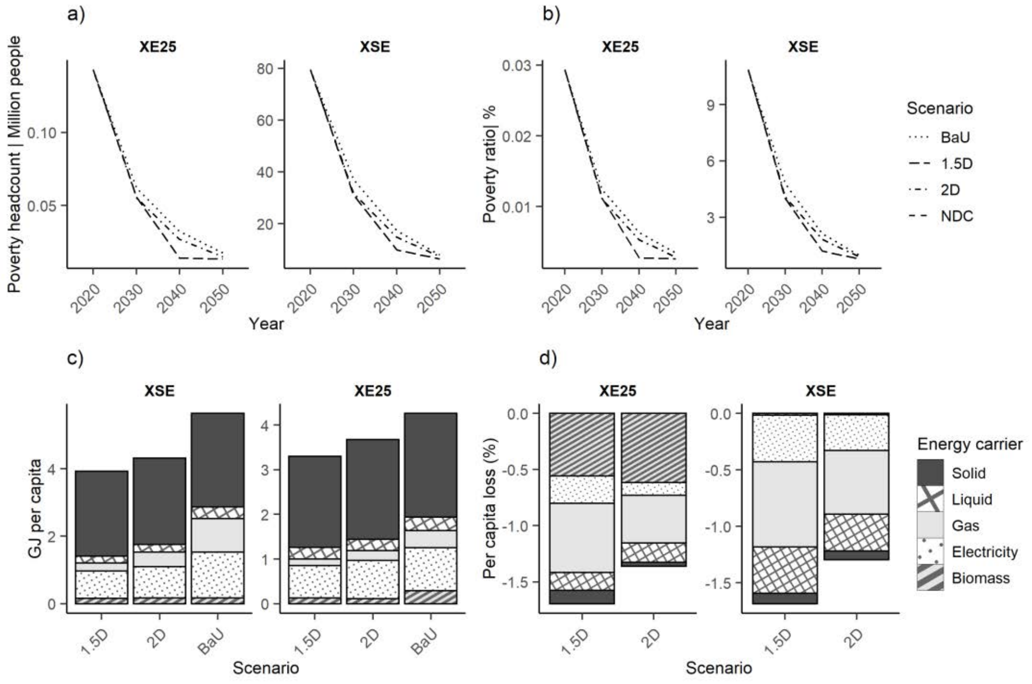

Figure 3 Residential energy use for people in poverty (living on $3.2 per capita per day expenditure) in the EU (XE25) and Southeast Asia (XSE). a) Poverty headcount (compared to BaU), b) poverty ratio, c) household energy use by poor households, and d) per capita loss in household energy consumption.

suitable indicator for our assessment due to its sensitivity to both the price and income shocks. But more well-grounded decomposition and income elasticities analysis will be needed in the future.

4. DISUSSION AND CONCLUSION

The economic loss brought about by climate change mitigation is very uneven. China, the United States, and India are the three regions that need to achieve the PA, but face very different challenges. For China and India, economic growth and welfare promotion will be their development priority. It is necessary to assess carefully whether the economic damage due to climate change and climate change mitigation policies are acceptable.

The preliminary results showed that the 1.5°C scenario with a uniform carbon price comes at the cost of compromising the living standards of individuals. Investment in high-efficiency energy technologies in India and Southeast Asia could be crucial for future mitigation and equity promotion. Financial and technology transfer from the global north to the global south and the equitable distribution of mitigation responsibility are critical to the PA temperature goal and multiple sustainable development goals.

The study is limited by the inconsistency between the household level simulation and the regional level consumption in the CGE model.

This limitation undermines the validity of our simulations and hinders the assessment of many other policy instruments (for example behavioral changes, low-energy-demand scenarios, hunger risk and nutrition deficiency analysis, etc.). Therefore, getting reliable physical term consumption projections in key sectors (energy, food, transport, etc.) is the top priority of the model development.

Another critical question is how the carbon tax revenue was used. It is influential over the distributional outcome of climate policies [15]. Now in the model, the carbon tax revenues collected from all sectors are redistributed to the representative household as an increase in the total household income. In the expenditure modeling, it is assumed that the same proportion of the budget comes from the tax revenues. This implies a neutral distribution of the carbon tax revenues.

In the future, we hope to devise an optimal pathway where the carbon tax revenues, combined with demand-side management, are effectively used to secure household energy services and to narrow down the regional difference in living standards.

To achieve that goal, scenarios allowing flexible designs of tax revenue recyclings and demand-side management will be built.

Key assumptions on tax revenue recycling include:

a) How many revenues can be collected and redistributed to households?

