Will Global Convergence of Per Capita Emissions Lead the Way to Meeting the UNFCCC Goal?

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Will Global Convergence of Per Capita Emission Lead Meeting UNFCCC Goal?

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Abstract

One of the contentious issues of the ongoing climate negotiations is the huge differences in per capita CO_2 emissions between Annex I and Non-Annex I countries. We analyze the costs of reducing this gap using a global CGE model. A range of carbon taxes are considered for Annex I countries as policy instruments. We find that the average per capita CO_2 emissions of Annex I countries would still remain almost twice as high as that of Non-Annex I countries in 2030 even if CO_2 emissions of the former is reduced by 57% from the baseline through a heavy carbon tax of \$250/tCO_2. The global reduction of CO_2 emission would be only 18% due to an increase in CO_2 emissions in the Non-Annex I countries. This reduction would not be sufficient to stabilize atmospheric CO_2 concentration at the level implied by UNFCCC to avoid the dangerous climate change. The \$250/tCO_2 carbon tax, on the other hand, would reduce Annex I countries' GDP by 2.4%, and global trade volume by 2%. We conclude that a demand for the convergence of per capita emissions between industrialized and developing countries would not be fruitful in climate change negotiations.

Key Words: Emission intensity; International negotiation on climate change; General equilibrium modeling

JEL Classification: D58, Q43, Q54

Introduction

One of the contentious issues of the ongoing climate change negotiations is the huge difference in per capita emissions between developed and developing countries. Developing countries, which mostly fall in the Non-Annex I group, argue that since their per capita CO_2 emissions are very small compared to that of developed countries, it should be legitimate for them to increase their emissions to achieve anticipated economic growth. They further argue that one of the principles of a long-term climate change agreement should be equity in that per capita emission converges between the countries in the long-run. Several existing studies (e.g., Lecocq and Hourcade, 2012; Gaisford, 2010; Carraro (2010); Tol, 2005; Manne and Stephan, 2005) highlight this issue of equity in climate change negotiation. On the other hand, developed countries assert that without meaningful participation of developing countries, especially the emerging developing economies, such as China, India, Brazil, South Africa, achieving the objective the United Nations framework Convention on Climate Change (UNFCC)—stabilization of atmospheric concentrations of greenhouse gases (GHGs) at a level that would prevent dangerous anthropogenic interference with the climate system—would not be feasible (Rong, 2010; Timilsina, 2008). The merit of this argument rests on the fact that China has already surpassed the United States in CO_2 emissions (IEA, 2012) and that Non-OECD countries account for 90% of population growth, 70% of the increase in economic output and 90% of energy demand growth over the period from 2010 to 2035 (IEA, 2011). These arguments could be attributed to the failure of climate change negotiations in the past (Campbell and Klaes, 2011; Dimitrov, 2010) and for causing the world to wait for more than two decades to reach the recent

global agreement (i.e., the Paris agreement resulted at 21st meeting of the Conference of Parties to UNFCCC in Paris in December 2015).

A critical question is that can the stabilization of GHG concentrations in the atmosphere to avoid climate change be achieved while converging the per capita emissions between industrialized and developing countries? To avoid dangerous consequences in the earth's atmosphere, the earth mean average temperature should not be higher than 2 degree Celsius from the pre-industrialization level (Stern, 2006). The Fourth Assessment of the Intergovernmental Panel on Climate Change (IPCC) reports that concentrations of CO_2 (GHG) emissions should be stabilized at 350 ppm (445 PPM CO_2-equivalent) to maintain temperature rise at 2 degree Celsius (IPCC, 2007). This entails reduction of CO_2 emissions 85% below 2000 level.

Historical trends indicate that per capita CO_2 emission has been decreasing for Annex I countries (with exception in 2010) and increasing for Non-Annex I countries (see Figure 1). In 1990, per capita CO_2 emission of Annex I countries was 11.83 tonnes CO_2 (or tCO_2 hereafter), this has decreased by 12% to 10.41 tCO_2 in 2010. During the same period (i.e., 1990-2010), Non-Annex countries per capita emissions increased by 80% from 1.58 tCO_2 per capita to 2.85 tCO_2. The per capita emission gap between the Annex I countries and Non-Annex I countries has decreased by around 26% from 10.25 tCO_2 in 1990 to 7.56tCO_2 in 2010.

As of year 2010, globally average per capita CO_2 emission is 4.44 tCO_2 (IEA, 2012). To meet the 2 Degree target, global CO_2 emissions should drop by 85% in 2050 from 2000 level. This implies that global CO_2 emission from fuel combustion, which was 23.5 billion tCO_2 in 2000, should be limited at 3.5 billion tCO_2 in 2050. According to UN Population Foundation projection, global population would reach 9.6 billion by 2050 (UN 2013) implying 0.367 tCO_2

globally average per capita CO_2 emission in that year. Thus, to meet the UNFCCC objective (i.e., maintaining earth' mean surface temperature at 2 degree Celsius above the pre-industrial level), globally average per capita CO_2 emission from fuel combustion required to be dropped by 92% in 2050 from the current (2010) level. In average, global per capita CO_2 emission required to be dropped by 6% annually during the 2010-2050 period. Such a high rate of annual reduction of per capita CO_2 emissions indicates the challenge ahead to meet the ultimate objective of the UNFCCC.

The objective of this analysis is to examine the costs to the global economy of moving forward in the direction to converge per capita emissions between Annex I and Non-Annex I countries. Note that in the very long-run (50 to100 years) it could be technically viable to have global convergence of per capita CO2 emissions. This could happen when both Annex I and Non-Annex I groups reduce their respective aggregate per capita emissions from their current levels with Annex I countries many fold faster than Non-Annex I countries. However, Non-Annex I countries argument is for increasing their per capita emissions in the near term so that they move towards narrowing the per capita CO2 emission gap. The paper attempts to capture this reality of climate change negotiations and demonstrates that this notion of convergence is counterproductive to meet the UNFCCC objective. A range of uniform carbon taxes are introduced in Annex I countries as a policy instrument while non-Annex I countries are exempted from the carbon taxes. The impacts of the policy instruments are simulated using a global, dynamic, multi-sector computable general equilibrium model. A number of studies examining the consequences of meeting the 2 degree Celsius target at regional and global levels (see e.g., ; Edenhofer et al. 2010; den Elzen and Meinshausen, 2006). In so doing, these studies consider global carbon tax. We focus on the impacts of narrowing per capita emission gaps

between Annex I and Non-Annex I groups by imposing carbon tax only on the former whereas the latter could still increase their per capita CO_2 emissions.

Figure 1: Historical per capita emission gap between the Annex I and Non-Annex countries (tCO_2 per capita)

The paper is organized as follows. Section 2 discusses CO_2 emissions and per capita emissions focusing on top 30 emitters in 2010. This is followed by brief description the model in Section 3. Section 4 present impacts on CO_2 emissions and per capita emissions of various countries and region due to the policy instrument implemented to reduce the per capita emission gaps. This is followed by a discussion of the impacts of the policy instrument on economic outputs and international trade. Finally, key conclusions are drawn in Section 6.

Current Status of Per Capita and Total CO_2 Emissions

In 1990, just two years before the adoption of the UNFCCC, the total CO_2 emissions of Non-Annex I countries from fuel consumption was 32% of the global CO_2 emissions from fuel consumption; for the rest 68%, Annex I countries were responsible. After 20 years in 2010, the situation has reversed with Non-Annex I countries accounting for the 52% of the global CO_2 emissions (see Figure 2). These statistics also imply the need for Non-Annex I countries increasing contribution in reducing global CO_2 reduction. Moreover, of the global CO_2 emissions from fuel consumption in 2010, 90% was contributed by only 33 countries and Taiwan[1]. China and the US alone contributed 43% of the global CO_2 emissions from fuel consumption in 2010. If India, Russia, Japan and Germany are added, these six countries contributed more than 60% of

[1] Since Taiwan is not a UN member, we have not included in the list of "countries" in this paper. It ranks 20th largest economies in terms of CO_2 emissions in 2010.

the global CO_2 emissions from fuel consumption in 2010 (see Figure 3). Of the 33 countries that accounted for 90% of the global CO_2 emissions from fuel consumption in 2010, 17 are non-Annex I countries and remaining 16 are Annex I countries. Figure 2 implies two important caveats: (i) its only 30 plus countries not necessarily all 186 UNFCCC signatory countries need to lead to reduce global CO_2 emissions and (ii) its not only Annex I countries but also non-Annex I countries, such as China, India, Republic of Korea, Iran, Saudi Arabia, Brazil, Indonesia, Mexico, South Africa, Thailand, Malaysia, Venezuela, Argentina, United Arab Emirates, Egypt, Pakistan and Vietnam would need to contribute to reduce global CO_2 emissions. This, however, does not imply that all of these Non-Annex I countries should finance their GHG mitigation efforts by themselves. The debate of who should finance the cost of GHG mitigation is beyond the scope of this study.

