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The effectiveness of energy service demand reduction: A scenario analysis of global climate change mitigation

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HIGHLIGHTS

- The effectiveness of a reduction in energy service demand is quantified.
- A 25% reduction in energy service demand would be equivalent to 1% of GDP in 2050.
- Stringent mitigation increases the effectiveness of energy service demand reduction.
- Effectiveness of a reduction in energy demand service is higher in the building sector.

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ABSTRACT

A reduction of energy service demand is a climate mitigation option, but its effectiveness has never been quantified. We quantify the effectiveness of energy service demand reduction in the building, transport, and industry sectors using the Asia-Pacific Integrated Assessment/Computable General Equilibrium (AIM/CGE) model for the period 2015–2050 under various scenarios. There were two major findings. First, a 25% energy service demand reduction in the building, transport, and basic material industry sectors would reduce the GDP loss induced by climate mitigation from 4.0% to 3.0% and from 1.2% to 0.7% in 2050 under the 450 ppm and 550 ppm CO_2 equivalent concentration stabilization scenarios, respectively. Second, the effectiveness of a reduction in the building sector's energy service demand would be higher than those of the other sectors at the same rate of the energy service demand reduction. Furthermore, we also conducted a sensitivity analysis of different socioeconomic conditions, and the climate mitigation target was found to be a key determinant of the effectiveness of energy service demand reduction measures. Therefore, more certain climate mitigation targets would be useful for the decision makers who design energy service demand reduction measures.

1. Introduction

Integrated assessment models are widely used in climate mitigation analysis. For example, the following integrated assessment models are all well-known: AIM/CGE (Masui et al., 2011), GCAM (Vuuren et al., 2011), IMAGE (van Vuuren et al., 2011), MESSAGE (Riahi et al., 2011), and ReMIND (Kriegler et al., 2013). These models basically couple economic, energy, greenhouse gas (GHG) emissions, agricultural, land use, and climate components. They estimate energy production and consumption as well as CO_2 emissions and climate change mitigation costs. Therefore, final energy consumption is a key element of these models. Final energy consumption is determined by two factors—energy service demand and energy technological choices. The former is an indicator that represents the energy consumption activity level. The latter is the combination of energy technological device selections that satisfies the energy service demand. Furthermore, the energy service demand is affected by basic socioeconomic indicators such as GDP and population.

Reducing energy service demand is a mitigation option, but there are various types of energy service demand and different potential sources to reduce demand. For example, improving land use management and the efficiency of urban structural design could potentially reduce transport demand (IEA, 2009d; Ito et al., 2013). In industrial sectors, extending the lifespan of buildings and infrastructure and facilitating material recycling could reduce the production of basic building materials (IEA, 2009c; Kahn Ribeiro et al., 2012; Shi et al., 2012). Building design, holistic retrofits, and other similar techniques could also reduce energy service demand in the building sectors (Ürge-Vorsatz et al., 2012). Consumer

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behavioral change might also have broad impacts on energy service demand. Weatherization and proper maintenance and adjustment of electrical equipment are examples of consumer behavioral changes (Dietz et al., 2009). Changing consumption patterns that do not have direct linkages with energy-using equipment can also affect energy service demand. For example, if people were to spend more money on cultural or non-materialized services such as reading books and listening to music rather than buying new cars, the energy service demand for private car usage would be directly reduced. In addition, industrial production (including metal production) would also decrease. Eventually, structural economic changes would be induced. In terms of travel, changes in people's location preferences could reduce transport demand even if they spend the same amount of time traveling (Girod et al., 2012). Some technological changes that are not directly related to energy technology and not originally intended to change energy consumption can also affect energy service demand. For example, recent technological progress in information technology could improve the efficiency of various industrial activities.

