1. INTRODUCTION

Recently, the concept of sectoral approaches has been discussed actively under the UNFCCC framework as it could realize GHG mitigations for the Kyoto Protocol and beyond. However, most studies have never introduced this approach to the transport sector explicitly or analyzed its impacts quantitatively. In this paper, we introduce a sectoral approach which aims to set sector-specific emission reduction targets for the transport sector for the post-2012 climate regime. We suppose that developed countries will commit to the sectoral reduction target and key developing countries such as China and India will have the sectoral no-lose targets—no penalties for the failure to meet targets but the right to sell exceeding reductions—for the medium term commitment, i.e. 2013-2020. Six scenarios of total CO₂ emission reduction target in the transport sector in 2020, varying from 5% to 30% reductions from the 2005 level are established. The paper preliminarily analyzes shares of emission reductions and abatement costs to meet the targets for key developed countries including the USA, EU-15, Russia, Japan and Canada. To analyze the impacts of the proposed approach, we generate sectoral marginal abatement cost (MAC) curves by region through extending a top-down economic model, namely the AIM-CGE model. The total emission reduction targets are analyzed against the developed MAC curves for the transport sector in order to obtain an equal marginal abatement cost which derives optimal emission reduction for each country and minimizes total abatement cost. The results indicate that the USA will play a crucial role in GHG mitigations in the transport sector as it is most responsible for emission reductions (i.e. accounts for more than 70%) while Japan will least reduce (i.e. accounts for about 3%) for all scenarios. In the case of a 5% reduction, the total abatement is equal to 171.1 MtCO₂ with a total cost of 1.61 billion USD; and in the case of a 30% reduction, the total abatement is equal to 1,026.4 MtCO₂ with a total cost of 116.17 billion USD. The emission reductions according to the total targets of the five developed regions could cover around 3% to 15% of global CO₂ emissions in the transport sector in 2020.

Key Words: Sectoral approach, Sectoral emission reduction target, Post-2012 climate regime, Marginal abatement cost curve, Transport sector
tered CDM (i.e. Clean Development Mechanism) projects and not one JI (i.e. Joint Implementation) project in the transport sector (as of 1 June 2009)\(^3\). Furthermore, the transport sector only plays a minor role in the current negotiations. The transport sector needs preferential support for policies and measures that reduce greenhouse gas (GHG) emissions and have co-benefit or other sustainable objectives, such as reductions in air pollution, noise, and congestion\(^4\).

This paper aims to introduce a sectoral approach in order to curb CO\(_2\) emissions especially from transportation by introducing sectoral emission reduction targets in the transport sector for the post-2012 climate regime. We suppose that CO\(_2\) emission reduction targets in the transport sector are assigned for key developed countries including USA, EU-15 (i.e. the States who were EU members in 1990), Russia, Japan and Canada which emits over 60% of global CO\(_2\) emissions in transport sector in 2005. Furthermore, in order to assess the potential of the proposed sectoral approach, we employ a global computable general equilibrium (CGE) model namely AIM/CGE model to generate marginal abatement cost (MAC) curves for the transport sector by region. The total emission reduction targets in the transport sector for the committed countries will be analyzed against the developed MAC curves for the transport sector in order to obtain an equal marginal abatement cost which results in optimal emission reduction for each country that minimizes total abatement cost.

**2. SECTORAL APPROACHES**

The concept of sectoral approaches is actually included in Article 4.1 (c) of the 1992 UNFCCC which requires governments to ‘promote and cooperate in the development, application and diffusion, including transfer, of technologies, practices and processes that control, reduce or prevent anthropogenic greenhouse gases emissions in all relevant sectors, including the energy, transport, industry, agriculture, forestry and waste management sectors’. Later, the concept of the sectoral approach was embedded in the Kyoto Protocol to the UNFCCC which the sectors and energy sources are defined in Annex A. Further, paragraph 1 (b) (iv) of the Bali Action Plan notes ‘cooperative sectoral approaches and sector-specific actions’ in order to enhance implementation of Article 4.1 (c) of the Convention. However, there is confusion and concern around the concept of sectoral approaches—their exact specification is often unclear\(^5,6\).