Figure 2: Fuel consumption related CO_2 emissions from Annex I and Non-Annex countries in 1990 and 2010

One of the crucial issues that discourages Non-Annex I countries, which falls in the list of top 30 CO_2 emitters in 2010 (Figure 2), to have any sort of binding commitment to reduce their GHG emissions is that their per capita emissions are much lower compared to that of Annex I countries in the same group of top 30 emitters. For example, India is the third largest CO_2 emitter in 2010, however, its per capita emission is more than 12 times smaller compared to that of the US, the second largest emitter and Australia, the 16th largest emitter (see Table 1). Similarly, although China is the largest emitter in 2010, its per capita emission is more than 3 times smaller to that of the US. This implies that per capita emission in large non-Annex I emitters such as China, India, Mexico, Indonesia, Brazil, South Africa are expected to rise in the near future.

Figure 3: Countries that contributed 90% of global CO_2 emissions in 2010

Table 1: Per capita emission in descending order in 2010 (tCO_2)

Some non-Annex I countries such as Korea, Saudi Arabia, United Arab Emirates, which fall under the group of top 30 emitters accounting for 90% of global emissions, have per capita emissions higher than several Annex I countries. Some non-Annex I countries under the top 30 emitters' group, such as Iran, Malaysia, South Africa and Venezuela have per capita emissions comparable to several Annex I countries.

Methodology and Data

We used a multi-regional, multi-sector, recursive dynamic CGE model for the purpose of this study. Please refer to Timilsina et al. (2011) for the detailed description of the model and data. Note that CGE models are the most appropriate and widely applied analytical tools to examine economic and environmental consequences of climate change policies and measures at the national as well as global level. Please refer to Edenhofer et al. (2010) for more details on the application of CGE models for climate policy analysis.

The model has 28 sectors and 25 countries/regions. Each of the 28 sectors is depicted by a set of nested constant elasticity of substitution (CES) production functions (see Figure 4). At the top tier of the production structure, firms in each country/region minimize their production costs by choosing an optimal combination of the aggregate non-energy intermediate input (ND) and the composite of value added and the aggregate energy input (VAE). The non-energy

intermediate input in a country/region is formed through a CES combination of that commodity produced in the country/region and that imported from various countries/regions. Similarly, the value added-energy composite is formed through a CES combination of land and non land factor input, where the latter is the CES composite of labor and capital-energy composite. This aggregation continues as illustrated in Figure 4.

Figure 4: Structure of the CGE model developed for the study

The study gives special attention to the energy sector modeling for two reasons. First, since a carbon tax is introduced to fossil fuels, we need an explicit representation of the fossil fuel sector including various petroleum products. Second, the study aims to assess the competitiveness of biofuels with fossil fuels when carbon tax is introduced into the latter; therefore, we also need an explicit representation of biofuels. As shown in the 'Energy Block' in Figure 4, the total demand for energy is a CES composite of electricity and an aggregate of non-electric energy commodities.[2] One component of the latter is the liquid fuel, which is a CES composite of the ethanol-gasoline and diesel-biodiesel bundles. The model is structured in such a way that it allows direct substitution between gasoline and ethanol, and between diesel and biodiesel.

Land use changes are incorporated into the model via a constant elasticity of transformation (CET) representation of land supply for each country/region. 'Land Block' in Figure 4 presents structure of the land-use module incorporated in the CGE model. Total land

[2] In depth breakdown of power sector at technology level would be ideal. Studies such as Chen et al. (2013), Timilsina and Shrestha (2007) have done so for single country CGE models. However, the model used here is a global model using GTAP data (Narayan et al. 2012). Lack of information prevents us breaking down the electricity sector at technology level.

areas are first divided into 18 agro-ecological zones (AEZ) in every country/region. Under each AEZ in a country or region, total available land area is allocated to forest land, pasture and crop land. On the second level, crops are further divided into the four different categories: rice, sugar-crops, grains and oilseeds, and fruits, vegetables and other non-grain crops. Finally, the grains and oilseeds category is partitioned into wheat, corn, other coarse grains, and oilseeds. Land use change is induced by changes in relative returns to land as each of the CET nests of our land module, agents maximize payoffs by optimally allocating the fixed land area for this nest to the various competing uses.

While modeling the household sector, we assumed that a representative household maximizes its utility, using a non-homothetic Constant Difference of Elasticities (CDE) function, subject to the budget constraint. The households' disposable income consists of the factor incomes (net of taxes) minus the direct tax. A household savings rate determines the fraction of disposable income that is saved, and thus available for investments. Hence, total national income accrues to government expenditures, household expenditures, and investments.

The government derives revenue from a number of indirect taxes, tariffs and a direct tax on households. Government expenditures are an exogenously determined share of nominal GDP. Government revenue equals the sum of government expenditures and government savings so that, in the model, the public sector always has a balanced budget. The direct tax on households is adjusted each period to ensure a balanced public budget. International trade is modeled by a system of Armington demands that give rise to flows of goods and services between the regions. On the national/regional level, import demand is driven by CES functions of domestic and imported components of demand for Armington commodities. Export supply is depicted by a two tier constant elasticity of transformation (CET) function, where, on the first tier, the total

output of a sector is designated either to total exports or to domestic supply, and, at the second tier, total exports are partitioned according to their destinations.

The capital stock is composed of old and new capital, where new corresponds to the capital investments at the beginning of the period and old corresponds to the capital installed in previous periods. The ratio of new to old capital is also a measure of the flexibility of the economy, as new capital is assumed to be perfectly mobile across sectors. Furthermore, each period, a fraction of the old capital depreciates. Population and productivity growth are exogenous drivers of the model's dynamics. The former is taken from the projections of the United Nations Population Division, where labor force growth corresponds to growth of the population aged 15-64 years. Productivity growth is modeled as exogenous and factor neutral for agricultural sectors and labor augmenting for industrial and service sectors.

The model does not fix an exogenous penetration rate for the renewable energy. When carbon tax is introduced to fossil fuels, renewable energy becomes more competitive and their penetration increases. This is determined by the model endogenously. Technology development in the energy supply-side has been represented through productivity change. Availability of new resources (e.g., shale gas) could impact on energy prices, which are exogenous to this model. We used energy price forecasts from International Energy Agency, which account for new development in energy resources while developing their global energy outlook (IEA, 2011). Productivity of energy follows an autonomous energy efficiency improvement (AEEI) path so that there is no endogenous technological change in the model. To ensure equilibrium in the model, three sets of market clearing conditions are met. First, total production of each commodity equals the sum of domestic consumption and export so that the goods and services markets clear. Second, total investment equals total saving, where savings are composed of

private (household) savings, public (government) savings and exogenously fixed foreign savings. Third, factor markets clear, which implies full employment.

The basic data needed for the calibration of the model is derived from the GTAP 7.0 database (Narayan et al. 2012).[3] The main reason for using the GTAP database is that no other comprehensive global database required by this study exists. Moreover, most CGE models simulating climate change policies use the GTAP database, and the use of this database in our study helps compare our results with those of others. The original GTAP database provides information for 113 countries and 57 commodities and production sectors. For example, biofuels are not a proper sector in the original GTAP 7.0; therefore, we modified the database in a way that allowed us to introduce biofuels sectors in our CGE model. For this purpose, we collected detailed information on production, consumption and trade, a total of seven new biofuel sectors, which have been created by splitting existing GTAP sectors. The land data are also based on the GTAP 7.0 database.[4] The model was implemented using GAMS software developed by GAMS corporation[5].

