Evaluation of CO_2 emissions based on the consumption-based measurement under CO2 reduction scenarios of different reduction levels

Takashi Homma[1], Keigo Akimoto, Toshimasa Tomoda

Abstract

This study evaluates the regional and sectoral CO_2 emissions estimated by different CO_2 emissions accounting methodologies around 2050 under different CO_2 reduction scenarios. The production-based measurement of CO_2 emissions is based on polluter pays principle, while the consumption-based measurement is based on beneficiary pays principle. In the field of global warming, the widely used methodology for CO_2 emissions accounting is the production-based measurement of CO_2 emissions generated inside a country. Recently, the consumption-based emissions measurement, which is similar to the concepts of carbon footprint or CO2 visualization, started to be recognized as one of alternative approaches for the substantial reduction of CO_2. The international trade accompanied with the CO_2 emissions that are defined to be emitted in production and distribution processes outside the country is taken into account for consumption-based CO_2 emissions measurements. Most of previous studies only focused on the historical estimations of consumption-based CO2 emissions and there are few analyses on the future consumption-based emissions corresponding to CO2 reduction scenarios. This paper presents the future consumption-based CO_2 emissions by region and by sector toward 2050 under severe reduction scenarios of CO_2 using GTAP database in the base year and an energy-economic model with multi-regions and multi-sectors. The introductions of CO_2 emission reduction policies aimed at the level of 550ppmv CO2 stabilization target and the target of halving emissions by 2050 lead to the international structures of industry where goods with relatively high CO_2 intensity consumed in developed regions are produced in developing regions through international trade. More stringent reduction levels of production-based CO2 emission lead to much higher consumption-based CO2 emissions in the OECD region.

Keywords: input-output table, emission measurement

[1] Research Institute of Innovative Technology for the Earth (RITE),
Researcher,
homma@rite.or.jp

1. Introduction

The international framework for tackling climate change beyond 2012—the post-Kyoto regime—has been discussed. Based on the COP13 agreement known as the Bali roadmap which summarized a new negotiation process of the international framework on climate change to be concluded at the COP15 in Copenhagen in 2009, the COP14 continued to discuss various post-Kyoto international regimes on climate change to take effect in 2013. The framework should focus on real benefits not only at the global level but also at the country level. Moreover, it should consider the importance of the comprehensive strategies of long-term greenhouse gases (GHGs) emissions or its concentration stabilization levels at the global level and the intensities of GHGs emissions and energy consumption at the country and sector levels.

Most of the discussions are based on the authorized measuring methodology of GHGs emissions in the guidelines for national greenhouse gas inventories by IPCC (2006). The widely used methodology for measuring CO_2 emissions in the IEA (2007a) and IPCC (2006) is production-based, that is, the CO_2 that is emitted within the nation is measured. The idea of the IPCC methodology is that a country should only assume responsibility for the CO_2 emissions generated inside the country.

The alternative methodology has been considered from the viewpoint of equity; consumption-based emissions. Consumption-based CO_2 measurement focuses on the CO_2 emissions generated to produce goods that are consumed within a region, regardless of the production site locations; as a result, imports and exports must inevitably be taken into account. The basis of consumption-based measurement is that the country should assume responsibility for the consumption-based CO_2 emissions that take into account CO2 emissions generated in the production of imported goods for domestic consumption; however, they should not be held accountable for the CO_2 emissions through the production of goods that are to be exported and consumed outside the country. The two measurements reflect difference in the principle on emissions responsibilities: the consumption-based measurement corresponds to the “beneficiary pays principle,” while the

measurement of production-based emissions corresponds to the "polluter pays principle."

The estimation of CO_2 emissions by the alternative methodology, the consumption-based measurement, is meaningful for the future framework consideration of emission reduction. Peters *et al*. (2008) reported that consumption-based measurements offer the advantage of preventing carbon leakage, increasing the options available for mitigation, encouraging environmental comparative advantage, addressing competitiveness concerns. Moreover, they naturally encourage technology diffusion. The estimation based on the consumption-based methodology is important as basic information in terms of the equity. A workable introduction of international implementation based on the alternative methodology was recognized as difficulties in administration of measurement. However, at a commodity level, "carbon footprint" of commodity corresponding to the alternative methodology was introduced in the UK in March 2007, which was measured in the amount of CO_2 emissions generated using a life cycle assessment method by Carbon Trust (2007). METI (2008) reported that recently in most of developed countries and some developing countries such as China, Thailand and South Africa, introductions or feasibility studies of "carbon footprint" or CO2 visualization began to be considered.

