Optimal production resource reallocation for CO2 emissions reduction in manufacturing sectors

Fujii, Hidemichi and Managi, Shunsuke

31 May 2015

Optimal production resource reallocation for CO_2 emissions reduction in manufacturing sectors

Hidemichi Fujii[1] and Shunsuke Managi[2,3*]

[1] Graduate School of Fisheries Science and Environmental Studies, Nagasaki University
1-14 Bunkyo-machi, Nagasaki 852-8521, Japan
E-mail: hidemichifujii@nagasaki-u.ac.jp

[2] School of Engineering, Kyushu University
744 Motooka, Nishiku, Fukuoka, 819-0395, Japan.
Tel/Fax: 092-802-3405, E-mail: managi.s@gmail.com

[3] Queensland University of Technology
Level 8, Z Block, Gardens Point, 2 George St, Brisbane QLD 4000, Australia.
* Corresponding Author

Abstract: To mitigate the effects of climate change, countries worldwide are advancing technologies to reduce greenhouse gas emissions. This paper proposes and measures optimal production resource reallocation using data envelopment analysis. This research attempts to clarify the effect of optimal production resource reallocation on CO_2 emissions reduction, focusing on regional and industrial characteristics. We use finance, energy, and CO_2 emissions data from 13 industrial sectors in 39 countries from 1995 to 2009. The resulting emissions reduction potential is 2.54 Gt-CO_2 in the year 2009, with former communist countries having the largest potential to reduce CO_2 emissions in the manufacturing sectors. In particular, basic material industry including chemical and steel sectors have a lot of potential to reduce CO_2 emissions.

Keywords: *Resource reallocation, CO_2 emissions, Data envelopment analysis, Manufacturing sector*

Acknowledgements

This research was funded by the Grant-in-Aid for Specially Promoted Research [26000001B]; the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan; Grant-in-Aid for Research Activity Start-up [26881006B], MEXT, Japan. The results and conclusions of this article do not necessary represent the views of the funding agencies.

1. Introduction

To mitigate the effects of climate change, countries worldwide are currently advancing research on methods and technologies for estimating and reducing greenhouse gas (GHG) emissions (IPCC, 2007; Lobell et al., 2011; Barros et al., 2014). Although previous studies have analyzed the potential to reduce GHG emissions, most of these studies have focused on the future adoption of new technologies at the national and global levels based on projected scenarios (e.g., Popp et al., 2010; Scovronick and Wilkinson, 2013; Wang et al., 2014). However, they have not considered the optimal production resource allocation to minimize GHG emissions based on current production technology in the manufacturing sector.

However, firms naturally reallocate production in response to the strong regulation of production activity or disadvantages in international market competitiveness. Thus, understanding the reallocation combination of production resources based on current production technology is important when analyzing the effect of GHG reduction policies. The impact of regulations pertaining to total GHG emissions on each industry in each country is uncertain.

Industrial activity contributes to both economic development and GHG emissions. Thus, the industrial sector plays a key role in balancing environmental protection and economic development (Fujii and Managi, 2013). However, the structure of GHG emissions is not uniform across countries. For example, emissions from the manufacturing sector may not be strongly correlated with population size because the sector produces products for both the domestic and global markets (Perkins and Neumayer, 2012). Additionally, global market dependency differs among industries and countries. CO_2 emissions also vary by industry, and the characteristics of an industry must be considered when analyzing strategies to reduce GHG emissions.

Therefore, this study determines the present potential to reduce CO_2 emissions and the optimal production resource reallocation combination in terms of CO_2 emissions for the manufacturing sector. The analysis implicitly assumes that climate policy is implicitly or explicitly introduced to reduce emissions, and this paper aims to understand the magnitude of its reduction potential by country and sector under optimal reallocation. The remainder of this paper is organized as follows. Section 2 presents background information relevant to the study. Section 3 introduces our methodology – an optimal resource reallocation problem using the Data Envelopment Analysis (DEA) nonparametric production approach. Section 4 describes the study data. In Section 5, we explain the results of the optimal production resource reallocation combination and the potential GHG emissions reduction. Finally, Section 6 presents our conclusions and discusses policy implications.

2. Research background and objectives

The optimal production resource reallocation combination is determined by production technology, capacity, and environmental policy regarding CO_2 emissions. There are several previous studies have analyzed allocation problems under environmental restriction or coalition pattern to reduce CO_2 emissions.

Wu et al. (2013) analyzed optimal production resource allocation problems of paper mills in the Huai River region in China. They clarify the optimal allocation of labor and capital input of each firm to minimize biochemical oxygen demand emissions by firms in Huai river region. Feng et al. (2015) estimate optimal carbon emissions abatement allocation using 21 OECD countries' data. They used gross domestic product as desirable output and country's CO_2 emissions as undesirable output.

Pollak et al. (2011) identified energy coalition and climate coalition defined by their beliefs about the primary purpose of CO_2 injection which is energy supply or greenhouse gas emission reduction by carbon capture and storage focusing on the policy in the United States. They conclude that the energy coalition has had greater success that the climate coalition in shaping laws and rules to align with its policy preferences. Chen and Chen (2011) clarified the embodied CO_2 emissions of three supra-national coalition which are group of seven (G7), group of Brazil, Russia, India, and China (BRIC), and rest of the world (ROW) applied multi-region input-output modeling for 2004 year data. Their results shows that per capita consumption based CO_2 emissions for G7, BRIC, and ROW are determined as 12.95, 1.53, and 2.22 ton-CO_2, respectively.

Most of these previous studies focus on the industrial sector as a whole or use country-level data to estimate the optimal resource allocation combination or optimal coalition pattern. However, it is clear that the required capital equipment investment and operating costs of reducing GHG emissions vary by industry because fuel type and production process requirements differ. Table 1 shows CO_2 emissions and a simple efficiency index by industrial sector. From Table 1, it can be observed that the other non-metallic mineral industry has a low ratio of sales per CO_2 emissions. However, the machinery, electrical and optical equipment, and transport equipment industries have high ratios because each of these industries primarily assembles intermediate products. Assembly procedures primarily require electricity but not fossil fuels, which have high carbon intensity. Additionally, the required energy input, material, labor, and capital equipment differ among industries. These differences among manufacturing sectors must be considered when analyzing strategies to reduce GHG emissions.

<Table 1 about here>

Similar to the differences in industry characteristics, regional characteristics are important to consider in resource allocation problems. Schandl and West (2010) show that there is a large production technology gap among regions. Thus, this research proposes and measures optimal production resource reallocation using the DEA. The objective of this research is to clarify the effect of optimal production resource reallocation (hereafter, optimal production) on CO_2 emissions, focusing on regional and industrial characteristics.

3. Methodology

This study measures the CO_2 emissions reduction that results from optimal production. We apply the DEA to measure the optimal production effect and estimate the amount of potential CO_2 reduction (see Managi (2011) and Barros et al. (2012) for a review). Färe et al. (2011) introduce the framework of optimal coalition formation using DEA. We extend their framework and apply it in the environmental management field.