To follow the Bali Road Map which aims to complete negotiations by 2009 at the Conference of the Parties in Copenhagen (COP15), sectoral approaches have been proposed and discussed actively under both the Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol (AWG-KP) and the Ad Hoc Working Group on Long-term Cooperative Action under the Convention (AWG-LCA). At the 3\(^{rd}\) Session of the AWG-LCA, several governments have proposed principles, definitions and concepts of sectoral approaches. Among the proponents of sectoral approaches, the Japanese Government is the most active and has its own sectoral approach which basically aims to set midterm national targets for each major emitting country (including China and India) by calculating the emission reduction potential in each sector, such as power-generation, transport, and others with certain indicators. Japan has also promoted a sectoral approach outside the UNFCCC process at the G8 Environment Ministers Meeting in Kobe and at the G8 Submit in Hokkaido. The G8 stated that the sectoral approach proposed by Japan is recognized as a useful tool for achieving national emission reduction goals.

There are two main concepts of sectoral approaches according to commitment periods of the climate regime. The earlier sectoral-based concepts aim to refine the CDM under the Kyoto Protocol\(^5,6\). The latter concepts of sectoral approaches are proposals for post-2012 international climate agreements\(^7,8\) which are elaborated in this paper. The definitions of sectoral approaches for the post-2012 climate mitigation regime can be summarized as follows. Firstly, sectoral approaches can be used to analyze GHG emission reduction potential by sectors and can be useful tools for setting a fair emission reduction target for each country. A country can apply the sectoral approach to assemble sector-based mitigation potentials to contribute to the estimation of a quantified national emission reduction target. Secondly, the sectoral approach might mean a sector-wide transnational agreement which aims to engage a sector on a broad international basis or a global sectoral industry approach. It can be also applied to identify the best practices and technologies for each sector and policy measures and encourages transfer of the practices through public-private cooperation according to energy efficiency and technology diffusion rate in each country. For example, countries might agree to establish a long-term emission reduction goal, fuel economy standards for vehicles, low-carbon standards for fuels, and a cooperative program to develop alternative technologies\(^9\). Alternatively, the sectoral emission cap can be imposed to major developing countries in the near future.
by implementing the sectoral no-lose targets (SNLTs). The failure to meet the SNLTs target would not involve any penalties or any requirement to purchase emissions reduction credits from other countries. In contrast, if they can abate exceeding the target, they will have the right to sell that exceeding amount to Annex I countries.

The advantages of sectoral approaches are mentioned in several aspects. For example, sectoral approaches would enable us to tackle specific sectors with rapidly rising emissions and involve key emitting countries such as USA, China and India, in the climate agreement. The implementation of sectoral approaches would also bring multi-benefits, such as helping to mobilize technology development and transfer, and providing frameworks for financing clean projects and measures in developing countries. In addition, sectoral approaches may help to identify emissions on a sector-by-sector basis, building confidence that policies and measures can be put in place to reduce emissions. They can also help identify national or global commitments through the aggregation of sectoral data.

3. INTRODUCING A SECTORAL APPROACH TO THE TRANSPORT SECTOR

The transport sector is one of the major sources of greenhouse gas emission as it accounts for about 25% of global CO₂ emissions with the rapidly growing rate. Trends of GHG emissions in the transport sector for most countries are still increasing. There is no significant signal of GHG mitigations in the transport sector even though the Kyoto Protocol to the UNFCCC has entered into force since 2005. More importantly, the USA—the biggest emitter accounting for 34% of global CO₂ emissions in the transport sector—is at the time of writing outside of the protocol due to its withdrawal in 2001. Also, GHG mitigations in developed countries are likely to go to other sectors where reducing emission is easier than the transport sector, in conjunction with several difficulties regarding qualification of emission reductions in the transport sector. However, the emission source from transportation is relatively small and moveable, and depends very much on traveler behavior. Therefore, it is difficult to forecast travel demand and associated CO₂ emissions. In addition, transport projects generally need huge budgets and most of these are provided and subsidized by the government. The transport sector, therefore, is not attractive to project developers or investors.