Impacts on Per Capita and Absolute Emissions

The study simulates various level of carbon tax ranging from US$10 to US$250 per ton of carbon dioxide. Per ton of carbon, the range corresponds to US$37 to US$917 the upper range is indeed a very high level of carbon tax. Revenue from the carbon tax is recycled, through a

[3] Note that we have used only data from GTAP. The CGE model presented here is not a GTAP CGE model. It is a revised/upgraded version of model presented in Timilsina et al. (2011).
[4] We acknowledge that a more recent version of GTAP data (GTAP 8.0) is available now (Narayan et al. 2012). The new database presents data for year 2007; the version of GTAP database used in this analysis uses data for year 2004. Since there would not be much change in structure of an economy in 3 years; using new version of data is not expected to alter the results significantly.

[5] For information about GAMS software, please visit https://www.gams.com/.

lump-sum transfer, to households after maintaining the government revenue neutral. This section presents key results from simulations of the model.

Impacts on per capita emissions

Figure 5 illustrates that per capita emissions of Annex I and Non-Annex I countries are moving closer as rate of carbon tax increases. Under the business as usual scenario the average per capita emission of the Annex countries would be 13.2 tCO_2 in 2030. This is 3.62 times as high as the average per capita emission of Non-Annex I countries in the same year. A uniform carbon tax of US$10/$tCO_2$, US$50/tCO_2 and US$ 100/tCO_2 in the Annex I countries would reduce their per capita emissions by 8%, 24% and 33%, respectively from the BAU case. If the carbon tax is raised to a very high rate of US$ 250/tCO_2, the average per capita emission of Annex I country would drop by 46%. On the other hand, the 250/tCO_2 carbon tax in Annex I countries would cause the per capita emission of Non-Annex countries to increase slightly, by 2.8%. Although Annex I countries' per capita emission would still be 1.9 times as high as that of Non-Annex I countries at 250/tCO_2 carbon tax case, the gap in per capita emissions between Annex I and Non-Annex I groups would drop by almost 65%.

One interesting observation is that at carbon tax rate greater than 50/tCO_2, not only Annex I countries would suffer with economic losses but also non-Annex country starts exhibiting economic losses despite the fact these countries are exempted from any carbon tax. This is due to international trade effect. Although a carbon tax in Annex I countries might cause moving some emission intensive industrial production to Non-Annex countries, this substitution

effect would not be able to cause a complete offset of losses in economic outputs that occurred in Annex I countries.

Table 2 presents change in per capita emissions in various countries and region. Countries such as Australia, United Kingdom and United States would exhibit relatively higher drop of their per capita emissions, whereas France will see the lowest drop. This is because the energy system, particularly electricity generation is based on fossil fuels, such as coal in the former countries, whereas more than 80% of electricity is generated from nuclear power plants in France. All developing countries would experience increase in their per capita emissions as these countries are exempted from carbon tax. This clearly indicates the leakage in emission reduction as the carbon tax in Annex I countries would cause migration of carbon intensive industrial production to Non-Annex I countries.

The movement towards the convergence of per capita emissions occurs if a high carbon tax is imposed to developed countries, and developing countries are exempted from any carbon tax. However, meeting the ultimate objective of the UNFCCC - stabilizing atmospheric concentration of GHG emissions at the level that avoids climate change - would not be possible through reductions of GHG emissions from developed countries only. Developing countries also need to significantly reduce their emissions to achieve the ultimate goal of the UNFCCC. But, if developing countries start reducing their emissions, per capita emissions of developed and developing countries start diverging instead of converging. Some developing countries, such as India and China, have announced their plans to reduce their per capita emissions, particularly CO_2 emissions per unit of GDP. To achieve their plans, these countries are expected to make huge investment in clean energy technologies on both energy supply and demand sides. Furthermore, their per capita emissions are expected to decrease in spite of significant increase in

their income (i.e., GDP per capita) unless the income effect (i.e., the rate of increase in GDP per capita) is greater than intensity effect (i.e., the rate of decrease in emission per capita GDP). The decrease in per capita emissions in developing countries would lead to further divergence of per capita emissions between developed and developing countries.

Table 2: Change in CO_2 emissions per capita from the BAU case in 2030 (%)

Figure 5. Movement of per capita emission gap between Annex I and Non-Annex countries along with Annex I Countries' carbon tax rates

Impacts on CO_2 Emissions

Figure 6 illustrates reduction in total CO_2 emissions due to the per capita emissions converging efforts. A US$10/t$CO_2$ carbon tax to Annex I countries would reduce their aggregate emissions by 11% in 2030. Since, the leakage effect (i.e., increase in emission in Non-Annex I countries due to carbon tax in Annex I countries) of this relatively small level of carbon tax would be negligible, it would reduce the global CO_2 emissions by 4% from the baseline. If the carbon tax level is raised to US$250/tCO2, the aggregate emission reduction in Annex I countries would be 57% in 2030. This high level carbon tax in Annex I countries would produce a significant leakage in Non-Annex I countries, thereby increasing the aggregate Non-Annex I CO_2 emissions by 3% in 2030. At the global, level the emission reduction would be around 18% from the baseline.

Figure 6: Impacts on Total CO_2 Emissions (percentage change from the baseline in 2030)

Table 3 presents reductions of CO_2 emissions by countries or region. As discussed above, countries with pre-dominant use of fossil fuel in their power generation would experience the relatively higher reductions in their total CO_2 emissions. A US$50/t$CO_2$ carbon tax in Annex I countries lead to reduction of their CO_2 emissions by 11% to 36% in 2030. On the other hand the US$50//t$CO_2$ carbon tax in Annex I countries causes up to 2.2% increase of CO_2 emissions in non-Annex I countries.

Table 3: Change in total CO_2 emissions at various levels of carbon tax in Annex I countries in 2030 from baselines (%)

Note that at the 50% probability of maintaining the global mean temperature rise below 2°C relative to pre-industrial levels, atmospheric GHG concentrations must stabilize below 450ppm CO_2 equivalence (IPCC, 2007). To achieve this target, global GHG emissions should peak by 2020 at the latest and then be more than halved by 2050 relative to 1990 (Stern 2006). The Fifth Assessment Report (AR5) suggests that there would be negative emissions in the long-run (e.g., 2100) to stabilize the atmospheric CO_2 concentration to avoid dangerous climate change (IPCC, 2014). Our analysis shows that the global CO_2 emissions in 2030 would be only 18% lower compared to that in the baseline, whereas more reduction would be needed to remain in the trajectory to maintain 2050 emission level at the half of 1990 level.

Impacts on Economic Outputs and International Trade

Impacts on GDP

Figure 7 presents economic impacts of moving towards convergence of per capita emissions. A US$50/t$CO_2$ carbon tax to Annex I countries that reduces per capita CO_2 emission gap between Annex I countries and Non-Annex I countries by 33% from the BAU case, would cause 0.5% and 0.3% GDP losses at the Annex I and global levels, respectively in 2030. If the carbon tax level is raised to US$250/t$CO_2$, it would reduce the per capita CO_2 emission gap by 65% at GDP costs of 2.4% and 1.4%s at the Annex I and global levels, respectively in 2030.

The impacts on GDP would vary significantly across the Annex I countries (see Table 4). For example, the 33% reduction of CO2 emission intensity gap between Annex I countries and Non-Annex I countries (i.e., US$50/tCO2 carbon tax case) would cause GDP losses from 0.1% (France) to 0.7% (Canada, Australia & New Zealand) in 2030. If the carbon tax level is raised to US$250/tCO2, the economic costs in some countries, such as Canada, would be very high. It is interesting to note that the adverse GDP impacts of oil exporting non-Annex I countries (e.g., Middle East and North Africa) would even be larger than that of Annex I countries for all carbon tax rates considered here except US$250/tCO2.