Some past studies focused on consumption-based GHGs emissions. Most of the previous studies only focused on the quantitative analyses on historical estimations of consumption-based CO2 emissions by region and by sector. Bosi and Riey (2002) and Ahamad and Wyckoff (2003) have investigated consumption-based CO_2 emissions for the energy products in the IEA countries, and for the manufactured goods in Annex I countries and in selected countries in Annex II, respectively. These studies also indicated that most of Annex I countries imported CO_2-intensive commodities instead of producing them by themselves. Helm *et al.* (2007) reported that since 1990, UK's GHGs emissions have fallen by 15% on the IPCC measurement, while they have risen by 19% over the same period on a consumption-based measurement. The report suggests that the differences between the accounting methodologies of GHGs emissions can exert a substantial impact on the implementation of coherent emission reduction policies across countries. Wang(2008) focused on the historical trends of consumption-based CO2 emissions for China. Homma et al. (2008) represented

the historical estimations of time-series consumption-based CO2 emissions at 27 regions by sector using GTAP database and UN trade data. There is little information available for future consumption-based CO_2 emissions at region and sector levels across regions and sectors under CO2 emission reduction cases.

The purpose of this study is to evaluate future consumption-based CO_2 emissions at region and sector levels using two types of measuring methodologies, and to discuss the virtues of reduction targets based on consumption-based CO_2 emissions under CO2 reduction policies.

The structure of the paper is as follows. Section 2 outlines the methodology of time-series CO_2 emissions measurement. Section 3 describes the results by the consumption-based measurement and compares them with the production-based emissions with CO2 reduction policies. Finally, Section 4 presents the conclusions.

2. Methodology

This study defines two types of CO2 emissions: production-based emissions and consumption-based emissions. Production-based emissions are defined as total emissions generated within a country, and consumption-based emissions as emissions generated through the production of goods and services that are consumed within a region regardless of the production site locations. In this study, consumption-based emissions are focused on manufacturing industries and service sectors which exclude transport sectors (Aviation and Other transport sectors) and residential sector according to Homma et al.(2008). Production-based emissions correspond to the emissions used in the past emissions reduction framework of the UN Framework Convention on Climate Change (UNFCCC), such as the Kyoto protocol. The differences between production-based and consumption-based emissions are attributed to the CO_2 emissions embodied in the goods across the national border through trade.

This study use at a starting point production-based and consumption-based CO2 emissions in 2001 by sector and by region historically estimated in Homma et al.(2008). These estimation were based on the GTAP data set (ver6) and IEA statistics. This study only focuses on the CO_2 emissions

from the combustion of fossil fuels and excludes the international aviation and marine bunker sectors. These exclusions correspond to the CO_2 sectoral approach proposed by the IEA (2007a). The CO2 emissions from power plant are counted as emissions in the industrial and residential sectors based on the proportion of consumed electricity.

In this study, the future production-based and consumption-based CO2 emissions by sector and by region are estimated using DEARS (Dynamic Energy-economic Assessment model with multi-Regions and multi-Sectors) that was developed by Homma et al.(2007). This model is an optimization model, which maximizes global discounted consumption utilities and evaluates the impacts of CO2 emissions reduction policies on energy and economic systems. The model can evaluate consumption-based CO2 emissions because of explicit representation of industrial structures of production, consumption and trade, where the world is divided into 18 regions, and 18 non-energy and residential sectors are represented explicitly. The model also can evaluate the changes in industrial structures and consumption-based CO2 emissions for CO2 emission reduction cases.

The model can calculate total exports and imports by sector and by region endogenously while the current version of the model cannot evaluate the future trade matrixes representing sectoral exports from region A to region B. The original GTAP data base has the sectoral trade matrixes by region in the base year. This study estimates the future trade matrixes minimizing the deviations of square sum of the values of a future year from in the base year under the assumption of the estimated total exports and imports by region and by sector which can be calculated endogenously in DEARS.

It is noted that this study evaluated consumption-based CO_2 emissions on the assumption that CO_2 intensities are constant for domestic goods even after some international goods of the same type are imported within the same year; the influence of imported goods on the CO_2 intensities of domestic goods is negligible because of the neglegibly small amounts of imported goods and services.