Developed countries shared significantly 75.4% of global CO₂ emissions in the transport sector in 1990, but the trend of the share is decreasing gradually, becoming 66.7% in 2005. On the other hand, the share of developing countries is increasing, from 23.2% in 1990 to 31.6% in 2005. The share of CO₂ emissions in the transport sector from developing countries will be higher than the share of developed countries in the near further. Therefore, the mitigation of CO₂ emissions in the transport sector in developing countries is also crucially important for the next rounds of international climate regime. From the aforementioned issues, we can establish a framework of a sectoral approach towards GHG mitigations in the transport sector for the international climate agreement, after the Kyoto Protocol as follows.

- USA is crucially needed to have a commitment to curb emissions in the transport sector for the next international climate agreement.
- Other key developed regions, e.g. EU, Russia, Canada and Japan should have in addition a legally binding emission reduction target in the transport sector to ensure that emissions from the transport sector will be under control from those major emitters.
- Key developing countries, e.g. China, India, Brazil, and Mexico should join in the commitment earlier than other developing countries. However, it might be too fast to give any absolute emission reduction targets to developing countries for the mid-term regime.

The framework of a sectoral approach proposed in this paper (Table 1), is based on the assumption that the transport sector is crucially needed to curb emissions. The assigned amount of CO₂ emission reductions in the transport sector should be assigned to countries in a step-wise manner. The assigned amount in the transport sector would be additionally imposed to the existing national emission reduction target, i.e. Kyoto’s target for each Annex I country. Developing countries would be divided into at least two groups regarding their emissions; key developing countries and others. We suggest the ‘no-lose’ target in the transport sector for the key developing countries and ‘no target’ for other developing countries for the next round of the post-2012 climate regime, i.e. 2013-2020.

<table>
<thead>
<tr>
<th>Region</th>
<th>Commitment Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2013-2020</td>
</tr>
<tr>
<td>Developed</td>
<td>Absolute</td>
</tr>
<tr>
<td>Key developing</td>
<td>No-lose</td>
</tr>
<tr>
<td>Other</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1 Proposed target commitments in the transport sector for the post-2012 climate regime
In this paper, to simplify analysis, only five key developed countries or regions namely the USA, EU-15, Russia, Japan and Canada will be preliminarily analyzed for the impacts of introducing emission reduction targets in the transport sector. In 1990, these countries covered almost 70% of global CO₂ emissions and over 90% of industrialized countries emissions from transportation. The no-lose emission reduction target in the transport sector for the key developing countries for the medium-term climate regime will not be included in the analysis. However, any reduction exceeding the no-lose target would facilitate the developed countries to meet the binding target in the transport sector. The results of the preliminary analysis will be discussed in Section 5.

4. GENERATING MAC CURVES FOR THE TRANSPORT SECTOR BY REGION THROUGH USING A CGE MODEL

4.1 Marginal abatement cost curves

Recently, the marginal abatement cost (MAC) curve has been become one of the proper instruments to analyze the impacts of the implementation of the Kyoto Protocol and emission trading. There are two general approaches to generate MAC curves. The first approach is top-down which is based on aggregated microeconomic models, mostly computable general equilibrium (CGE) models that may carry a detailed representation of the energy sector. In a CGE model, the marginal abatement cost is defined as the shadow cost that is produced by a constraint on carbon emissions for a given region and a given time. This shadow cost is equal to the tax that would have to be levied on the emission to achieve the targeted level or the price of an emission permit in the case of emission trading. Marginal abatement cost curves are obtained, when the costs associated with different levels of reductions are generated11-13. Bottom-up models on the other hand are based on an engineering approach that analyzes in detail the different technical potentials for emission reductions. There are several studies of GHG emission reduction potential and mitigation costs by the bottom-up approach14,15.

However, according to the literature there is no study that has a large coverage of countries and options, particularly for the transport sector. In order to evaluate impacts of introducing emission reduction targets in the transport sector, therefore, it is necessary to have MAC curves for the transport sector by region. This study extended a global CGE model namely the AIM/CGE model developed by the National Institute for Environmental Studies (NIES), Japan, in order to generate sectoral MAC curves by region. This model is discussed in the next section.