Let $x \in \Re_+^{L}, b \in \Re_+^{R}, y \in \Re_+^{M}$ be vectors of inputs, environmental output (or undesirable output) and market outputs (or desirable output), respectively. Define the production technology as

$$\mathrm{P(x)} = \{(\mathrm{x, y, b}) : \mathrm{x\ can\ produce\ (y, b)}\} \tag{1}$$

We make two assumptions. First, we assume strong disposability of input and output. We also assume constant return to scale production. These two assumptions are represented by following equations (Färe et al., 2011), where λ is the intensity variable.

$$\mathrm{P}(\lambda x) = \lambda \mathrm{P}(x), \qquad \lambda \geq 0 \tag{2}$$

By referring to the efficient production technology, decision-making unit (DMU) k can control the amount of undesirable output until $\mathrm{Q}(x_k, y_k)$.

$$\mathrm{Q}(x_k, y_k) = \mathrm{Min}\left\{\sum_{n=1}^{N} \lambda_n b_n : \sum_{n=1}^{N} \lambda_n x_n \leq x_k, \sum_{n=1}^{N} \lambda_n y_n \geq y_k, \lambda_n \geq 0, n = 1,2,\cdots,N\right\} \tag{3}$$

Here, we consider the production resource reallocation among multiple DMUs. We define the optimal production resource reallocation as the joint production combination of DMUs to minimize total undesirable output ($\sum_{n=1}^{N} \lambda_n b_n$) without increasing total input ($\sum_{n=1}^{N} \lambda_n x_n$) and decreasing total desirable output ($\sum_{n=1}^{N} \lambda_n y_n$). The optimal production resource reallocation problem can be solved using the following equations:

$$\mathrm{Q}(x, y) = \mathrm{Min} \sum_{n=1}^{N} \lambda_n b_n \tag{4}$$

s.t.

$$\sum_{n=1}^{N} \lambda_n x_n \leq \sum_{n=1}^{N} x_n \tag{5}$$

$$\sum_{n=1}^{N} \lambda_n y_n \geq \sum_{n=1}^{N} y_n \tag{6}$$

$$0 \leq \lambda_n \tag{7}$$

$Q(x, y)$ represents minimized CO_2 emissions without decreasing the desirable output or increasing input. Equations (5) and (6) are restriction formulas of input and desirable output, respectively. The optimal resource reallocation combination can be represented by λ_n. In this model, λ_n shows the optimal production site and scale to minimize CO_2 emissions, considering each country's production technology.

Here, we introduce a simple example. Consider data from two countries, country P and country Q. The result of the estimation model is $\lambda_P = 2.0$, $\lambda_Q = 0.7$, which indicates that CO_2 emissions from the two countries can be minimized if the production scale of country P doubles and the production scale of country Q decreases by 30%. Additionally, the production combination of $\lambda_P = 2.0$, $\lambda_Q = 0.7$ does not result in a decrease in total desirable output or an increase in total input compared with the case of $\lambda_P = 1.0$, $\lambda_Q = 1.0$.

4. Data

We use data from 39 countries and 13 industries between 1995 and 2009 (Table 2). We observed the total CO_2 emissions, energy use, sales, labor costs, capital stock, and intermediate material from the World Input Output Table database (Marcel, 2012). CO_2 emissions and energy use are physical data and the other data variables are financial data. All financial data are in 1995 dollars (U.S.$), applying deflation factors from the world input-output database (WIOD). We compile the 13-panel dataset (39 countries x 15 years) by industry type. The DEA models are estimated using each panel of the dataset separately.

The result of production resource reallocation model provides us the optimal production scale in each countries with current production technology. In this study, we set the restriction that optimal production resource reallocation satisfies the market demand in global level. This restriction is represented as equation (6) in previous section. However, international trade of electricity strongly depends on the geological condition comparing with other industrial products because of cost of power grid and outage risk. We have difficulty to obtain the cost and risk information to set the restriction for production resource allocation problems in electricity sector. Additionally, infrastructure of power grid is not sufficient to transmit the electricity between countries with long distance (e.g. Transmission of the electricity from USA to Japan). Under this situation, it is unrealistic assumption for electricity sector to allow trading electricity in the world. Therefore, we exclude the electricity sector from our research target industry.

Additionally, composition of energy input is diverse among countries (Kumar et al., 2015). Shifting low carbon energy is important to reduce CO_2 emissions in manufacturing sectors. For example, the steel sector in a region uses a lot of coal for converter furnace while that in another region is heavily dependent on electricity for electric furnace. Even when the energy use in the steel sectors of the two regions are the same, the emission intensity of the former region is much higher that the latter. However, DEA has difficulty to evaluate productive efficiency using many input variables (e.g. each disaggregated energy consumption data). The main reason about the difficulty of DEA to use many disaggregated input variables is that most of countries in sample data are evaluated as efficient production if we use disaggregated energy data (e.g. coal, coke, petroleum, natural gas, renewable) as input variables.[1]

The differences of carbon intensity should be considered in estimation model because choice of low carbon intensity energy is important to reduce CO_2 emissions. However, applying individual disaggregated energy data will diminish the discriminatory power of DEA. To avoid this problems, we only use aggregated energy consumption data for production resource allocation model in this

[1] Cook et al. (2014) pointed out "it is likely that a significant portion of decision making units (DMUs) will be deemed as efficient, if there are too many inputs and outputs given the number of DMUs" at line 16 on page 3. Cooper et al. (2006) pointed out "the optimal weights may (and generally will) vary from one DMU to another DMU. Thus, the weights in DEA are derived from the data instead of being fixed in advance. Each DMU is assigned a best set of weights with values that may vary from one DMU to another" on page 33.

Variable weights are decided to maximize the efficiency of each DMU (e.g. country) in DEA. In this case, country p which uses a lot of petroleum and a little of natural gas will select high weight score of natural gas and low weight score of petroleum to minimize the virtual input amount to increase efficiency. On the other hand, country q which uses a lot of natural gas and a little of petroleum select high weight score of petroleum and low weight score of natural gas to minimize the virtual input. Thus, input weight combination strongly depends on the energy mix of each country in DEA. However, share of each fossil fuel use is diverse and depends on the each country's resource reserve. Therefore, most countries are evaluated as efficient due to differences of energy mix strategies if we use disaggregated energy input data.

research. We consider that the differences of carbon intensity of each energy type is reflected to our estimation results through the ratio of aggregated energy input and CO_2 emissions because our model use both aggregated energy input and CO_2 emissions.

<Table 2 about here>

Next, we explain about the transfer potential of productive resources in each country. According to Méon and Sekkat (2012), company focus on the country's political risk to select the location of plant in manufacturing sectors. They pointed out that "foreign direct investment inflows are on average negatively affected by political risk" on page 2,203. Following their finding, we set the assumption that manufacturing company consider the political risk of located area to select the place for productive resource allocation. Additionally, physical limitation of new plant building is affected by land area of each country. Both political and physical condition of productive resource allocation are important to analyse the optimization model. Therefore, we create the additional production transfer potential (APTP) indicator to reflect the both political and physical condition into estimation results.

This study uses each country's land area and degree of political freedom as constraints on additional production transfer potential (APTP). Land area is obtained from the World Development Indicator database published by the World Bank. Land area data reflect the constraint of land capacity of additional industrial plant building. Additionally, we use the worldwide governance indicators (WGI) published by the World Bank as a policy variable. WGI evaluates each country's policies relating to six areas ([1] Voice and Accountability, [2] Political Stability and Absence of Violence/Terrorism, [3] Government Effectiveness, [4] Regulatory Quality, [5] Rule of Law, and [6] Control of Corruption) (Kaufmann et al., 2010). The WGI score is defined on a scale from one to five, with higher scores indicating more freedom. We use the numerical average of the six WGI scores as the degree of political freedom for businesses in each country. APTP is estimated using the multiplied estimation of land area (million km^2) and average of six WGI score. Therefore, APTP score reflects both land restriction and political situation for additional industrial plant building. The value of mean, median, variance, minimum, and maximum of APTP are 5.29, 0.57, 110.19, 0.0011, and 37.96, respectively. The calculation process of country *k*' APTP is that:

$$\text{APTP}_k = \text{Land area of country } k \text{ (million km}^2\text{)} \times \text{average score of six WGI in country } k \quad (8)$$

Thus, we can describe the model calculations as follows:

$$\text{Objective function:} \quad \text{Min.} \sum_{n=1}^{N} \lambda_n b_n \quad (9)$$

s.t.