Table 1 Assumed 19 sectors

No.	Sectoral code	Description

1	Iron and Steel	Iron and steel
2	Chemical	Chemical and petrochemical
3	Non-ferrous Metals	Non-Ferrous metals
4	Non-metallic Minerals	Non-Metallic minerals
5	Transport Equipment	Transport equipment
6	Machinery	Machinery
7	Mining	Mining and quarrying
8	Food	Food and tobacco
9	Paper and Pulp	Paper, pulp, and paper products
10	Wood and Wood	Wood and wood products
11	Construction	Construction
12	Textile	Textile and leather
13	Other Manufacturing	Other manufacturing
14	Agriculture	Agriculture, forestry, and fishing
15	Aviation	Aviation excluding international aviation
16	Other Transport	Road, rail, and navigation
17	Business Service	Trade, insurance, and other business services
18	Social Service	Recreation, dwellings, and other services
19	Residential	Residential

3. Simulation study

3.1 Simulation cases and model assumptions

This study evaluated the reference case (with no climate policy) and the following CO2 emission reduction cases: S550 and Halving cases. S550 case means that the global CO_2 emissions are constrained so that they do not exceed IPCC WGI stabilization profiles with emission trading allowed. Halving case represents the CO2 emission target to halve global emissions by around 2050 relative to the current emission level (2005 values applied in this study) , which nearly corresponds to the Japanese proposal “Cool Earth 50” presented on 2007.

Figure 1 shows CO2 emission paths for the reference, S550 and Halving cases. In order to avoid the “terminal effect,” which influences the computational results around the end of time horizon, we accept the solutions only until the year 2047, although we solve our dynamic model through the time horizon until the year 2067. It should be noted that the lifespan of power plants and other plants was not explicitly considered.

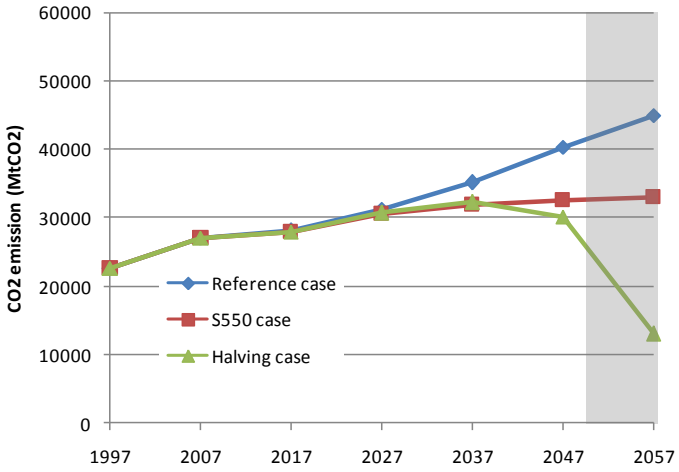

Figure 1 CO2 emission paths for Reference, S550 and Halving cases

The population scenario in this study is taken from SRES-B2. CO_2 emissions and GDP trajectories, which are determined endogenously in the model, are harmonized with the SRES-B2 marker scenario by adjusting parameters such as the regional annual rates of technical progress. We assumed that the parameters of both the annual discount and depreciation rates are 5% in all the regions. The intermediate coefficients of the input-output tables in the economic module are based on the time-series input-output coefficients estimated under an industrial structure changes scenario where all the economies gradually proceed to service economy from the base year in a world. The optimization software GAMS/CONOPT3 was used for the simulation study.

3.2 Results and discussion

Figures 2, 3 and 4 show per capita production-based and consumption-based CO2 emissions in 2047 for Reference, S550, and Halving cases, respectively. The effects of international trade on consumption-based CO2 emissions are observed. Per capita production-based CO2 emissions in the OECD regions for Reference, S550, and Halving cases is 14.7, 10.6 and 9.6 (tCO2/person) while per capita consumption-based CO2 emissions is 15.1, 11.0 and 9.9 (tCO2/person), respectively. The developed regions have

constantly higher consumption-based CO2 emissions around the middle of this century as well as the historical trends in developed regions as mentioned previously. Transport sector has large share in total emissions in all cases because the transport sector is more difficult to reduce its emissions than other sectors under the conservative assumptions of the current model version having less innovative technologies in the transport sector.