Figure 7: Impacts on GDP (percentage change from the baseline in 2030)

Impacts on international trade

The carbon tax introduced in Annex I countries to move forward in the direction of converging per capita emissions would have large impacts on international trade. Global trade would shrink by 0.5% in 2030 if the per capita emission gap between the Annex I and non-Annex I countries is reduced by 33% through a US$50/t$CO_2$ carbon tax introduced in Annex I countries (see Figure 8). The contraction in global trade would reach 2% when the per capita

emission gap is reduced by 65% (i.e., introduction of a US$250/t$CO_2$ carbon tax in the Annex I countries). Since domestic production would be more expensive due to carbon tax, Annex I countries exports would get impacted the most: 1.5% and 5% drops under US$50/t$CO_2$ and US$250/t$CO_2$ carbon tax cases, respectively in 2030. Non-Annex I countries would benefit as their exports increase and imports drop.

Table 4: Change in GDP at various levels of carbon tax in Annex I countries in 2030 from the baseline (%)

Like in the impacts on GDP, Annex I countries with carbon intensive economy (e.g., United States, Japan and Australia) would exhibit the highest impacts on their international trade (see Table 5). For example, a US$50/t$CO_2$ carbon tax would cause reduction of exports by 1.5% in Australia and Japan and 2.5% in the United States. Most Non-Annex I countries would gain through increase in their exports.

Figure 8: Impacts on international trade (percentage change from the baseline in 2030)

Table 5: Change in international trade at various levels of carbon tax in Annex I countries from the baseline in 2030

Policy Implications

We argued in this paper that GHG mitigation would be required in both developed and developing countries to achieve the ultimate goal of the UNFCCC. Developing countries have been advocating the convergence of emission intensity. Our study suggests, through an empirical analysis, that the emission convergence issue should not be presented as a condition for a global agreement on climate change mitigation. This was what exactly happened in the Paris Agreement (please see UNFCCC, 2015). Instead of splitting into developed and developing country blocks, all Parties to UNFCCC agreed to contribute to the global efforts to combat climate change. They made pledges (also known as 'Intended Nationally Determined Contributions' or INDC) on how much each party could reduce GHG emissions over a given timeframe. Most parties have already submitted their INDC and the remaining parties are expected to do so soon. Parties also recognized that the current INDC would not be sufficient to achieve the ultimate objective of UNFCCC and they will agree for additional mitigation actions through future negotiations. The Paris Agreement has arranged several funding windows to support climate change mitigation and adaptation activities (e.g., Green Climate Fund, Least Developed Countries Fund, Special Climate Change Fund). These funding windows are expected to be utilized focusing on low income and most vulnerable countries. The Paris Agreement allows market based instruments to reduce GHG emissions. For example, it allows international emission trading through a provision called "internationally transferred mitigation outcomes" in its Article 6. It aims to facilitate knowledge and technology transfer through the 'Technology Mechanism" introduced in Article 10. In the nutshell, the Paris Agreement is leading the global climate change policy initiatives to the direction which is also implied by the findings of this study.

Concluding remarks

Currently Annex I countries' per capita CO_2 emission is about 4 times as high as that of Non-Annex I countries. Developing countries are strongly arguing that an agreement on ongoing climate change negotiation should help reduce this disparity thereby moving forward in the direction of converging on per capita emissions between the industrialized and developing economies. In the absence of climate change mitigation policies in the industrialized countries, the per capita emission gap between the Annex I and Non-Annex I countries would still remain almost at the same level as of today. Using a global CGE model, we simulated a range of potential carbon taxes (S10/tCO_2 to \$250/tCO_2) uniformly introduced in Annex I countries as a policy instrument to reduce the gaps. The highest carbon tax considered in this study (\$250/tCO_2) would reduce Annex I countries' average per capita emission by 46% from the baseline case in 2030. Since the Non-Annex I countries are exempted from the carbon tax, their average per capita emission would increase by 3% from the baseline in 2030. The net result is a 65% drop in the gap of per capita emissions between the Annex I and Non-Annex I countries. This would lead to around 60% of reduction of Annex I countries' total CO_2 emissions reduction from the baseline in 2030. However, this reduction would be mostly offset by increase in CO_2 emissions in Non-Annex I countries thereby leaving a merely 18% reduction at the global level. This reduction may be smaller than needed to remain in the emission trajectory to meet the 2050 level, which should be a half of 1990 level, for stabilization of atmospheric concentration of GHG emissions at the level to avoid dangerous climate change.

The carbon tax, on the other hand, would reduce Annex I countries GDP by 2.5% from the baseline in 2030. The economic impacts vary substantially across countries depending upon their fossil fuel intensities of economic outputs. Countries such as Australia & New Zealand, United Kingdom and the United states, are found to suffer with the higher economic loss compared to

other countries. On the other hand, countries like France where nuclear power produces more than 80% of electricity would face the lowest economic loss. The policy instrument to reduce the per capita emission gaps between the Annex I and Non-Annex I countries would cause the global trade volume to shrink. The \$250/tCO_2 carbon tax would reduce global trade by 2% from the baseline in 2030. Since domestic production would be more expensive due to carbon tax, Annex I countries' exports would drop by 5% in 2030.

Since the emerging developing countries, such as India and China, are planning to reduce their CO_2 emissions per capita GDP, they are expected to scale up deployment of clean energy technologies and substitute towards cleaner fuels. This could lead to a decrease in per capita emission unless the income effect (i.e., the rate of increase in GDP per capita) is greater than intensity effect (i.e., the rate of decrease in emission per capita GDP). In such case, the gap in per capita emissions between the developed and developing countries may not converge unless developed countries reduce their emissions at levels much higher than estimated in this study.

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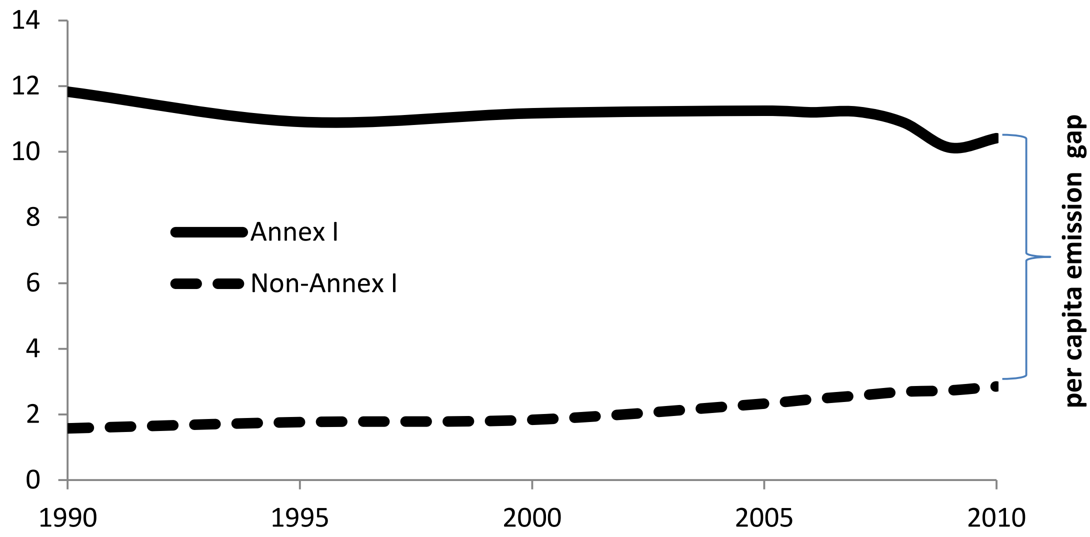
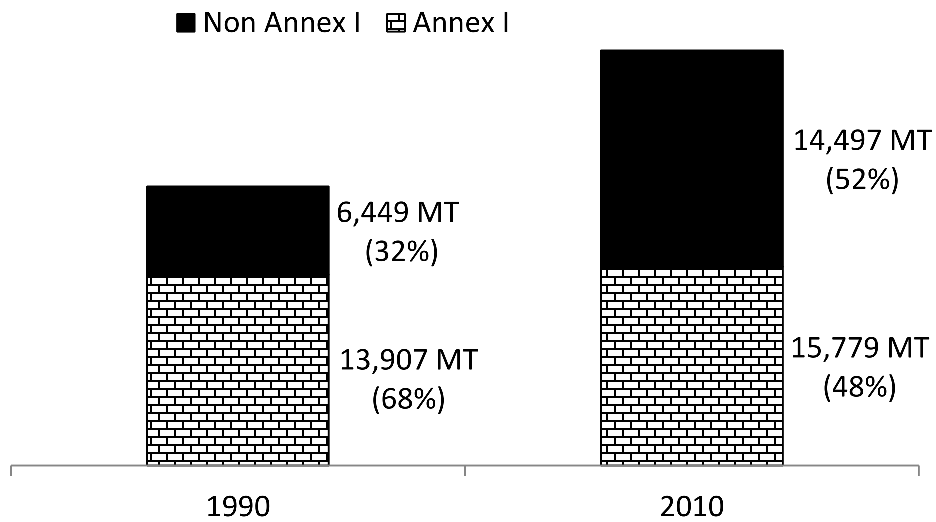
Figure 1: Historical per capita emission gap between the Annex I and Non-Annex countries (tCO_2 per capita)