$$\sum_{n=1}^{n=N} \lambda_n Labor_n \leq \sum_{n=1}^{n=N} Labor_n \quad (10)$$

$$\sum_{n=1}^{n=N} \lambda_n Capital_n \leq \sum_{n=1}^{n=N} Capital_n \quad (11)$$

$$\sum_{n=1}^{n=N} \lambda_n Material_n \leq \sum_{n=1}^{n=N} Material_n \quad (12)$$

$$\sum_{n=1}^{n=N} \lambda_n Energy_n \leq \sum_{n=1}^{n=N} Energy_n \quad (13)$$

$$\sum_{n=1}^{n=N} \lambda_n Sale_n \geq \sum_{n=1}^{n=N} Sale_n \quad (14)$$

$$0 \leq \lambda_n \leq 1 + APTP_n \qquad n = 1, \dots, N \quad (15)$$

Here, we explain about λ using the case of a country k ($1 \leq k \leq$ N). Equation (15) indicates that country k can expand its production until 1+$APTP_k$ scale. Thus, an $APTP_k$ score close to zero indicates country k cannot expand its production further. If $APTP_k$ equals zero, λ_k is restricted from zero to one. The estimation results show that $\lambda_k = 0$, then it indicates that when the production of country k equals zero, the optimal production is achieved, thereby minimizing CO_2 emissions.

Generally, transferences of labor and capital stock are more difficult than intermediate material and energy input. Therefore, restriction condition tends to be stricter for labor and capital. Meanwhile, transferences of intermediate material and energy input without shifting labor and capital caused excess or insufficient input use which become productive efficiency worse. Thus, decision makers of productive resource allocation focuses on the entire input and output balance. Based on the above, we assume that decision makers select the optimal productive resource allocation with proportionally. Thus, this study set the proportional production scale change which is represented as parameter λ.[2]

To analyze the effect of industry characteristics, we categorize the thirteen industrial sectors into three groups following Fujii et al. (2011): (1) Daily commodity group, (2) Basic material group, and (3) Processing and assembly group. The daily commodity group includes the food, textile, leather, and wood industries. The basic material group includes the pulp and paper, coal and oil, chemical, rubber, nonferrous mineral, and steel industries. Finally, the processing and assembly group includes the industrial machinery, electric product, and transport equipment industries.

In general, the basic materials sector has heavy industrial production systems. These industries require large amounts of fossil fuel energy to move equipment. Additionally, some industries use fossil fuels as intermediate products (e.g. the steel and metal industry uses coal both as

[2] By applying proportional change of both whole input and output is more consistent with real situation in manufacturing sector. Meanwhile, this study does not capture the production scale efficiency change and input substitution technology clearly. This point is limitation of this study.

a fuel and for oxidation-reduction reactions in shaft furnaces). The processing and assembly group uses automated production systems, which require large investments.

Table 3 shows the average score for each variable by manufacturing sector. From Table 3, we can see that the basic material sectors (pulp and paper, coal and oil, chemical, rubber, mineral, metal) are responsible for more than 85% of CO_2 emissions from the 13 sectors.

<Table 3 about here>

5. Result

We establish four scenarios considering political and economic relationships. The scenarios are denoted as follows: (1) former Communist scenario, (2) Trans-Pacific Strategic Economic Partnership Agreement (TPP) scenario, (3) European Union (EU) scenario, and (4) Global scenario. Target countries are defined for each scenario. Under each scenario, each country can produce products by reallocating its production resources (i.e., labor, capital, material, energy) freely among the target countries to minimize CO_2 emissions. The target countries for each scenario are listed in Table 4.

<Table 4 about here>

Figure 1 shows the CO_2 emissions reduction ratio by scenario. The CO_2 emissions reduction ratio is calculated by dividing the CO_2 emissions under optimal production by CO_2 emissions in the reference case (all country's $\lambda = 1$). From Figure 1, we observe a high CO_2 reduction ratio under the EU and Global scenarios. However, the CO_2 reduction ratios under the former Communist and TPP scenarios are low in 1995. From 1997 to 2000, the CO_2 reduction ratio under the former Communist scenario increased.

<Figure 1 about here>

The rapid increase in the CO_2 reduction ratio is caused by the modernization of production equipment in the metal industry and iron and steel industry in China during the late 1990s. According to Fujii et al. (2010), the Chinese iron and steel industry introduced modern production equipment for converter furnaces and continuous casting in the 1990s. This modernization of production equipment allowed the Chinese iron and steel sector to improve its energy efficiency and reduce the CO_2 emissions associated with steel production in China. Fujii et al. (2010) pointed out that energy consumption per unit of crude steel production dramatically improved when the continuous casting method came into general use during the 1990s due to rising continuous casting share from 20% in 1990 to almost 90% in 1999.

Meanwhile, the Russian iron and steel industry did not update their production equipment and continued to produce steel with inefficient technology in the 1990s. Thus, the production efficiency gap widened during this period. Under the optimal production case, steel production shifts from Russia to China because the Chinese iron and steel industry is at an advantage in reducing CO_2 emissions. As a result, total CO_2 emissions in former Communist countries decrease under the optimal production scenario.

Figures 2 through 5 show the CO_2 emissions reduction impact of optimal production in 1995 (hereafter referred to as old) and 2009 (hereafter referred to as recent) under each scenario. From Figure 2, there is little difference in the CO_2 emissions between the reference case and the optimal case in 1995. This result might be related to the characteristics of former communist countries.

In the 1980s, China's iron and steel was produced in inefficient facilities, and its industry lagged behind that of developed countries. Until 1990, because of internal and external political factors, limited technology transfer from developed countries contributed to this lag, and China was limited to introducing aging technologies and equipment from the former Soviet Union and Eastern Europe (Fujii et al., 2010).

Thus, former communist countries had difficulty introducing modern productive equipment invented in capitalistic countries. As a result, the industrial sector in former communist countries relied on old and inefficient equipment. Therefore, technology gap in industrial production is small among former communist countries. The optimal productive resource allocation effectively reduces CO_2 emissions if the productive technology gap is larger.

In the recent period, the CO_2 emissions in the reference case increased relative to the old period as a result of production scale expansion in the Chinese industrial sector. Correspondingly, the CO_2 emissions from the basic material industry in optimal case decreased 0.398 Gton-CO_2 compared with the reference case. This decrease can be explained primarily by the technological progress in production equipment in Chinese steel sector discussed above. Additionally, productive resources shifted from Russia and Poland to China in the chemical and wood industries in the optimal case under the former communist scenario.

<Figure 2 about here>

Figure 3 shows the CO_2 emissions under the TPP scenario. In Figure 3, there is not a large difference between the optimal case and the reference case in the old period. Meanwhile, in the optimal case, there is a large reduction in CO_2 emissions in the recent period. The reduction in CO_2 emissions in this case was achieved primarily by the basic material industry, particularly the pulp and mineral industries. Additionally, productive resources were shifted from Australia and Mexico to Canada in the pulp industry in the optimal case under the TPP scenario.

One interpretation of this result is that the Canadian pulp industry uses large amounts of black liquor as renewable energy. The main renewable energy source in the pulp industry is black liquor, and the investment and operating costs of black liquor have become cheaper over time as a result of technological progress (e.g., Black liquor gasification, see Naqvi et al. (2010)). This technological advancement has allowed the pulp industry to reduce CO_2 emissions without significant financial stress.

From the data, we can see that black liquor comprises a small share of total energy in the pulp industry in Mexico and Australia, with shares of 1% and 15% in 2009, respectively. However, the share of black liquor in the Canadian pulp industry was 58% in 2009. Thus, the low fossil fuel dependency of the Canadian pulp industry creates an advantage in terms of carbon intensity. Therefore, the dissemination rate of renewable energy is one reason why the production location shifted from Australia and Mexico to Canada in the optimal case under the TPP scenario.