The consumption-based emissions of chemical and other manufacturing sectors in the developed region are much larger than production-based ones. This is because both sectors have characteristics of high energy-intensity and much international trade. Chemical and other manufacturing sectors are classified into the energy-intensive sectors in IEA statistics. It is noted that according to the IEA (2007a), the consumption data on the other manufacturing sector (corresponding to the "non-specified industry" in the statistics) should be used with caution due to difficulties in providing an industrial breakdown of fuel consumption within sectors in most countries. Although the data on the Other manufacturing sector might have lower reliability, this study used this data set. The chemical and other manufacturing sectors play important roles in international trade having large shares in total exports in terms of monetary unit because the model structure of DEARS is based on optimization of industrial structures at a global level under maximization of consumption utilities.

Figure 5 show the differences between production-based and consumption-based CO2 emissions in 2047 for Reference, S550, and Halving cases. The result indicates that according to the SRES four regions the consumption-based CO2 emissions in the OECD regions are higher than the production-based emissions while the opposite results of consumption-based CO2 emissions in other regions are observed. The rate of consumption-based CO2 emissions in the OECD regions relative to the production-based emissions rise from 2.8% in the reference case to 3.3% in the S550

case to 3.5% in the Halving case. Compared to the individual targets for Annex I Parties listed in Kyoto protocol and the proposed Post Kyoto regimes of 20% reduction below 1990 levels by 2020 (Commission of the European Communities, 2009) and USA plan of 14% reduction below 2005 levels by 2020 (The White House, 2009), these differences between the production-based and consumption-based CO_2 emissions should not be negligible because of having significant impacts on allocation regimes. The more stringent reduction levels of CO2 emission lead to the larger difference between the production-based and consumption-based CO2 emissions in the OECD, REF and ALM regions while the opposite results in the ASIA region are observed. ASIA region The has the same trend that more stringent reduction levels of CO2 emission lead to the larger consumption-based emissions relative to the production-based emissions. That is because in the case of more stringent cases the OECD and ASIA regions import more easily the CO2-intensive commodities from the REF and ALM regions than reduce their own production-based emissions in their production processes in order to keep high consumption utilities of the OECD and ASIA regions although OECD and ASIA regions have relatively less energy-intensities of sectors than the REF and ALM regions.