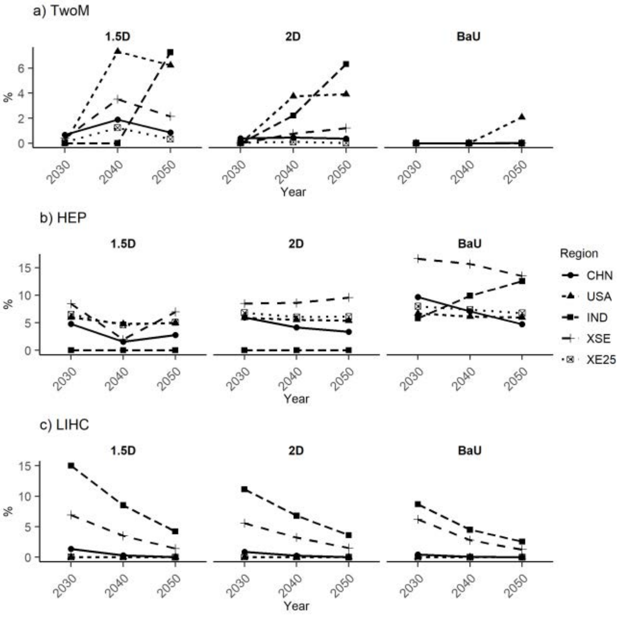

Figure 4 Energy poverty indicators (%) in the 6 largest contributors to emission reductions.

b) How can we redistribute the revenues to reduce energy poverty and inequality?

c) How much will the rebound effect affect the emission reductions?

d) How can we design the subsidy policies to reduce the rebound effect?

Key questions on household-related demand side management include:

a) To what extent should we consider the household heterogeneity?

b) How much efficiency gains can we get by the retrofit of household equipment and the building stock?

c) How can we account for the extra cost by demand side management?

To address the abovementioned questions, we would like to construct, based on the current household energy module, a household energy use model where the energy expenditure is decided by the energy service need, which depends on the income and location, and the performance of the household equipment and dwellings. Using this new modeling framework to derive more reliable global and regional assessments, we could finally provide more realistic and well-focused advice concerning an equitable international climate policy agreement as well as national climate change mitigation policies.

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REFERENCE

1) UNFCCC. The Paris Agreement. Conference of the Parties on its twenty-first session 2015.
2) Ürge-Vorsatz, D.; Herrero, S. T. Building Synergies between Climate Change Mitigation and Energy Poverty Alleviation. Energy Policy 2012, 49, 83–90.
3) Fujimori, S.; Hasegawa, T.; Masui, T.; Takahashi, K.; Herran, D. S.; Dai, H.; Hijioka, Y.; Kainuma, M. SSP3: AIM Implementation of Shared Socioeconomic Pathways. Global Environmental Change 2017, 42, 268–283.
4) Jain, G. Energy Security Issues at Household Level in India. Energy Policy 2010, 38.
5) Pathak, M.; Shukla, P. R.; Skea, J.; Pichs-Madruga, R.; Ürge-Vorsatz, D. Technical Summary. In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (Eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. 2022.
6) Fujimori, S.; Hasegawa, T.; Oshiro, K. An Assessment of the Potential of Using Carbon Tax Revenue to Tackle Poverty. Environmental Research Letters 2020, 15 (11).
7) Rimmer, M.; Powell, A. An Implicitly Directly Additive Demand System: Estimates for Australia. Centre of Policy Studies and Impact Porject 1992.
8) AUS-HES. Australian Household Expenditure Survey. 2018.
9) NSFIE. National Survey of Family Income and Expenditure. 2019.
10) NSFIE. Family Income and Expenditure Survey. 2020.
11) DHEAICS. Distributions of Household Economic Accounts, Income, Consumption and Saving. 2021.
12) CEX. Consumer Expenditure Survey. 2020.
13) IEA. WORLD ENERGY BALANCES 2020 EDITION DATABASE DOCUMENTATION. 2020.
14) Trinomics. Selecting Indicators to Measure Energy Poverty - Under the Pilot Project ‘Energy Poverty – Assessment of the Impact of the Crisis and Review of Existing and Possible New Measures in the Member States’; 2016; pp 1–130.
15) Budolfson, M.; Dennig, F.; Errickson, F.; Feindt, S.; Ferranna, M.; Fleurbaey, M.; Klenert, D.; Kornek, U.; Kuruc, K.; Méjean, A.; Peng, W.; Scovronick, N.; Spears, D.; Wagner, F.; Zuber, S. Climate Action with Revenue Recycling Has Benefits for Poverty, Inequality and Well-Being. Nat. Clim. Chang. 2021, 11 (12), 1111–1116.