<Figure 3 about here>

Figure 4 shows CO_2 emissions under the EU scenario. Under this scenario, the emissions reduction is large in both the old and recent periods. Additionally, the CO_2 reduction ratio under the EU scenario is in the same range for each industry. From figure 4, the CO_2 reduction ratios are 43.8% in daily commodities, 39.7% in basic materials, and 48.1% in the processing industry in the old period, and 35.5% in daily commodities, 35.9% in basic materials, and 35.3% in the processing industry in the recent period. However, the scenarios shown in Figures 2 and 3 in which the CO_2 reduction ratio is primarily in the basic materials industry. Thus, the CO_2 emissions reduction potential is large in all three industrial groups under the EU scenario.

The differences in CO_2 emissions reduction across scenarios can be explained by the large production technology gap between former communist countries and Western countries in both the old and recent periods. Kravtsova and Radosevic (2012) noted that the economic growth in Eastern Europe since 1996 is attributable to an increase in production scale, and not to innovation. Additionally, the authors concluded that Eastern European countries are inefficient at converting their research and development, innovation and production capabilities into appropriate levels of productivity.

As noted above, politics limited the technology transfer from Western countries to former communist countries in the old period, and the production technologies in these countries were relatively old and inefficient as a result. Additionally, the evidence identified by Kravtsova and Radosevic (2012) indicates that the production technology gap between former communist countries and Western countries may still exist in the recent period.

Our results show most former communist countries' λ parameter is close to zero, which indicates that shifting production from former communist to Western countries would minimize CO_2 emissions without increasing input or decreasing sales.

<Figure 4 about here>

Finally, Figure 5 represents the CO_2 emissions under the Global scenario. The CO_2 emissions in the reference case increase from the old period to the recent period because CO_2 emissions from Brazil, China, India, and Russia increase due to the expansion of the industrial sector. In Figure 5, the CO_2 reduction ratio is high in both the old and recent periods compared with the previous Figures. The high number of sample countries in this scenario (39 countries) explains this difference because the model has more countries available to shift production and minimize CO_2 emissions.

From the results, we find parameter λ is diverse among the countries in each industry (see Appendix 1). Our results show that nine countries (Australia, Canada, Germany, France, Italy, Japan, Netherland, Spain, and Sweden) score high on the parameter λ for most industrial sectors. However, a low score on parameter λ is observed in ten countries, which include Bulgaria, Cyprus, Indonesia, India, Latvia, Poland, Romania, Russia, Slovenia, and Turkey. Thus, shifting the location of production from the latter countries to the former countries effectively minimizes industrial CO_2 emissions in the 39 countries.

The APTP score affected the production transfer potential by setting upper limit of parameter λ. To confirm the effect of APTP, we described the country list whose parameter λ achieved upper limit defined as (1+APTP) in Appendix 2. From Appendix 2, the effect of APTP into production transfer potential is different by type of industries. Only one countries is listed in Rubber, mineral and transportation equipment industries. Meanwhile there are more than six countries listed in Appendix 2 in textile, pulp, and chemical industries.

From Appendix 2, we can understand that there are several industries which are weakly and strongly affected by APTP. Therefore, APTP is needed to estimate considering each industrial characteristic which needs the detail data about production processes and technologies which are difficult to obtain. Further research is needed to set the APTP parameter considering each industrial characteristic to improve accuracy of analysis.

Additionally, the results show that scale down of the production in Indonesia is needed to minimize CO_2 emissions in global model. One interpretation of this result is that production technology in Indonesia has disadvantage to prevent increasing CO_2 emissions in manufacturing sector. It implies that current production technology in Indonesia or other developing countries have difficulty to keep international competitiveness in the global market if international environmental policy for climate change (e.g. carbon tax) is enforced. Thus, low carbon production technology in manufacturing sector is needed to keep international market competitiveness under carbon emission restriction.

Intergovernmental Panel on Climate Change (IPCC) pointed that bio-energy with carbon capture and storage (BECCS) is important approach to achieve atmospheric concentration levels of about 450ppm CO_2 equivalent by year 2100 in their fifth assessment report reports (IPCC, 2014). Meanwhile, Benson (2014) pointed out the concern about whether biomass could be practically and sustainably harvested, dried, and collected without interfering with food production or negatively affecting other ecosystem services.

Today, many developing countries have rich forest resources which can be enough to provide bio-mass energy (Ricci and Selosse, 2013). Thus, disseminate the technology of BECCS in developing countries contribute to create manufacturing sectors with low carbon emissions which enable to reduce global CO_2 emissions and keep international market competitiveness.

<Figure 5 about here>

6. Conclusion

To mitigate the effects of climate change, countries worldwide are advancing research and introducing policies to reduce CO_2 emissions (Somanathan et al. 2014). This research analyzes the potential to reduce CO_2 emissions by reallocating production, considering both regional economic and emissions characteristics. The results of this study can aid our understanding of feasible emission reduction estimates and inform climate policy. Compared with previous studies of climate policy, which used top-down or bottom-up approaches, we are able to estimate a realistic potential reduction using actual emissions production characteristics in the economy.

Evaluation of existing policies in climate change is provided in Somanathan et al. (2014). The review stated that once stringent policy implemented, reduction in emissions are expected though practically there are many institution blocking the policy implementation. Our estimate shows middle term expected reduction once stringent policy implemented such as emission trading in major emitting countries. Especially, new policy starts from developed countries such as OECD therefore we focus our study on 39 countries where the data is available. This provides clear signal to the market and firms can re-allocate plants based on emission and other economic factors in which we considered in this paper. Once the signal informed, labor and capital changed accordingly.

Our methods analyze relative performance of production technology where one inefficient country can improve the performance by catching up to their counterpart countries. This limitation in their comparison is meaningful as not all country can use world-best technology available in the market. In addition, this study applies to aggregate data of industry as we can think increased capital as additional capital installed which could be added plants in new or old plants.

Applying optimal production resource reallocation, we found a large potential to reduce CO_2 emissions. In particular, there is a significant potential to reduce CO_2 emissions in the manufacturing sectors of former communist countries. This potential implies that the previous productivity improvements in former communist countries are insufficient to catch up with Western countries in terms of emissions reduction. Our results show that more drastic changes could significantly reduce CO_2 emissions.

In this study, we apply the production resource reallocation model to minimize the CO_2 emissions. However, drastic shifts in production location can also cause social problems such as increasing the unemployment ratio and decreasing corporate taxes. Meanwhile, we can only replace the production resource reallocation as an international joint venture if national policy supports such a change because the production technology of an international joint venture is comparable with the main plant. Thus, the results can be understood as the CO_2 reduction potential of transferring production technology from efficient countries to inefficient countries, considering current production technology at the manufacturing sector level. It is often said that reducing CO_2 emissions is difficult, though the potential to reduce CO_2 emissions is huge. Meanwhile, global production resource reallocation would solve this problem if international collaboration for CO_2 reduction were enhanced.

This study contributes in two ways to the literature on regional cooperation in climate policy and international technology transfer. First, the paper clarifies the CO_2 emissions reduction potential considering current production technology at the manufacturing sector level. Second, the paper develops an application model using a nonparametric production approach to estimate the effect of production resource reallocation. It is important for policymakers to understand the size of potential CO_2 emissions reduction considering current technology because it provides a realistic estimate.

Steininger et.al. (2014) noted clean technology transfer to developing countries is a crucial complement for climate policy. However, this research clarifies that several OECD countries' production technology is not sufficient to reduce CO_2 emissions compared with efficient countries. Thus, the policy implication of this study is that the diffusion of production technologies from Western countries to former communist countries is an effective way to reduce CO_2 emissions without increasing input resource consumption or sacrificing economic output, particularly in the basic materials industry.