Source: IEA (2012)

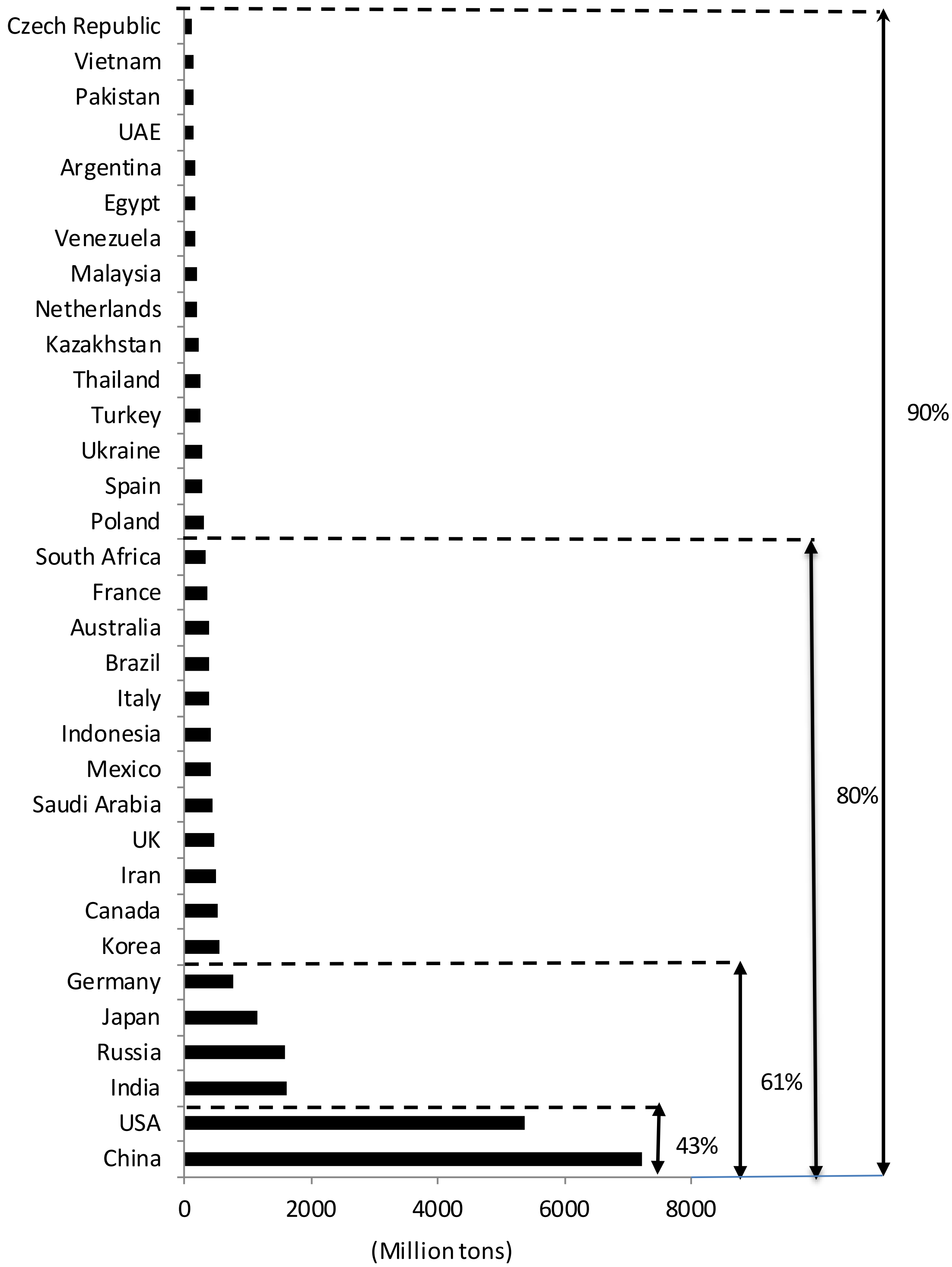
Note: *This figure presents per capita CO_2 emissions from fuel consumption only; per capita CO_2 emissions would be higher if fugitive emissions and CO_2 emissions from industrial processes are included. If other GHG are also included, per capita GHG (CO_2 equivalent) would be significantly higher. Emission inventory data other than CO_2 emission from fuel consumption are not reliable especially for earlier years. Therefore, we presented emissions from fuel combustion only.*

Figure 2: Fuel consumption related CO_2 emissions from Annex I and Non-Annex countries in 1990 and 2010



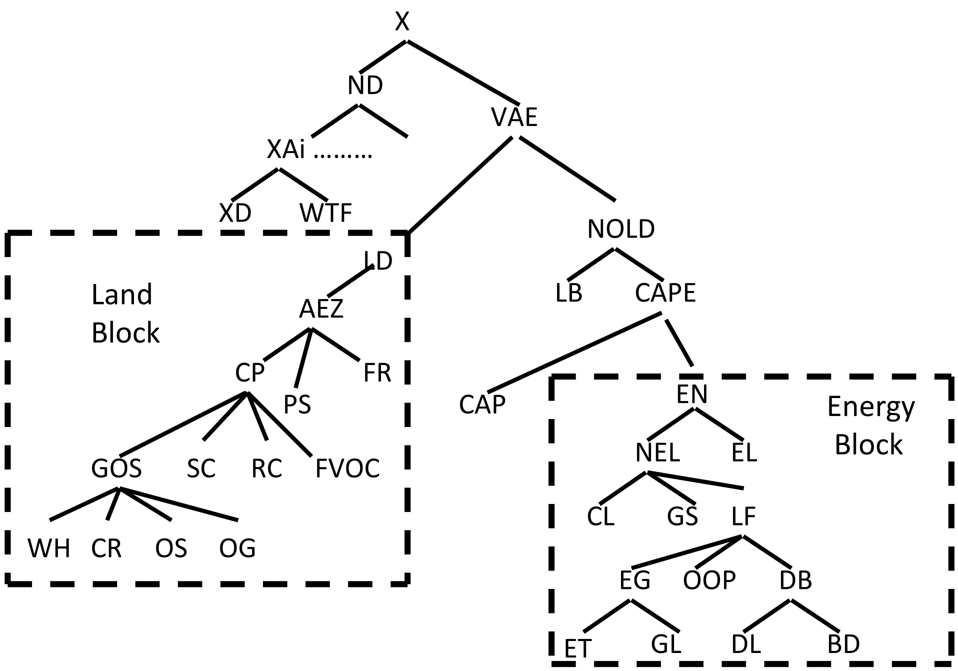
Source: IEA (2012).

Figure 3: Countries that contributed 90% of global CO_2 emissions in 2010



Note: Taiwan is not included in this figure as this is not a UN member.