4.2 The AIM/CGE Model

The AIM/CGE model presented in this paper is a recursive dynamic global CGE model developed by NIES16 (AIM stands for the Asia-Pacific Integrated Model). It is developed by the GAMS/MPG modeling language, based on GTAP in GAMS and GTAP-EG datasets17. Nevertheless, many items were added to the model, for example, more GHGs, biomass, and power generation technologies. The AIM/CGE model aggregates the GTAP dataset into 24 countries and regions (Table 2), and 22 production sectors as well as a final consumption sector as presented (Table 3).

The main actors in the AIM/CGE model are; (1) a representative agent of households who owns primary factors of production, i.e. capital, labor, land, natural resources and emission permits, (2) production sectors who rent production factors from households and buy intermediate input from other production sectors to produce single goods or services to be then inputted into other production sectors and consumed by households through the final demand sector. The model represents the government passively, i.e. to collect taxes (including carbon tax) and disburse the revenues to households as lump-sum transfers. The model treats saving or investment in a region through sector no. 11 (Table 3) which inputs produced goods from every sector in order to produce its output, so-called investment goods. The production structure of the investment sector is similar to other non-energy production sectors (Fig. 1), except that the investment sector will not input production factors or value-added.

Table 2 Countries and regions in the AIM/CGE model

<table>
<thead>
<tr>
<th>Developed Countries</th>
<th>Developing Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan (JPN)</td>
<td>Korea (KOR)</td>
</tr>
<tr>
<td>Australia (AUS)</td>
<td>China (CHN)</td>
</tr>
<tr>
<td>New Zealand (NZL)</td>
<td>Indonesia (IDN)</td>
</tr>
<tr>
<td>Canada (CAN)</td>
<td>India (IND)</td>
</tr>
<tr>
<td>United States of America (USA)</td>
<td>Thailand (THA)</td>
</tr>
<tr>
<td>Western Europe (EU15)</td>
<td>Other South-east Asia (XSE)</td>
</tr>
<tr>
<td>Eastern Europe (EU10)</td>
<td>Other South Asia (XSA)</td>
</tr>
<tr>
<td>Russia (RUS)</td>
<td>Rest of Asia-Pacific (XRA)</td>
</tr>
<tr>
<td>Rest of Europe (XRE)</td>
<td>Mexico (MEX)</td>
</tr>
<tr>
<td></td>
<td>Argentina (ARG)</td>
</tr>
<tr>
<td></td>
<td>Brazil (BRA)</td>
</tr>
<tr>
<td></td>
<td>Other Latin America (XLM)</td>
</tr>
<tr>
<td></td>
<td>Middle East (XME)</td>
</tr>
<tr>
<td></td>
<td>South Africa (ZAF)</td>
</tr>
<tr>
<td></td>
<td>Other Africa (XAF)</td>
</tr>
</tbody>
</table>
e.g. capital and labor. The investment goods are then demanded by the representative agent of households only. The investment goods enter to the utility function of the households at the second level along with other non-energy produced goods under the Cobb-Douglas form. Then, non-energy goods composite and fossil fuel/electricity goods composite enter the utility function by the Leontief form (Fig. 2). The households will use the investment goods to invest in the next period as the households’ endowment of production factor, the capital. The produced goods demanded as intermediate inputs for productions and as final demand for consumption are generated through Armington aggregation which mixes domestic and imported goods as imperfect substitutes.