A limitation of our study is the difficulty of obtaining cost and CO_2 emissions data for shipping for international trade. However, the trade barrier will be weakened by the recent TPP and regional free trade agreements (Baghdadi et al., 2013). Additionally, new shipping operations have been developed using new simulation methods. Research in this area predicts that new operations will make it possible to significantly reduce cost and CO_2 emissions by optimizing shipping speed (Chang and Wang, 2014).

Further research is needed to analyze optimal resource allocation considering with inter-industry relationship using input-output coefficient matrix, which is provided WIOD (Timmer et al., 2015). Inter-industry relationship play important roles to analyze the domestic optimal productive resource allocation problems to reduce CO_2 emissions. Such an analysis could provide a more comprehensive estimate of the potential to reduce CO_2 emissions among countries considering industrial characteristics.

References

Baghdadi, L., Martinez-Zarzoso, I., Zitouna, H., 2013. Are RTA agreements with environmental provisions reducing emissions? Journal of International Economics 90(2), 378-390.

Barros, C.P., Managi, S. and Matousek, R. 2012. The technical efficiency of the Japanese banks: Non-radial directional performance measurement with undesirable output. Omega 40 (1), 1-8.

Barros, C.P.; Gil Alana, L. and Gracia, F.P. 2014. Stationarity and long range dependency of carbon dioxide emissions: Evidence from disaggregated data. Environment and Resource Economics (forthcoming).

Benson, S.M. 2014. Negative-emissions insurance. Science 344(6191): 1431.

Chang, C.C., Wang, C.M., 2014. Evaluating the effects of speed reduce for shipping costs and CO_2 emission. Transportation Research Part D: Transport and Environment 31, 110–115.

Chen, Z.M., Chen, G.Q. 2011. Embodied carbon dioxide emission at supra-national scale: A coalition analysis for G7, BRIC, and the rest of the world. Energy Policy 39(5), 2899-2909.

Cook, W.D., Tone, K., Zhu, J. 2014. Data envelopment analysis: Prior to choosing a model. Omega - The International Journal of Management Science 44, 1–4.

Cooper, W.W., Seiford, L.M., Tone, K. 2006. Introduction to Data Envelopment Analysis and Its Uses. Springer US, New York, US.

Färe, R., Grosskopf, S., Margaritis, D., 2011. Coalition formation and data envelopment analysis. Journal of CENTRUM Cathedra 4(2), 216-223.

Feng, C., Chu, F., Ding, J., Bi, G., Liang, L., 2015. Carbon Emissions Abatement (CEA) allocation and compensation schemes based on DEA. Omega 53, 78-89.

Fujii, H., Kaneko, S., Managi, S., 2010. Changes in environmentally sensitive productivity and technological modernization in China's iron and steel industry in the 1990s. Environment and Development Economics 15(4), 485-504.

Fujii, H., Managi, S., Kawahara, H., 2011. The Pollution Release and Transfer Register system in the U.S. and Japan: An analysis of productivity. Journal of Cleaner Production 19(12), 1330-1338.

Fujii, H., Managi, S., 2013. Which Industry is Greener? An empirical study of nine industries in OECD countries. Energy Policy 57, 381-388.

Intergovernmental Panel on Climate Change (IPCC). 2007. Impacts, Adapation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (eds, Parry, M. L., Canziani, O. F., Palutikof, J. P., van der Linden, P. J. & Hanson, C. E.) 7–22 (Cambridge Univ. Press, Cambridge, UK, 2007)

Intergovernmental Panel on Climate Change (IPCC). 2014. Climate Change 2014: Mitigation of Climate Change. IPCC Fifth Assessment Report (AR5).

Kaufmann, D., Kraay, A., Mastruzzi, M., 2010. The Worldwide Governance Indicators: Methodology and Analytical Issues. Policy Research Working Paper 5430.

Kumar, S., Fujii, H., Managi, S., 2015. Substitute or complement? Assessing renewable and nonrenewable energy in OECD countries. Applied Economics 47(14), 1438-1459.

Kravtsova, V., Radosevic, S., 2012. Are systems of innovation in Eastern Europe efficient? Economic Systems 36(1), 109–126.

Lobell, D.B., Schlenker, W., Costa-Roberts, J., 2011. Climate Trends and Global Crop Production Since 1980. Science 333, 616-620.

Managi, S. 2011. Technology, Natural Resources and Economic Growth: Improving the Environment for a Greener Future. Edward Elgar Publishing Ltd, Cheltenham, UK.

Marcel P.T. (ed) 2012. The World Input-Output Database (WIOD): Contents, Sources and Methods, WIOD Working Paper Number 10.

Méon, P., Sekkat, K. (2012) FDI Waves, Waves of Neglect of Political Risk. World Development 40(11): 2194–2205

Naqvi, M., Yan, J., Dahlquist, E., 2010. Black Liquor Gasification Integrated in Pulp and Paper Mills: A Critical Review. Bioresource Technology, 101(21), 8001-8015.

Perkins R, Neumayer E., 2012. Do recipient country characteristics affect international spillovers of CO2-efficiency via trade and foreign direct investment? Climatic Change 112(2), 469-491.

Pollak, M., Phillips, S.J., Vajjhala, S., 2011. Carbon capture and storage policy in the United States: A new coalition endeavors to change existing policy. Global Environmental Change, 21(2), 313-323.

Popp, A., Lotze-Campen, H., Bodirsky, B., 2010. Food consumption, diet shifts and associated non-CO_2 greenhouse gases from agricultural production. Global Environmental Change 20(3), 451-462.

Ricci, O., Selosse, S. 2013. Global and regional potential for bioelectricity with carbon capture and storage. Energy Policy 52, 689–698.

Schandl, H., West, J. 2010. Resource use and resource efficiency in the Asia–Pacific region. Global Environmental Change 20(4), 636-647.

Scovronick, N, Wilkinson, P., 2013. The impact of biofuel-induced food-price inflation on dietary energy demand and dietary greenhouse gas emissions. Global Environmental Change 23(6), 1587-1593.

Somanathan E., T. Sterner, T. Sugiyama, D. Chimanikire, N.K. Dubash, J. Essandoh-Yeddu, S. Fifita, L. Goulder, A. Jaffe, X. Labandeira, S. Managi, C. Mitchell, J.P. Montero, F. Teng, and T. Zylicz, 2014: National and Sub-national Policies and Institutions. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Steininger, K., Lininger, C., Droege, S., Roser, D., Tomlinson, L., Meyer, L., 2014. Justice and cost effectiveness of consumption-based versus production-based approaches in the case of unilateral climate policies. Global Environmental Change 24, 75-87.

Timmer, M. P., Dietzenbacher, E., Los, B., Stehrer, R. and de Vries, G. J. (2015), "An Illustrated User Guide to the World Input–Output Database: the Case of Global Automotive Production", Review of International Economics.

Wang, W., Koslowski, F., Nayak, D.R., Smith, P., Saetnan, E., Ju, X., Guo, L., Han, G., de Perthuis, C., Lin, E., Moran, D., 2014. Greenhouse gas mitigation in Chinese agriculture: Distinguishing technical and economic potentials. Global Environmental Change 26, 53–62.

Wu, J., An, W., Ali, S., Liang, L. 2013. DEA based resource allocation considering environmental factors. Mathematical and Computer Modelling 58(5–6), 1128-1137.