Figure 4: Structure of the CGE model developed for the study



X – sectoral output; ND –aggregate non energy intermediate consumption; VAE – value added and energy composite; XA_i – consumption of non energy intermediate consumption of good and service i; XD and WTF - domestic and imported components of goods and services; AEZ- Agro-ecological zones; CP – crops; PS – pasture; FR- forest; GOS – grains and oil seeds; SC – sugar crops; RC- rice; FVOC – fruits , vegetables and other non-grain crops; WH – wheat; CR – corn; OS – oil seeds; OG- other grains; LB- labor; CAPE – capital and energy composite; NOLD – composite of LB and CAPE; CAP – capital; EN – energy aggregate; EL – electricity; NEL- non electric energy; CL –coal; GS – gas; LF- liquid fuel; EG – ethanol & gasoline composite; DB – diesel & biodiesel composite; OOP – other petroleum products; ET – ethanol; GL – gasoline; DL – diesel and BD – biodiesel.

Figure 5. Movement of per capita emission gap between Annex I and Non-Annex countries along with Annex I Countries' carbon tax rates

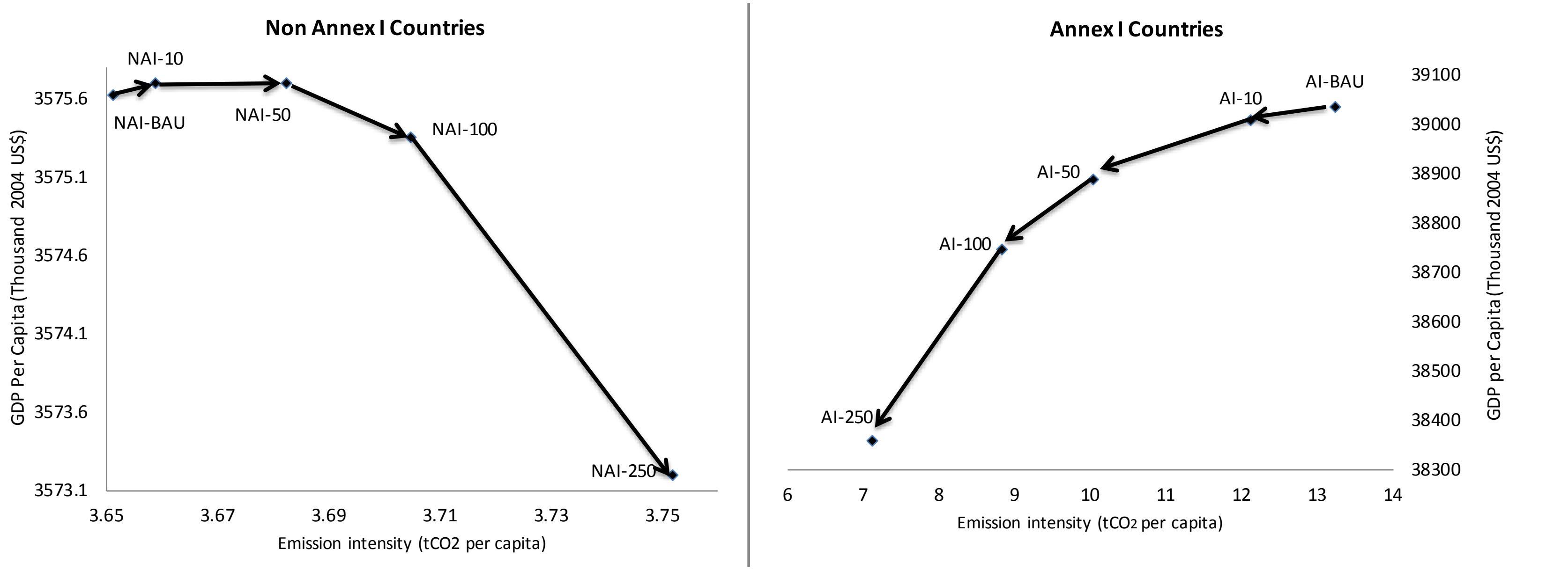


Figure 6: Impacts on Total CO_2 Emissions (percentage change from the baseline in 2030)

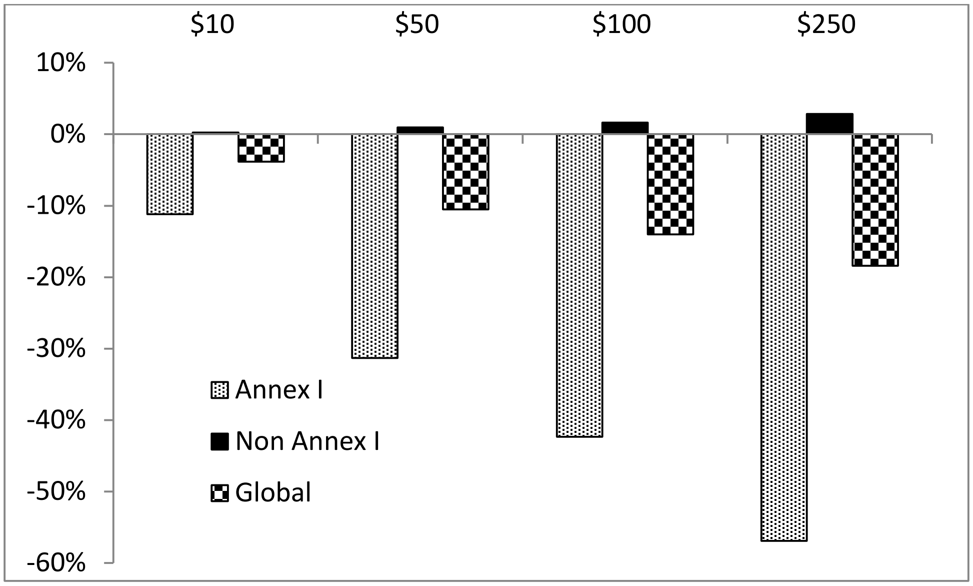


Figure 7: Impacts on GDP (percentage change from the baseline in 2030)

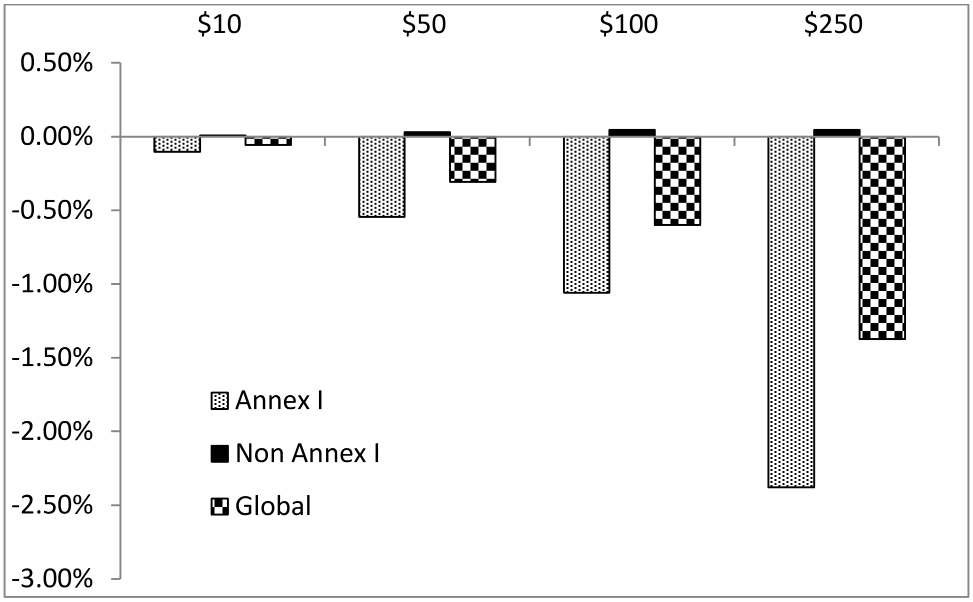


Figure 8: Impacts on international trade (percentage change from the baseline in 2030)