In the AIM/CGE model, CO₂ emission permit is modeled as other production factors owned by the households. Production sectors (Fig. 1) that input fossil fuels need CO₂ emission permit according to amount of CO₂ emitted from burning fossil fuels. Analogously, final consumption sector (Fig. 2) also need emission permits upon fossil fuels consumed. Therefore, we can track the flow of CO₂ emissions and corresponding emission permits by simply following the flow of fossil fuel inputted to production sectors and households. CO₂ emissions from each sector can be calculated through intermediate inputs of fossil fuels into that sector in conjunction with emissions sector (Fig. 2) also need emission permits upon fossil fuels consumed. Therefore, we can track the flow of CO₂ emissions and corresponding emission permits by simply following the flow of fossil fuel inputted to production sectors and households. CO₂ emissions from each sector can be calculated through intermediate inputs of fossil fuels into that sector in conjunction with emissions

\[ \text{emission permit} \times \text{emission factor} \times \text{paid price} = \text{carbon tax} \]

Once we introduce a CO₂ emission tax or a price to emission permit, then the price of consuming fossil fuel will be increased as it is a carbon-content goods. The price increase is a multiple of its emission factor and the tax level levied. The CO₂ emission reduction of each sector for each region due to the introduction of CO₂ emission taxes can be calculated by subtracting the emissions of the taxing case from the emissions of the base case.

The elasticities of substitution (σ) are key parameters in production and utility functions which represent the ability of individuals to make tradeoffs among the inputs. All production sectors and final consumption are modeled using nested Constant Elasticity of Substitution (CES) production functions, or Cobb-Douglas (C-D, \( \sigma = 1 \)) and Leontief (LT, \( \sigma = 0 \)) forms, which are a special case of the CES as shown in Figures 1 and 2.

### Table 3 Production and final consumption sectors

<table>
<thead>
<tr>
<th>Non-Energy</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Food</td>
<td>17. Coal</td>
</tr>
<tr>
<td>2. Energy intensive products</td>
<td>18. Crude oil</td>
</tr>
<tr>
<td>3. Metal and machinery</td>
<td>19. Petroleum products</td>
</tr>
<tr>
<td>4. Other manufactures</td>
<td>20. Gas</td>
</tr>
<tr>
<td>6. Construction</td>
<td>22. Electricity</td>
</tr>
<tr>
<td>7. Transport</td>
<td></td>
</tr>
<tr>
<td>8. Communication</td>
<td></td>
</tr>
<tr>
<td>9. Public service</td>
<td></td>
</tr>
<tr>
<td>10. Other service</td>
<td></td>
</tr>
<tr>
<td>11. Investment</td>
<td></td>
</tr>
<tr>
<td>12. Agriculture</td>
<td></td>
</tr>
<tr>
<td>13. Livestock</td>
<td></td>
</tr>
<tr>
<td>14. Forestry</td>
<td></td>
</tr>
<tr>
<td>15. Fishing</td>
<td></td>
</tr>
<tr>
<td>16. Mining, except fossil fuels</td>
<td></td>
</tr>
</tbody>
</table>

Household: Capital, Labor, Land, Natural resources

Final consumption: Production factors

4.3 Treatment of the transport sector in the AIM/CGE model

The transport sector of a region produces transportation services (transportation supply) for providing movements of commodities and passengers in a region and exporting transportation services for bilateral trade flows through an international transportation pool. The relationship between domestic output and exports is defined as a Constant Elasticity of Transformation (CET), as shown in Figure 3. The output of the transport sector is transportation service revenue in the monetary unit (Billion USD). Number of trips, transportation modes, and travel time are not considered in the model. The production structure of the transport sector is mostly identical to other non-energy sectors (Fig. 1), inputting intermediate (produced) goods from other sectors and production factors from the households. At the top level, non-energy intermediate inputs and value-added/energy composite enter the production function in a fixed factor manner. In the other word, the transport sector decides on input volume of each non-energy intermediate goods and value-added/energy composite to minimize production costs under the Leontief type technology constraint. The value-added/energy composite is a CES function. The value-added inputs of labor and capital are aggregated through a Cobb-Douglas production function. The energy composite is a CES function of electricity versus fossil fuels composite. The fossil fuels composite is further a CES function of coal, liquid fuels, and gas fuels. The liquid and gas fuels composites are a C-D production function of oil versus petroleum products, and gas versus gas man-
ufacturing, respectively. Finally, each fossil fuel and its associated CO₂ emission tax enter as fixed-coefficient composites as shown in Figure 1.