Table 1. CO_2 emissions and simple efficiency by industrial sector

Industry name	CO_2	Sale/CO_2	Sale/Energy	Sale/Material	Sale/Labor	Sale/Capital
Food, Beverages and Tobacco	8,198	8.36	0.35	1.32	8.30	1.60
Textiles and Textile Products	3,204	8.49	0.37	1.39	6.00	1.27
Leather, Leather and Footwear	300	13.83	0.72	1.30	6.80	1.06
Wood and Products of Wood and Cork	1,283	8.75	0.21	1.39	5.91	1.69
Pulp, Paper, Paper , Printing and Publishing	5,210	7.31	0.21	1.51	5.63	1.50
Coke, Refined Petroleum and Nuclear Fuel	16,945	3.26	0.20	1.03	37.80	3.33
Chemicals and Chemical Products	19,942	3.57	0.21	1.29	11.17	1.84
Rubber and Plastics	1,486	3.70	0.16	1.39	6.05	1.67
Other Non-Metallic Mineral	30,082	0.66	0.09	1.44	6.49	1.39
Basic Metals and Fabricated Metal	35,917	2.37	0.17	1.29	6.74	1.60
Machinery, Nec	2,118	26.73	1.16	1.43	5.49	2.23
Electrical and Optical Equipment	1,735	56.41	2.24	1.44	10.39	2.30
Transport Equipment	2,324	30.09	1.30	1.35	7.18	2.10

Source World input-Output Dataset. (Marcel P.T. (ed), 2012)

Note: score is global average from 1995-2009.

Table 2. Description of sample

Country Name	Australia, Austria, Belgium, Bulgaria, Brazil, Canada, China, Cyprus, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Hungary, Indonesia, India, Ireland, Italy, Japan, Korea, Lithuania, Luxembourg, Latvia, Mexico, Malta, Netherlands, Poland, Portugal, Romania, Russia, Slovak Republic, Slovenia, Sweden, Turkey, United States
Industry Name and code	*Daily commodity industry group* : [1] Food, Beverages and Tobacco (FOOD) [2] Textiles and Textile Products (TEXTILE) [3] Leather, leather and footwear (LEATHER) [4] Wood and Products of Wood and Cork (WOOD) *Basic material industry group* : [5] Pulp, Paper, Paper , Printing and Publishing (PULP) [6] Coke, Refined Petroleum and Nuclear Fuel (OIL) [7] Chemicals and Chemical Products (CHEMICAL) [8] Rubber and Plastics (RUBBER) [9] Other Non-Metallic Mineral (MINERAL) [10] Basic Metals and Fabricated Metal (METAL) *Processing and assembly industry group* : [11] Machinery, Nec (MACHINE) [12] Electrical and Optical Equipment (ELECTRIC PRODUCT) [13] Transport Equipment
Year	1995-2009

Table 3. Average score of data variables by type of industries

	CO_2 (kt-CO2)	Energy (TJ)	Sale (million US$)	Material (million US$)	Labor (million US$)	Capital (million US$)
Food, Beverages and Tobacco	8,198	188,785	57,513	42,614	7,770	31,814
Textiles and Textile Products	3,204	74,409	20,651	14,872	3,655	10,201
Leather, Leather and Footwear	300	5,796	3,518	2,673	558	1,747
Wood and Products of Wood and Cork	1,283	53,554	9,695	6,801	1,882	4,985
Pulp, Paper , Printing and Publishing	5,210	180,082	29,378	18,630	6,186	20,009
Coke, Refined Petroleum and Nuclear Fuel	16,945	291,593	17,417	18,990	880	10,002
Chemicals and Chemical Products	19,942	346,814	43,659	31,126	5,621	26,823
Rubber and Plastics	1,486	39,678	19,139	13,398	3,445	9,967
Other Non-Metallic Mineral	30,082	244,270	15,727	10,031	2,953	11,942
Basic Metals and Fabricated Metal	35,917	501,378	57,891	43,209	10,340	34,221
Machinery, Nec	2,118	49,545	38,899	25,510	7,749	19,077
Electrical and Optical Equipment	1,735	48,405	82,424	51,319	10,737	31,892
Transport Equipment	2,324	55,259	60,271	44,894	8,741	25,194

Source World Input-Output Dataset. (Marcel P.T. (ed), 2012)

Note: score is 39 countries and 15 years (1995-2009) average.

Table 4. Description of Scenario

Scenario	Countries
former Communist (8 countries)	China, Czech Republic, Hungary, Poland, Romania, Russia, Slovak Republic, Slovenia
TPP (5 countries)	Australia, Canada, Japan, Mexico, United States
EU (27 countries)	Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Sweden
Global (39 countries)	Australia, Austria, Belgium, Bulgaria, Brazil, Canada, China, Cyprus, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Hungary, Indonesia, India, Ireland, Italy, Japan, Korea, Lithuania, Luxembourg, Latvia, Mexico, Malta, Netherlands, Poland, Portugal, Romania, Russia, Slovak Republic, Slovenia, Sweden, Turkey, United States

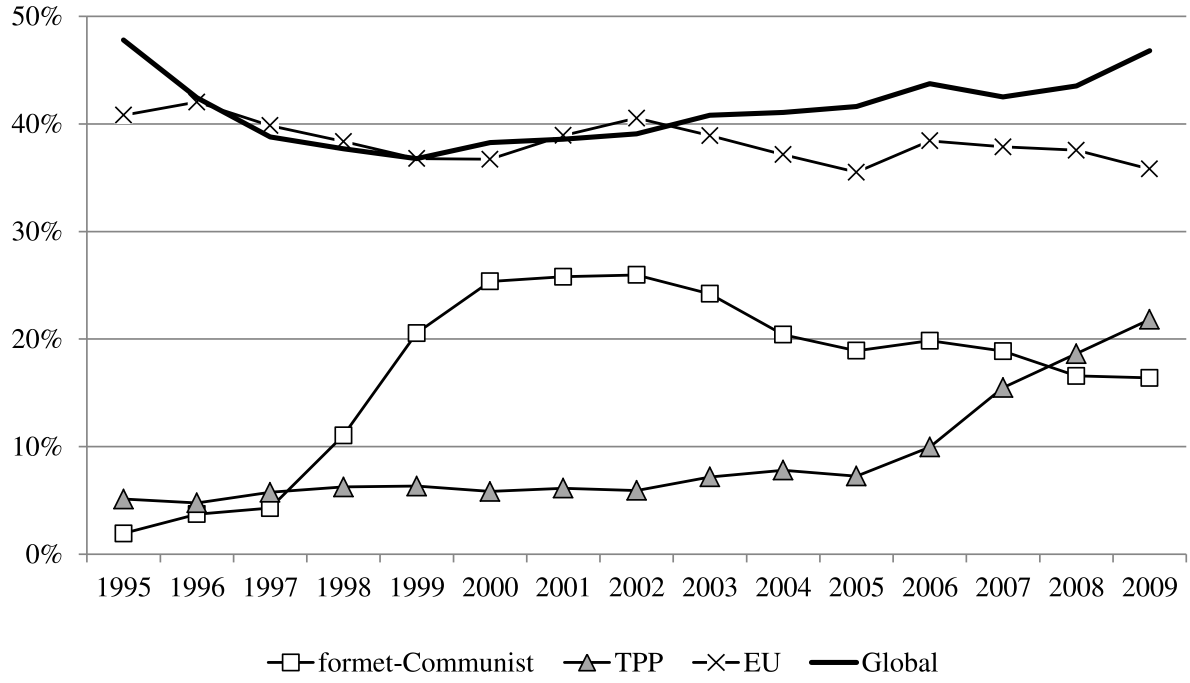


Figure 1. CO_2 emissions reduction ratio by scenario

Note : CO_2 reduction ratio = CO_2 emissions in optimal production case / CO_2 emissions in reference case.