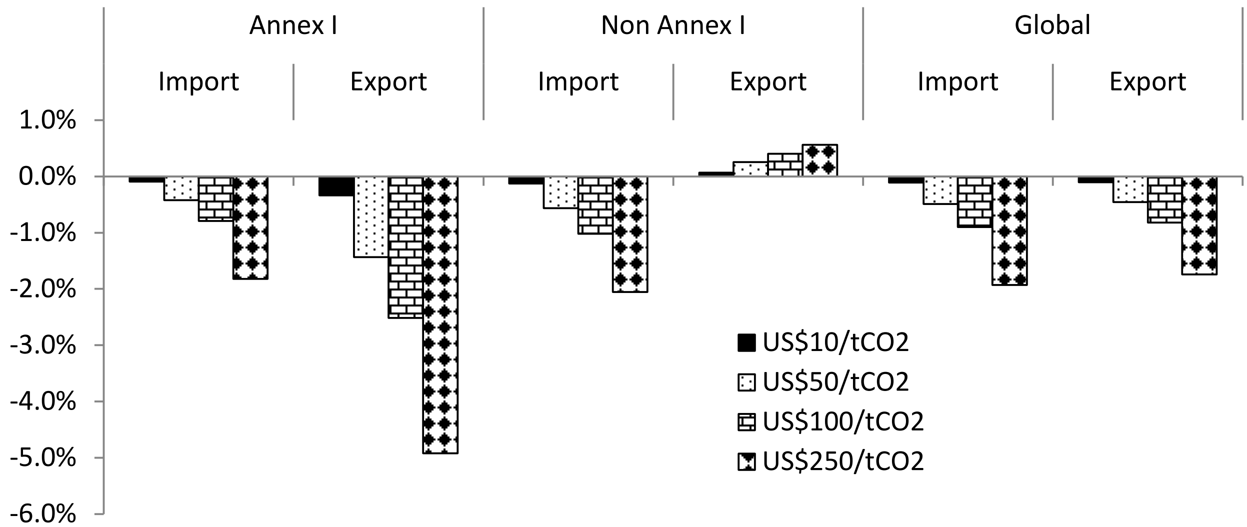


Table 1: Per capita emission in descending order in 2010 (tCO_2)

Country	Per capita emission
Countries with EI > 20 ton per capita	
Qatar	36.9
Kuwait	31.9
Trinidad Tobago	31.9
Luxembourg	21.0
Brunei Dar.	20.6
UAE	20.5
Countries with EI > between 10 and 20 ton per capita	
Bahrain	18.7
United States	17.3
Australia	17.0
Saudi Arabia	16.2
Canada	15.7
Oman	14.5
Kazakhstan	14.2
Estonia	13.8
Singapore	12.4
Finland	11.7
Korea Rep.	11.5
Netherlands	11.3
Russian Fed.	11.2
Czech Rep.	10.9
Turkmenistan	10.4
Countries with EI > between 7 and 10 ton per capita	
Belgium	9.8
Germany	9.3
Cyprus	9.0
Japan	9.0
Israel	8.9
Ireland	8.6
Denmark	8.5
Austria	8.3
Libya	8.1
Norway	8.0
Poland	8.0
United Kingdom	7.8
Slovenia	7.5
Greece	7.5
New Zealand	7.0
Countries with EI > between 5 and 7 ton per capita	
South Africa	6.9
Belarus	6.9
Iran	6.9
Italy	6.6
Malaysia	6.5
Slovak Rep.	6.4
Venezuela	6.3
Serbia	6.3
Iceland	6.0
Malta	6.0
Spain	5.8
Ukraine	5.8
Bulgaria	5.8
Switzerland	5.6
France	5.5
China	5.4
Bosnia & Herzg.	5.3
Sweden	5.1
Countries with EI > between 4 and 5 ton per capita	
Hungary	4.9
Portugal	4.5
Lebanon	4.4
Mongolia	4.3
Croatia	4.3
Argentina	4.2
Chile	4.1
Lithuania	4.0
Macedonia	4.0
Countries with EI > between 3 and 4 ton per capita	
Mexico	3.8
Turkey	3.6
Latvia	3.6
Thailand	3.6
Uzbekistan	3.6
Romania	3.5
Montenegro	3.3
Iraq	3.2
Jordan	3.1
Countries with EI > between 2 and 3 ton per capita	
Jamaica	2.9
Syria	2.8
Algeria	2.8
Azerbaijan	2.7
Cuba	2.7
North Korea	2.6
Panama	2.4
Botswana	2.3
Egypt	2.2
Ecuador	2.1
Tunisia	2.1
Brazil	2.0
Countries with EI > between 1 and 2 ton per capita	
Uruguay	1.9
Dom. Rep.	1.9
Gabon	1.8
Moldova	1.7
Indonesia	1.7
Vietnam	1.5
Namibia	1.5
Peru	1.4
Morocco	1.4
Bolivia	1.4
Costa Rica	1.4
India	1.4
Colombia	1.3
Armenia	1.3
Kyrgyzstan	1.3
Albania	1.2
Georgia	1.1
Honduras	1.0
Countries with EI > between 0.4 and 1 ton per capita	
El Salvador	0.9
Yemen	0.9
Angola	0.9
Philippines	0.8
Pakistan	0.8
Nicaragua	0.8
Paraguay	0.7
Zimbabwe	0.7
Guatemala	0.7
Sri Lanka	0.6
Benin	0.5
Senegal	0.4
Congo	0.4
Tajikistan	0.4
Ghana	0.4
Bangladesh	0.4
Countries with EI Less than 0.4 per capita	
Sudan	0.3
Côte d'Ivoire	0.3
Nigeria	0.3
Kenya	0.3
Cambodia	0.3
Cameroon	0.3
Haiti	0.2
Togo	0.2
Myanmar	0.2
Zambia	0.1
Tanzania	0.1
Nepal	0.1
Mozambique	0.1
Eritrea	0.1
Ethiopia	0.1
DR Congo	0.05

Source: OECD (2013)

Table 2: Change in CO_2 emissions per capita from the BAU case in 2030 (%)

	CO2 emission per capita				CO2 emission per GDP			
	Carbon tax rate (US$/$tCO_2$)							
	10	50	100	250	10	50	100	250
Australia & NZ	-14.9%	-36.0%	-46.2%	-58.7%	-14.8%	-35.6%	-45.5%	-57.6%
Canada	-9.4%	-26.7%	-36.6%	-50.8%	-9.3%	-26.2%	-35.7%	-49.2%
Germany	-6.4%	-21.1%	-30.5%	-43.8%	-6.4%	-21.0%	-30.2%	-43.2%
Spain	-4.2%	-15.2%	-23.6%	-37.5%	-4.2%	-15.0%	-23.2%	-36.7%
France	-2.9%	-10.8%	-17.3%	-29.4%	-2.9%	-10.7%	-17.1%	-29.0%
UK	-12.2%	-35.0%	-46.2%	-58.4%	-12.2%	-34.9%	-45.9%	-58.0%
Italy	-4.2%	-15.0%	-23.1%	-36.6%	-4.1%	-14.7%	-22.7%	-35.6%
Japan	-8.0%	-18.2%	-25.4%	-37.1%	-8.0%	-18.1%	-25.1%	-36.4%
EFTA & Rest of EU	-8.3%	-25.6%	-35.9%	-50.5%	-8.2%	-25.2%	-35.3%	-49.4%
United States	-10.8%	-31.6%	-43.1%	-57.8%	-10.7%	-31.3%	-42.5%	-56.9%
Non Annex I ECA	0.5%	1.9%	3.2%	4.7%	0.4%	1.8%	2.9%	4.3%
Argentina	0.1%	0.3%	0.6%	1.2%	0.1%	0.4%	0.7%	1.4%
Brazil	0.4%	1.6%	2.7%	4.9%	0.4%	1.6%	2.7%	5.0%
Rest of LAC	0.3%	1.2%	2.1%	4.1%	0.3%	1.3%	2.3%	4.6%
China	0.2%	0.8%	1.3%	2.5%	0.2%	0.6%	1.0%	1.9%
Indonesia	0.3%	1.2%	2.0%	3.7%	0.3%	1.2%	2.0%	3.5%
Rest of EAP	0.5%	1.8%	2.9%	5.0%	0.4%	1.6%	2.6%	4.4%
Malaysia	0.2%	0.8%	1.3%	2.4%	0.2%	0.9%	1.5%	2.9%
Thailand	0.3%	1.2%	2.1%	3.7%	0.3%	1.0%	1.8%	3.3%
India	0.2%	0.8%	1.2%	1.9%	0.2%	0.5%	0.8%	1.1%
Rest of South Asia	0.2%	0.8%	1.4%	2.7%	0.2%	0.7%	1.2%	2.3%
MENA	0.0%	0.2%	0.4%	1.0%	0.2%	1.1%	2.0%	4.0%
South Africa	0.7%	2.2%	2.9%	3.8%	0.8%	2.2%	2.9%	3.7%
Rest of SSA	0.2%	0.9%	1.7%	3.4%	0.3%	1.4%	2.6%	5.1%

NZ and EFTA stand for, respectively, New Zealand and European Free Trade Association; LAC, EAP, EAC, SSA and MENA refer to respectively, Latin America and Caribbean, East Asia and Pacific, Eastern Europe and Central Asia, Sub-Saharan Africa and Middle East and North Africa.