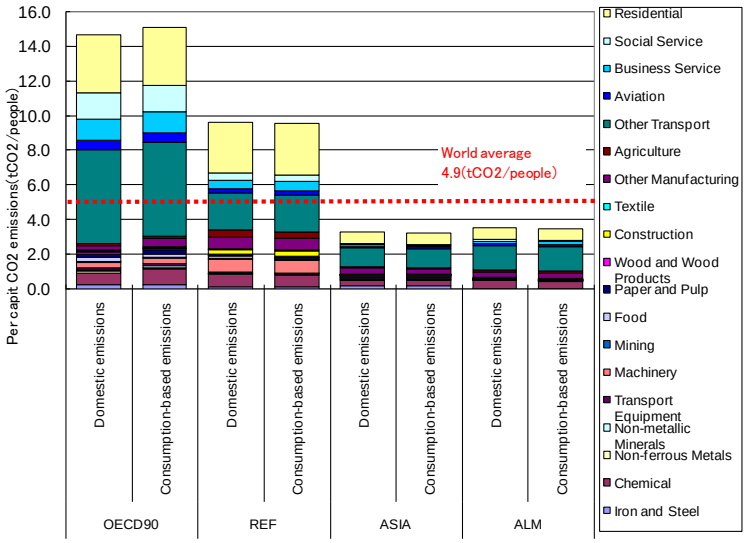

Figure 2 Production-based and consumption-based CO2 emissions for Reference case

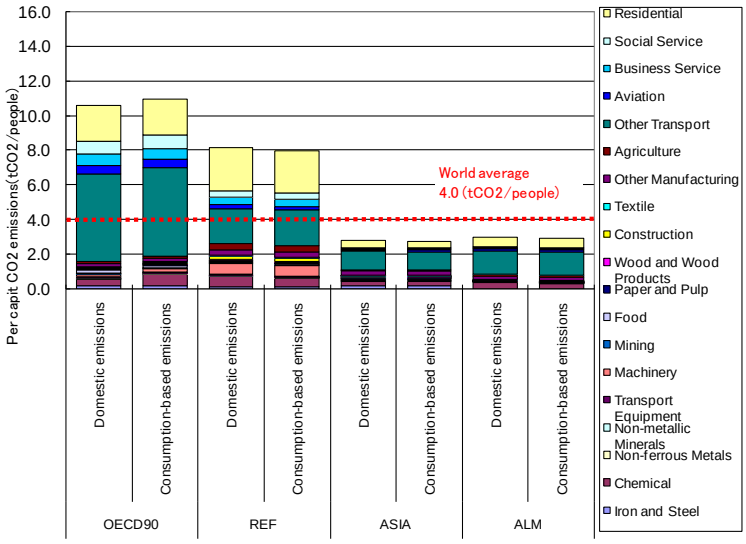

Figure 3 Production-based and consumption-based CO2 emissions for S550 case

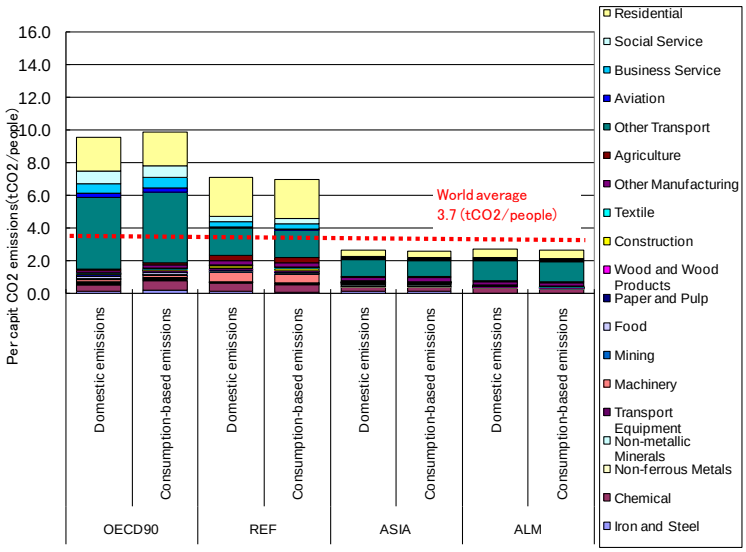

Figure 4 Production-based and consumption-based CO2 emissions for Halving case

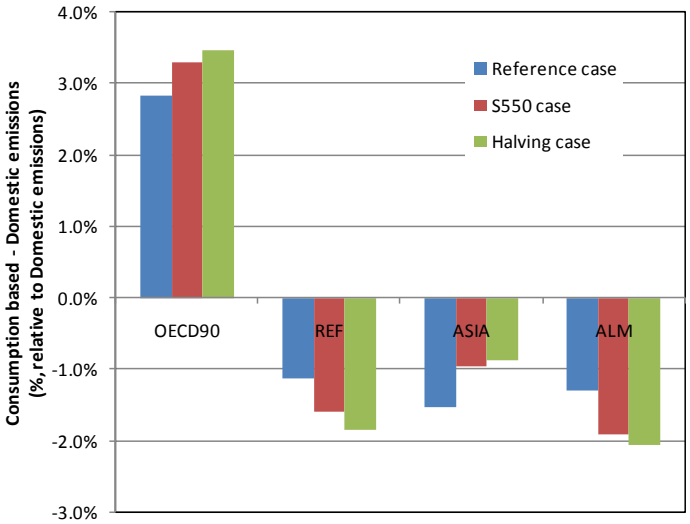

Figure 5 Differences between production-based and consumption-based CO2 emissions

4. Conclusion

This study evaluated the future consumption-based CO_2 emissions at the region and sector levels using two types of measuring methodologies of production-based and consumption-based CO_2 emissions under two reduction scenarios: 550ppmv stabilization scenario and halving by 2050 scenario.

The result indicates that the developed regions have constantly higher consumption-based CO2 emissions up to the middle of this century as well as the historical trends in the developed regions. The consumption-based CO2 emissions in the OECD regions are higher than the production-based emissions while the consumption-based CO2 emissions in other regions are lower than production-based emissions. The OECD and ASIA regions have the trend that more stringent reduction

levels of CO2 emission lead to the larger consumption-based emissions relative to the production-based emissions. That is because in the case of more stringent cases OECD and ASIA regions import more easily the CO2-intensive commodities than reduce their own production-based emissions in their production processes of the commodities in order to keep high their consumption utilities.

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