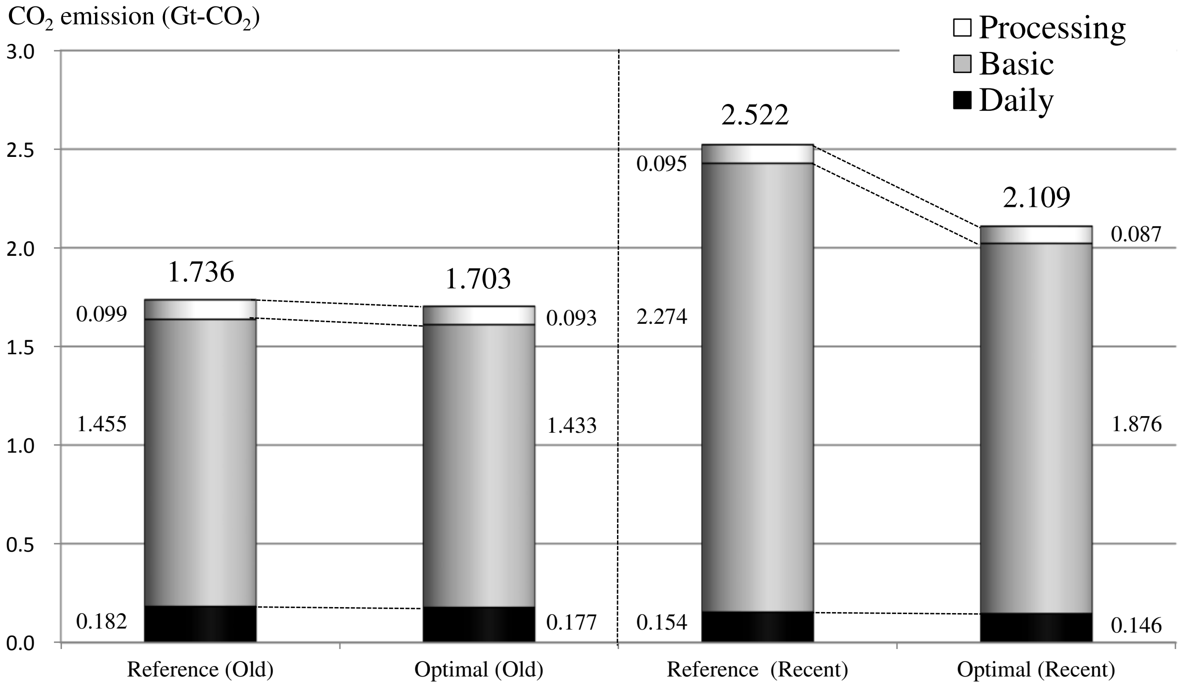


Figure 2. CO_2 emissions in optimal production case under former Communist scenario

Note : Reference case is estimated CO_2 emissions if all countries' $\lambda = 1$.

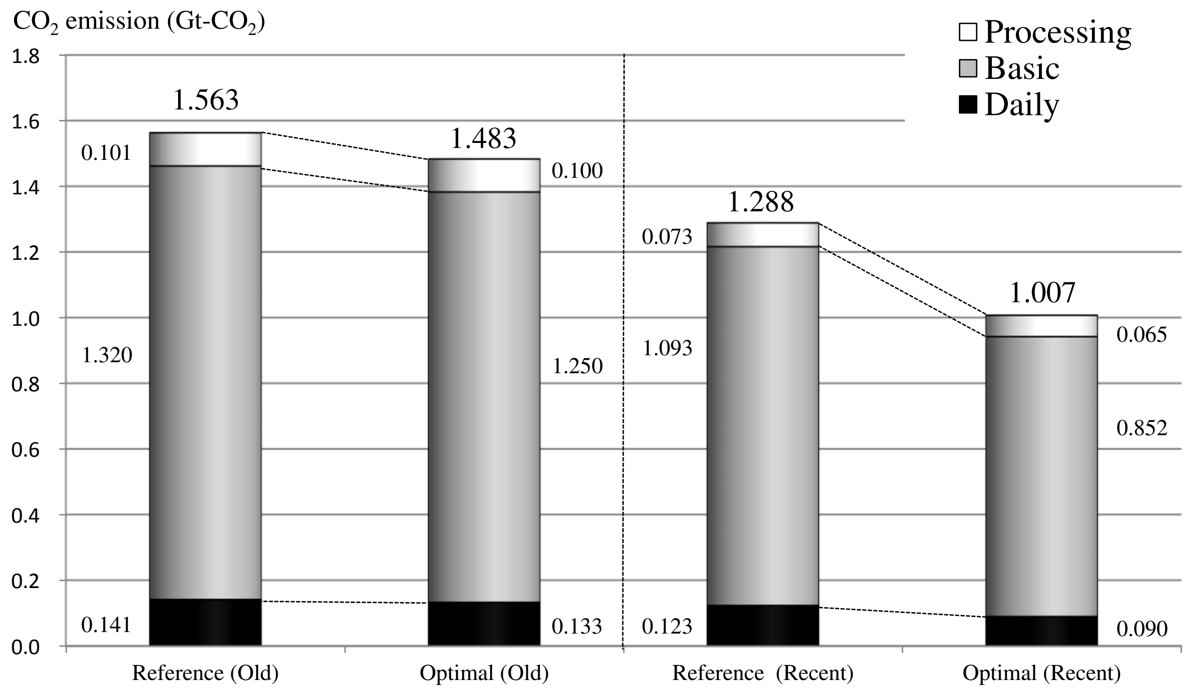


Figure 3. CO_2 emissions in optimal production case under TPP scenario

Note : Reference case is estimated CO_2 emissions if all countries' $\lambda = 1$.

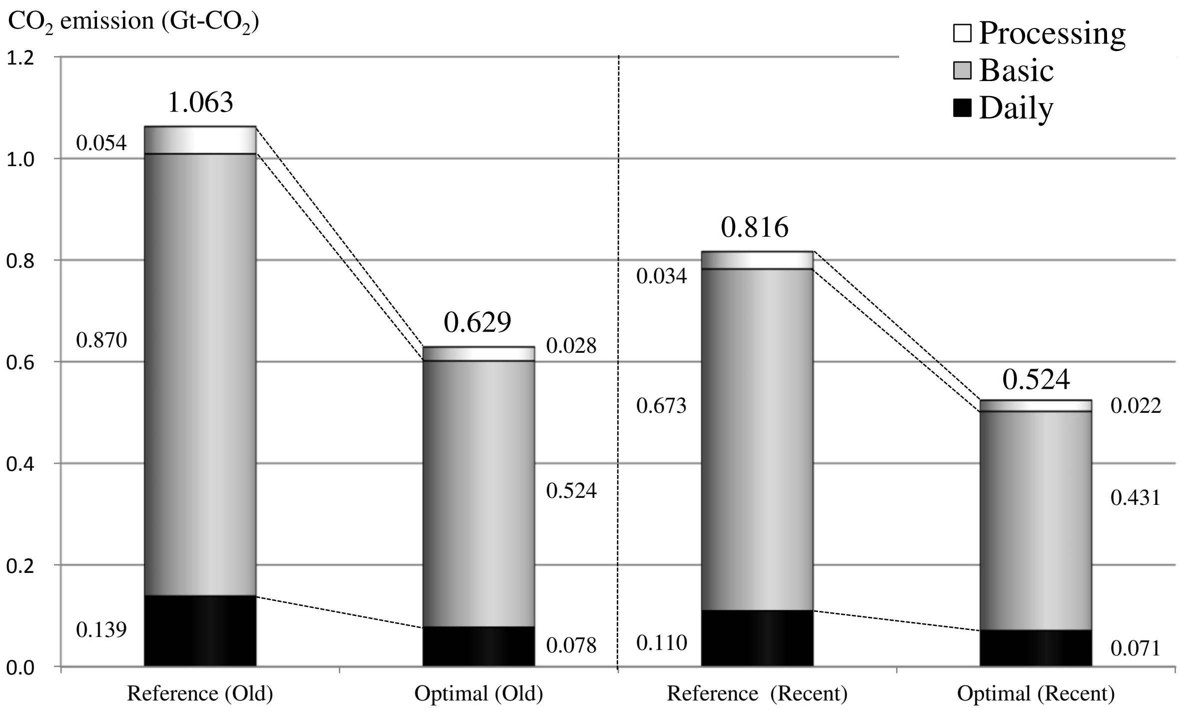


Figure 4. CO_2 emissions in optimal production case under EU scenario

Note : Reference case is estimated CO_2 emissions if all countries' $\lambda = 1$.