The transportation services produced for domestic use become intermediate inputs by other production sectors and as final consumption by households. As the transportation services, which is one of non-energy goods, enters the production function of the other production sectors at the top level along with other intermediate non-energy goods and value-added/energy composite under the LT type technology constraint. Therefore, transportation services demanded by other production sectors are proportional to the outputs of each production sector. For the final consumption of the households, transportation services enter the utility function of the households at the second level along with other non-energy goods by a C-D aggregation. Then, non-energy goods composite and fossil fuel/electricity goods composite enter the utility function in a fixed factor manner under the LT form as shown in Figure 2.

[Diagram of the production structure (non-energy sectors)]

Fig. 1 The production structure (non-energy sectors)

[Diagram of the final consumption structure]

Fig. 2 The final consumption structure
The supply of the international transportation services (Fig. 3), the international transportation pool \( (vt) \) is equal to value of transportation services exported from regions \( (vst_r) \) throughout the world. Market clearance conditions apply for international transportation services as the equation below.

\[
v_t = \sum_r v_{st_r} \tag{1}
\]

Then, international transportation services input each imported goods, because every bilateral trade flow \( (vx_{md_{irs}}) \) demands its own transportation services \( (vtw_{irs}) \) in a fixed factor manner, the LT form (Fig. 4), reflecting differences in unit transportation margins across different goods and trading partners. \( vx_{md_{irs}} \) represents trade of goods \( i \) from region \( s \) to region \( r \). \( vtw_{irs} \) represents international transportation services for trade of goods \( i \) from region \( s \) to region \( r \). The supply-demand balance in the market for transportation service equates transport services supply to the sum across all bilateral trade flows of service inputs, see equation (2). The real transportation costs \( (T_{irs}) \) are proportional to trade, see equation (3). \( T_{irs} \) represents transportation cost for exporting goods \( i \) from region \( s \) to region \( r \). \( \tau_{irs} \) is proportion of transportation cost to trade.

\[
v_t = \sum_r vtw_{irs} \tag{2}
\]

\[
T_{irs} = \tau_{irs}vx_{md_{irs}} \tag{3}
\]

At equilibrium, the model will solve for the set of commodity and factor prices, and the levels of sectoral activity and household income that clear all markets in the economy, given aggregate factor endowments, households’ consumption technologies and production sectors’ transformation technologies. Production cost of transportation services for a region is product of activity levels and price of transportation service output. While transportation cost inputted by the other production sectors and consumed by the households is a product of input volume and price of transportation services. To importing goods from other regions, a region has to pay to the export price for these goods as well as transportation margins which are combined in a Leontief form as mentioned.

At equilibrium, we also obtain CO\(_2\) emissions which come with input volume of fossil fuels (i.e. coal, oil, petroleum product, gas, and gas manufacturing) to each production sector of regions for the benchmark case (i.e. no CO\(_2\) emission tax case) or the cases corresponding to the CO\(_2\) emission tax levels. Then, we can calculate CO\(_2\) emission reductions (i.e. CO\(_2\) emissions of the base case minus CO\(_2\) emissions of the taxing case) by sector and region for each CO\(_2\) emission tax case and then we can plot marginal abatement cost (MAC) curves. In this study, we considered the CO\(_2\) emission reductions and developed MAC curves only for the transport sector which are shown in the next section.

**4.4 MAC curves for the transport sector by region**

We applied the AIM/CGE model by varying a CO\(_2\) emission tax from 0 to 200 USD/tCO\(_2\) by intervals of 50 USD/tCO\(_2\). Consequently, the output of the model for each level of emission tax gives the corresponding CO\(_2\) emissions by sector by region by time. With having the coordinates of CO\(_2\) emission taxes and corresponding
emission reductions, we can plot sectoral MAC curves by region as mentioned in the previous section.

Figure 5 shows the MAC curves for the transport sector for developed and developing countries in 2020, which are derived from the outputs of the AIM/CGE model. Figure 5 (a) shows transport sector MAC curves for developed countries. It shows obviously that USA has high potential of CO\textsubscript{2} emission reductions in the trans-
port sector, i.e. abatement cost of CO₂ emissions is cheapest and very much cheaper than other countries. Therefore, in the next round of the international climate regime, i.e. 2012-2020, USA will play an important role in GHG mitigation in the transport sector as it has high potential for CO₂ emission reductions. For developing countries, abatement cost of CO₂ emissions in the transport sector are also cheap particularly, China, India, Brazil and a group of Middle-East countries as shown in Figure 5 (b).