Table 3: Change in total CO_2 emissions at various levels of carbon tax in Annex I countries in 2030 from baselines (%)

Country/Regions	Carbon tax rate (US$/t$CO_2$)			
	10	50	100	250
Australia and New Zealand	-14.9%	-36.0%	-46.2%	-58.7%
Canada	-9.4%	-26.7%	-36.6%	-50.8%
Germany	-6.4%	-21.1%	-30.5%	-43.8%
Spain	-4.2%	-15.2%	-23.6%	-37.5%
France	-2.9%	-10.8%	-17.3%	-29.4%
UK	-12.2%	-35.0%	-46.2%	-58.4%
Italy	-4.2%	-15.0%	-23.1%	-36.6%
Japan	-8.0%	-18.2%	-25.4%	-37.1%
EFTA Countries & Rest of EU	-8.3%	-25.6%	-35.9%	-50.5%
United States	-10.8%	-31.6%	-43.1%	-57.8%
Non Annex I ECA	0.5%	1.9%	3.2%	4.7%
Argentina	0.1%	0.3%	0.6%	1.2%
Brazil	0.4%	1.6%	2.7%	4.9%
Rest of Latin America & Caribbean	0.3%	1.2%	2.1%	4.1%
China	0.2%	0.8%	1.3%	2.5%
Indonesia	0.3%	1.2%	2.0%	3.7%
Rest of East Asia & Pacific	0.5%	1.8%	2.9%	5.0%
Malaysia	0.2%	0.8%	1.3%	2.4%
Thailand	0.3%	1.2%	2.1%	3.7%
India	0.2%	0.8%	1.2%	1.9%
Rest of South Asia	0.2%	0.8%	1.4%	2.7%
Middle East & North Africa	0.0%	0.2%	0.4%	1.0%
South Africa	0.7%	2.2%	2.9%	3.8%
Rest of Sub-Saharan Africa	0.2%	0.9%	1.7%	3.4%

Table 4: Change in GDP at various levels of carbon tax in Annex I countries in 2030 from the baseline (%)

Country/Regions	Carbon tax rate (US$/$tCO_2$)			
	10	50	100	250
Australia and New Zealand	-0.2%	-0.7%	-1.2%	-2.6%
Canada	-0.1%	-0.7%	-1.3%	-3.1%
Germany	0.0%	-0.2%	-0.4%	-1.1%
Spain	0.0%	-0.3%	-0.6%	-1.4%
France	0.0%	-0.1%	-0.2%	-0.6%
UK	0.0%	-0.2%	-0.4%	-1.0%
Italy	-0.1%	-0.3%	-0.6%	-1.4%
Japan	0.0%	-0.2%	-0.5%	-1.1%
EFTA Countries & Rest of EU	-0.1%	-0.4%	-0.9%	-2.1%
United States	-0.1%	-0.5%	-1.0%	-2.1%
Non Annex I Europe & Central Asia	0.0%	0.2%	0.3%	0.4%
Argentina	0.0%	-0.1%	-0.1%	-0.2%
Brazil	0.0%	0.0%	0.0%	-0.1%
Rest of Latin America & Caribbean	0.0%	-0.1%	-0.2%	-0.5%
China	0.0%	0.2%	0.3%	0.6%
Indonesia	0.0%	0.0%	0.1%	0.2%
Rest of East Asia & Pacific	0.0%	0.2%	0.3%	0.5%
Malaysia	0.0%	-0.1%	-0.2%	-0.5%
Thailand	0.0%	0.2%	0.3%	0.4%
India	0.1%	0.3%	0.4%	0.8%
Rest of South Asia	0.0%	0.1%	0.2%	0.4%
Middle East & North Africa	-0.2%	-0.9%	-1.6%	-2.9%
South Africa	0.0%	0.0%	0.0%	0.0%
Rest of Sub-Saharan Africa	-0.1%	-0.5%	-0.8%	-1.6%

Table 5: Change in international trade at various levels of carbon tax in Annex I countries from the baseline in 2030

	Exports				Imports			
	Carbon tax rate (US$/t$CO_2$)							
	10	50	100	250	10	50	100	250
Australia and New Zealand	-0.4%	-1.5%	-2.6%	-5.1%	-0.1%	-0.5%	-0.9%	-1.7%
Canada	-0.2%	-1.1%	-2.0%	-4.1%	-0.2%	-1.1%	-2.0%	-4.4%
Germany	-0.2%	-0.7%	-1.2%	-2.5%	-0.1%	-0.2%	-0.5%	-1.1%
Spain	-0.3%	-1.4%	-2.4%	-4.8%	0.0%	-0.2%	-0.5%	-1.3%
France	-0.1%	-0.7%	-1.3%	-2.6%	0.0%	-0.1%	-0.3%	-0.7%
UK	-0.1%	-0.5%	-0.9%	-2.0%	-0.1%	-0.3%	-0.6%	-1.3%
Italy	-0.2%	-1.1%	-1.9%	-4.0%	-0.1%	-0.4%	-0.7%	-1.8%
Japan	-0.4%	-1.5%	-2.7%	-5.3%	0.0%	-0.2%	-0.4%	-1.1%
EFTA Countries & Rest of European Union	-0.2%	-1.0%	-1.9%	-4.1%	-0.1%	-0.6%	-1.1%	-2.6%
United States	-0.6%	-2.5%	-4.3%	-8.0%	0.0%	-0.1%	-0.2%	-0.6%
Non Annex I Europe & Central Asia	0.0%	0.0%	0.0%	-0.5%	-0.1%	-0.3%	-0.5%	-1.3%
Argentina	0.2%	0.9%	1.6%	2.8%	-0.2%	-0.8%	-1.3%	-2.5%
Brazil	0.1%	0.3%	0.4%	0.6%	-0.2%	-0.7%	-1.3%	-2.7%
Rest of Latin America & Caribbean	0.2%	1.0%	1.6%	2.9%	-0.2%	-1.0%	-1.8%	-3.3%
China	0.0%	0.1%	0.2%	0.2%	0.0%	0.0%	-0.1%	-0.4%
Indonesia	0.1%	0.6%	0.9%	1.6%	0.0%	0.1%	0.1%	0.0%
Rest of East Asia & Pacific	0.0%	0.1%	0.2%	0.0%	0.0%	0.1%	0.1%	0.0%
Malaysia	0.1%	0.2%	0.3%	0.4%	0.0%	-0.2%	-0.4%	-0.9%
Thailand	0.0%	0.1%	0.2%	0.1%	0.1%	0.1%	0.2%	-0.1%
India	0.0%	0.0%	-0.1%	-0.4%	0.0%	0.1%	0.1%	-0.2%
Rest of South Asia	0.1%	0.3%	0.4%	0.7%	0.1%	0.2%	0.2%	0.2%
Middle East & North Africa	0.5%	2.3%	4.0%	7.7%	-0.7%	-3.0%	-5.1%	-9.2%
South Africa	0.0%	-0.2%	-0.4%	-0.8%	-0.1%	-0.3%	-0.4%	-0.8%
Rest of Sub-Saharan Africa	0.2%	0.9%	1.5%	2.6%	-0.3%	-1.1%	-2.0%	-3.8%