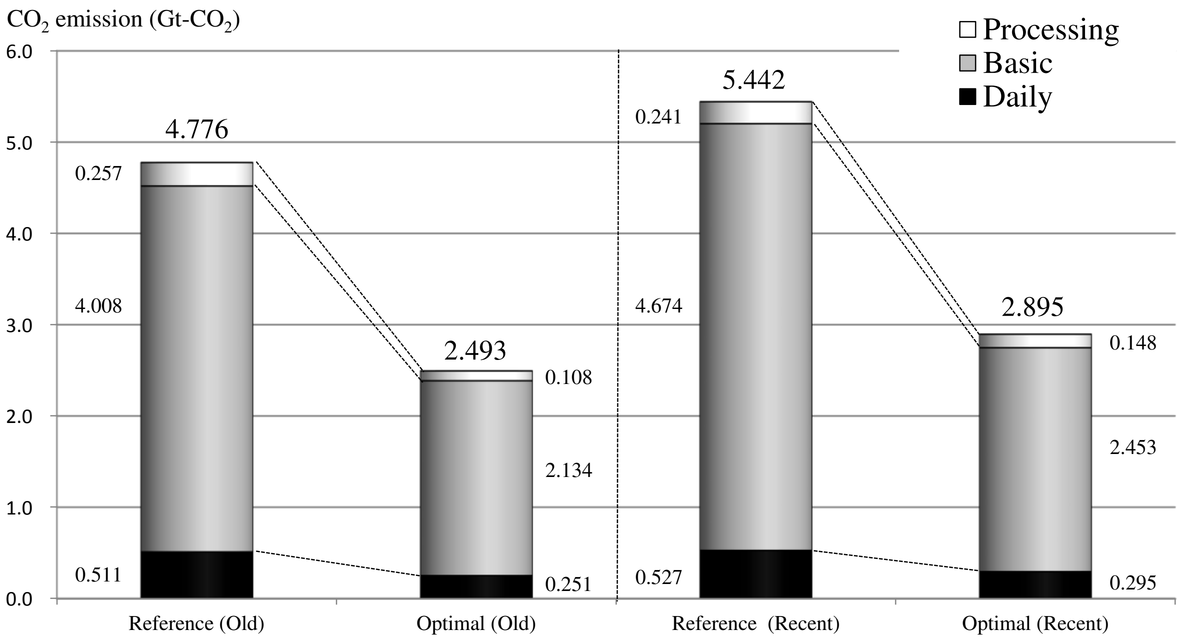
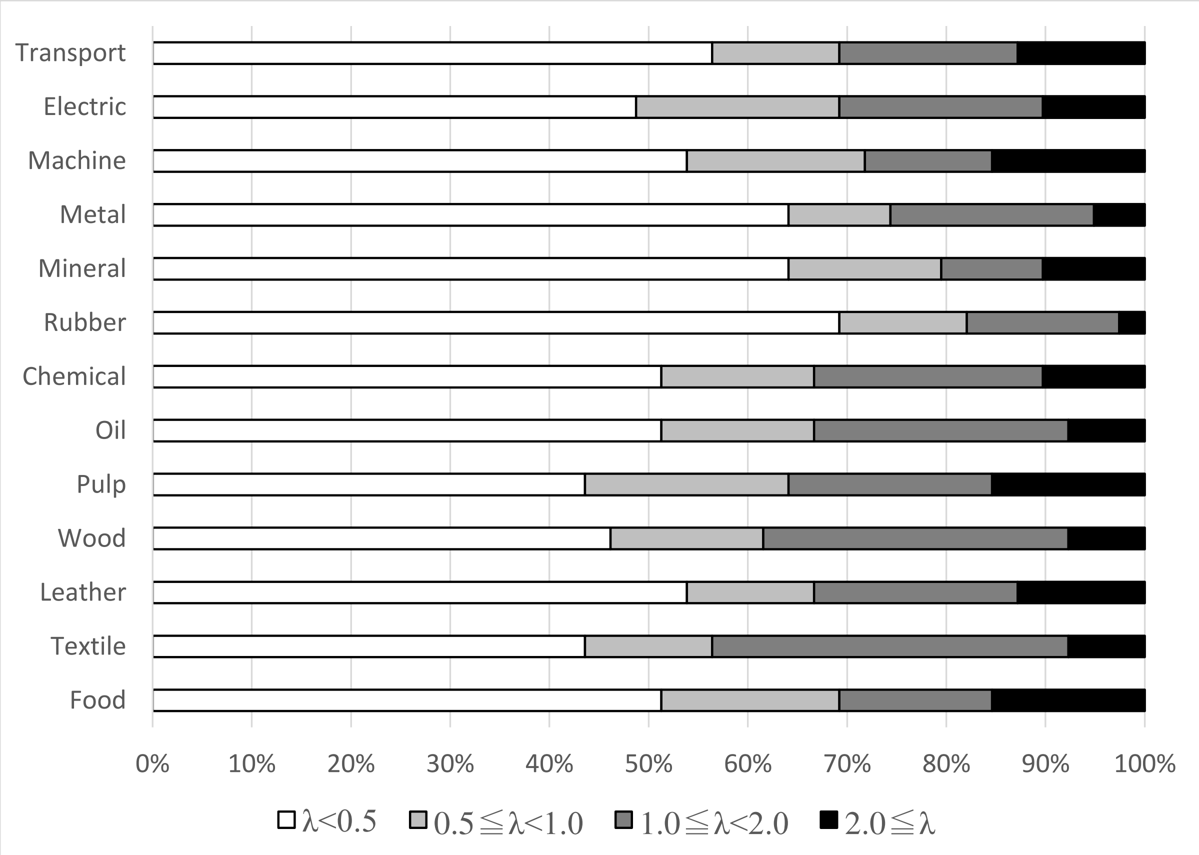


Figure 5. CO_2 emissions in optimal production case under Global scenario

Note : Reference case is estimated CO_2 emissions if all countries' $\lambda = 1$.



Appendix1. The distribution of parameter λ in global scenario (average score from 1995 to 2009)

Appendix2. The country list whose parameter λ achieved upper limit (1+APTP) in whole research period (1995 to 2009).

Type of industry (# of countries)	Country name list
Food (4)	Finland, Malta, Netherlands, Romania
Textile (8)	Belgium, Cyprus, Estonia, France, Hungary, Italy, Malta, Netherlands
Leather (5)	Austria, Finland, Hungary, Malta, Portugal
Wood (4)	Estonia, Finland, France, Sweden
Pulp (6)	Czech Republic, Hungary, Ireland, Italy, Malta, Netherlands
Oil (4)	Belgium, Greece, Ireland, Romania
Chemical (6)	Cyprus, Denmark, Greece, Ireland, Korea, Sweden
Rubber (1)	Italy
Mineral (1)	Czech Republic
Metal (2)	Greece, Portugal
Machine (4)	Austria, Finland, Netherlands, Sweden
Electric product (5)	Finland, Ireland, Malta, Portugal, Sweden
Transportation equipment(1)	Belgium