5. ANALYZING CO₂ EMISSION ABATEMENT COSTS IN THE TRANSPORT SECTOR FOR DEVELOPED COUNTRIES

A binding emission reduction target can ensure that emission reductions to meeting targets will be done due to the 1997 Kyoto Protocol assigned legally binding emission reduction targets to industrialized countries. Currently, developed countries are preparing their medium-term greenhouse gas emission reduction targets, i.e. for the period 2013 to 2020, for negotiating at the Copenhagen meeting (COP15) of the UNFCCC at the end of 2009. The key developed countries, such as the European Union and the United States have already announced their medium-term targets for 2020, with the former aiming for a 20% reduction from the 1990 level (or 14% from 2005), and the latter a 14% reduction from the 2005 level (i.e. no change from 1990). Meanwhile, Japan is determining its emission targets for 2020 by considering two types of approaches; one looks at what reductions could be achieved if certain actions are taken and the other focuses on fairness among industrialized countries. The targets which Japan is considering cover a 4%-30% reduction from the 2005 level.

In this paper, we preliminarily analyze the impacts of introducing CO₂ emission reduction targets in the transport sector for key developed countries namely USA, EU-15, Russia, Japan and Canada. Based on the time series GHG data for the transport sector provided in the UNFCCC website, six scenarios of total emission reduction target in the transport sector in 2020 for these countries are set up—by varying with 5% intervals from 5% up to 30% reduction from the 2005 level. The targets mostly cover emission reduction target options which are considered by developed countries. The targets presented in this paper are used to show the way of analyzing the impacts on participating countries when sectoral emission reduction targets are introduced. Once the real targets in the transport sector are known, this idea can be applied to analyze those targets directly.

From the MAC curves for the transport sector in 2020 generated in the previous section we can determine a relationship between marginal abatement costs for CO₂ emission reduction (y) and CO₂ emission reductions (x) with the coefficient of determination (R²) for each region as the equations shown in Figure 6. As a MAC curve represents the abatement cost of the last ton of emissions abated, the total abatement cost of emission reductions can be determined by finding the area under the curve. Therefore, with having a MAC curve, we can know the total cost to meet a given target, or we can know how much emissions can be abated according to a given budget. Further, if we have a total emission reduction target, we can allocate optimal emission reduction for each which minimizes the total abatement cost with an equal marginal abatement cost through using the equi-marginal principal.

Analogously, in this study, we analyzed the impacts of the total emission reduction targets by using the developed MAC curves for the transport sector derived in the previous section. Figure 6 shows the MAC curves for the transport sector for key developed countries in 2020, which are derived from the outputs of the AIM/CGE model. It shows obviously that CO₂ emission reduction, in other words, the reduction of fossil fuel uses in the transport sector in the USA is very sensitive to the CO₂ emission taxes. At the CO₂ emission tax of 50 USD/tCO₂, for example, it yields very high CO₂ emission reductions in the transport sector in the USA compared to other developed countries, i.e., the EU-15, Russia, Canada, and Japan, respectively. In other words, the USA has higher potential to reduce CO₂ emissions in the transport sector than other countries. A major reason of why the effects of the CO₂ emission taxes are particularly strong in the USA but are very weak in the other developed countries is that the fossil fuel prices and taxes in the USA are much lower than other countries. From key world energy statistics published by the International Energy Agency¹⁸, the gasoline price in the USA is cheaper than other countries, e.g. gasoline price in Japan is more than twice that of the USA price. Thus, when we introduce a CO₂ emission tax into the model, reductions in fossil fuel use in the USA are very sensitive. As the technology (i.e. represented by production function) of the transport sector, specifically the substitution rate between capital and energy for the USA and Japan are similar, then the price level of fossil fuels could be the reason for the difference of the sensitivity to the CO₂ emission taxes between the USA and Japan. Furthermore, the transport sector in the USA both passenger and goods movements relies on road transport
that demands a huge amount of fossil fuel, hence the effects of the CO\textsubscript{2} emission taxes in the USA become bigger. In addition, fuel economy in the USA is also low due to big-sized and old vehicles that are still used throughout the states. Therefore, there is room for the USA to reduce CO\textsubscript{2} emissions in the sector. For Japan, fossil fuel taxes are relatively high. With the same level of the CO\textsubscript{2} emission tax with the USA, reductions in fossil fuel use in Japan are very small. Also, energy efficiencies in Japan, particularly in the transport sector, are considerably high. It will be very expensive to reduce more a unit of CO\textsubscript{2} emissions in the transport sector for Japan. This is similar for other developed countries like the EU-15, Australia and New Zealand.