Although some studies have discussed the potential effectiveness of energy service demand reduction, no study has quantified its effectiveness or value. The majority of previous studies using integrated assessment models have focused on either technological or emission abatement options (Krey, 2014). For example, Energy Modeling Forum (EMF) 27 (Kriegler et al., 2014) dealt with technological constraints and their effects on mitigation costs (e.g., carbon capture and storage [CCS] and nuclear energy). Kriegler et al. (2014) compiled multiple integrated assessment model results and concluded that technology is a key element of climate mitigation. Energy intensity improvements and the electrification of energy end use coupled with a fast decarbonization of the electricity sector are required for the stringent climate mitigation target. Moreover, CCS and the use of bioenergy were found to be the most important elements, in part because of their combined ability to produce negative emissions. Although the scenario framework in EMF 27 distinguished between high and low energy demand, their study did not explicitly deal with energy service demand differences, and the assumptions regarding energy technology and energy service demand were mixed. In a pioneering work, Kainuma et al. (2013) explicitly considered energy service demand assumptions. They utilized two climate mitigation scenarios, one with and one without a reduction in energy service demand. The two scenarios, however, also had different assumptions not only about energy service demand but also about other GHG abatement technologies such as CCS. Therefore, it is difficult to extract information about the effectiveness of energy service demand reduction from that study.

This study aimed to quantify the effectiveness of energy service demand reduction by measuring the effectiveness of the demand reduction as a fraction of the gross domestic product (GDP). Section 2 presents the overall methodology, model, scenario framework, and data settings. In Section 3, we present the results of the analysis. In Section 4, we discuss our interpretations of the results and the limitations of this study. Finally, concluding remarks and policy implications are offered in Section 5.

2. Methodology

2.1. Overview of the method

Asia-Pacific Integrated Model/Computable General Equilibrium (AIM/CGE) was used for the analysis and its scenario analysis was adopted. AIM/CGE has been widely used for the assessment of climate mitigation and its associated impacts (e.g., (Masui et al., 2011; Schmitz et al., 2014; Thepkhun et al., 2013)). This model has the unique characteristic that energy service demand and energy end-use devices have high resolution. CGE models are generally able to assess the energy system, the cost of reductions in GHG emissions, and the macroeconomic effects induced by the emissions reduction. Therefore, we used a CGE model. The analytical period of this study was from 2005 to 2050, and we classified the world into 17 regions. The energy service demand reductions in three sectors were examined: buildings (household and commercial), transport, and industry (specifically, steel and cement). The recovery of GDP losses associated with the implementation of climate mitigation was used to measure the effectiveness of energy service demand reduction (see Section 2.5).

2.2. Basic model structure

The CGE model used is a one-year-step recursive-type dynamic general equilibrium model that includes 17 regions and 42 industrial classifications (see Tables A1 and A2 for lists of the regions and industries, respectively). A characteristic of the industrial classifications is that energy sectors, including power sectors, are disaggregated in detail. Moreover, to assess bioenergy and land use competition appropriately, agricultural sectors are also highly disaggregated. This CGE model was developed based on the “Standard CGE model” (Lofgren et al., 2002), and details of the model structure and mathematical formulas are described in the AIM/CGE basic manual (Fujimori et al., 2012).

The production sectors are assumed to maximize profits under multi-nested constant elasticity substitution (CES) functions and each input price. There are several power generation sectors, and the output of the power generation from several energy sources is combined with a logit function (Sands, 2004). This method was 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 parameters adopted in the LES function are recursively updated in accordance with income elasticity assumptions. The savings ratio is endogenously determined to balance savings 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. Land use is determined by the logit function (Fujimori et al., 2014a). The way in which the energy end use is determined is described in Section 2.3 in conjunction with the treatment of energy service demand.

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. The non-energy-related CO_2 emissions are derived from 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 as a result of fertilizer application and livestock manure management and 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 proportionate to the level of activity (such as output). Land use change emissions are estimated by multiplying the change in the forest land area between two years by the carbon stock density.

The implementation of climate change mitigation is represented by adding a global total emissions constraint. Once the emission constraint is added, the carbon tax becomes a complementary variable to the emission constraint, and it determines the marginal mitigation cost. This tax makes the price of fossil fuel goods higher when emissions are constrained and promotes energy savings and the substitution of fossil fuels with lower emission energy sources. The carbon tax is also an incentive to