The results of the analysis are shown in Table 4. To meet all scenarios of total emission reduction targets in the transport sector, the USA will be responsible for most reductions while Japan will reduce the least. In case of a 5% reduction from the 2005 level, the total emission reduction is equal to 171.1 MtCO\textsubscript{2} with a total abatement cost of 1.61 billion USD. The reduction covers 2.4% of global CO\textsubscript{2} emissions in the transport sector in 2020. In case of 30% reduction, the total emission reduction is equal to 1,026.4 MtCO\textsubscript{2} (i.e. covering 14.6%) with a total abatement cost of 116.17 billion USD. If the total emission reduction targets increase, the share of emission reductions for the USA and Russia will reduce but the share of emission reduction for EU-15, Canada and Japan will increase.

6. CONCLUSION AND FUTURE RESEARCH

In this paper, a sectoral approach which sets the sector-specific emission reduction targets to the transport sector is introduced based on the assumption that the transport sector really needs to curb CO\textsubscript{2} emissions. With having introduced this approach, it ensures that the GHG mitigations will take place in the transport sector. The mitigations may take place somewhere instead through the current Kyoto’s mechanisms. The preliminary analysis indicates that CO\textsubscript{2} emission reductions in the transport sector for the five key developed regions could cover almost 15% of global CO\textsubscript{2} emissions in the transport sector in 2020, if the emission reduction target is equal to 25% reduction from the 2005 level.

The paper shows obviously that the developed top-down MAC curves by sector by region can represent characteristics of emission reduction potentials for a spe-
cific sector which can be compared with other regions. The derived MAC curves cover all sectors and regions which would be difficult for a bottom-up approach. To meet the target in the transport sector, the USA will play an important role as it has the highest potential as well as the cheapest cost to reduce CO\textsubscript{2} emissions in the transport sector and it will be the biggest supply source of CO\textsubscript{2} emission permits in the transport sector. With having known the optimal emission reduction for each country which minimizes the total abatement cost, the real emission reduction targets in the transport sector which are fairness and acceptable for participating countries can be set up. Such information would be very useful for decision making and negotiating in the international climate regimes as well.

Further research is to analyze the impacts of participation of key developing countries in the medium-term commitment by accepting the ‘no-lose’ target in the transport sector and also when they would fully accept absolute targets in the transport sector, say after 2030. Another issue is that the MAC curves for the transport sector generated by the top-down model should be verified for the potential of emission reductions in a practical way, with the bottom-up MAC curves which are developed from detailed mitigation technologies.

**REFERENCES**

2. Kahn Ribeiro, S., Kobayashi, S., Beuthe, M., Gasca, J., Greene,

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Table 4 Equal marginal costs and shares of emission reductions to meet the targets in the transport sector for key developed countries in 2020

<table>
<thead>
<tr>
<th>Options of CO\textsubscript{2} emission reduction target from the 2005 level</th>
<th>USA</th>
<th>EU-15</th>
<th>Canada</th>
<th>Japan</th>
<th>Russia</th>
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<td>6.8</td>
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INTRODUCTION OF A SECTORAL APPROACH TO TRANSPORT SECTOR FOR POST-2012 CLIMATE REGIME

A. Tippichai, A. Fukuda, H. Morisugi


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