# How Carbon Market Cooperation Changes the Energy Systems in Northeast Asia

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This paper explores the impact of international emissions trading (IET) among Korea, China, and Japan, three countries that would form the largest potential carbon market in the world. The Nationally Determined Contribution for each country forms the bases for scenario analyses using GCAM (Global Change Assessment Model). As expected, China emerges as the sole net seller of emissions permits while Korea and Japan are net purchasers of emission permits produced by China. All participants enjoy gains from emissions trading. The implementation of IET changes the power systems of Korea and Japan by favoring increased conventional fossil fuel usage over renewable power technologies or attached carbon capture and storage (CCS) technologies, while China's power system moves in the opposite direction, by boosting the deployment of renewables and CCS-attached technologies. Considering the counterproductive incentives for Korea and Japan to consume more carbon-intensive energy sources, each country should consider such issues carefully before officially adopting IET as the pillar of climate policy.

*Keywords:* Korea; China; Japan; International Emissions Trading (IET); Nationally Determined Contribution (NDC); Global Change Assessment Model (GCAM)

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# 1. Introduction

The global community has agreed to pursue efforts to limit the average global temperature increase to well below 2℃ under the 2015 Paris Agreement. As one of the three market-based mechanisms under the prior Kyoto Protocol (KP), emissions trading is a cost-effective policy measure for greenhouse gas (GHG) mitigation. In the KP, participating parties in emissions trading systems (ETSs) were countries that had reduction commitments (United Nations, 1998). As of 2018, through the submission of the Intended Nationally Determined Contributions (INDCs) and other channels, ninety-two countries announced their intention to utilize the International Market Mechanism (Ikeda and Hattori, 2019). Recognizing the importance of “cooperative approaches,” Article 6 of the Paris Agreement emphasizes the institutional framework for voluntary cross-border cooperation on global GHG mitigation efforts (United Nations, 2015). The intentionally broad interpretation of “cooperative approaches” under Article 6.1 envisaged all types of cooperation, including carbon markets (Marcu, 2016).

Since the European Union (EU) ETS initiation in 2005, members of the global community have started to implement ETSs for their economies, and the number of ETSs implemented has increased threefold over the last decade. Various jurisdictions are cooperating on carbon markets, either in the form of bilateral or multilateral linkages (ICAP, 2019). As of 2017, the carbon market size currently implemented or scheduled for implementation was 7 Gt $CO_2$e or 13 percent of global GHG emissions, and the 2016 annual value was about 50 billion dollars (World Bank *et al*., 2016). The size of the international carbon market initiative is expected to increase gradually as the number of jurisdictions that intend to introduce ETSs and their connections increases.

Linking compatible ETSs would be one of the cooperative $CO_2$ abatement methods to lower abatement costs by acquiring gains from emissions trading while achieving the same aggregate reduction in greenhouse gas emissions (Ranson and Stavins, 2016). When an individual country mandates $CO_2$ mitigation nationwide, $CO_2$ should be reduced domestically, regardless of the abatement cost. However, when ETSs are linked, the overall abatement cost can be reduced through emissions trading.

As a cost-effective GHG abatement policy instrument, emissions trading has also become increasingly important in the Northeast Asian region (including South Korea, China, and Japan). The three countries account for 20% of global GDP (USDA, 2016) and 33% of global $CO_2$ emissions (World Resources Institute, 2015). A growing body of research has examined various methods, roadmaps, or expected results of ETS linkage among the three countries (Ma *et al*., 2019, Asian Development Bank, 2016; Ewing, 2016; Ewing and Shin, 2017; Marcu and Sugathan, 2018; Kim *et al*., 2018). According to these studies, it is expected that there will be a tremendous market potential in a “Northeast Asian ETS” judging from the size of the integrated economies and emissions. Also, ETS links in Northeast Asia are expected to provide a stable permit price to reduce the abatement cost for all participating countries.

Some qualitative approaches present potential ETS linkage pathways and expected benefits in Northeast Asia. However, quantitative studies of ETS linkage in this region are difficult to find, albeit required by the region’s policymakers. This paper, therefore, explores the potential quantitative impacts of ETS linkage among the three Northeast Asian countries assuming Nationally Determined Contributions (NDCs) as their $CO_2$ emissions targets. This study estimates the potential size of the Northeast Asian carbon market, expected gains from emissions trading, and expected changes in the energy systems.

This paper organizes our discussions as follows. Section 2 summarizes a review of the literature review on global cost savings resulting from international cooperation and various ETS types by jurisdiction. Section 3 introduces the model used in this paper and explains the design of the scenario analysis. Section 4 presents the results for the carbon market, energy systems, and $CO_2$ emissions from various scenarios developed in this work according to the degree of ETS linkage: unlinked, partial-linked, and fully-linked. Finally, Section 5 presents conclusions, implications, and future research directions.

## 2. Literature Review

### 2.1. *Previous Studies*

Previous studies have shown that cooperative approaches for GHG reduction lower global GHG abatement costs. Various combinations of the burden-sharing assumption (per capita $CO_2$ emissions or a uniform reduction from base year emissions), long-term climate target (450 ppm $CO_2$e or 550 ppm $CO_2$e), target achievement year, and regional scope are taken into account for the scenario development for such analyses (Böhringer and Welsch, 2004; Clarke *et al*., 2009; Hof *et al*., 2012; Dellink *et al*., 2013; Kossoy *et al*., 2015; Fujimori *et al*., 2015). Power sector investment costs have been evaluated under a long-term cooperative mitigation target (Chaturvedi *et al*., 2014; Iyer *et al*., 2015). The role of ETS under long-term climate targets has been examined from an economic perspective (Qi and Weng, 2016) or a technical and economic perspective (Fujimori *et al*., 2016). Table 1 provides a summary of the literature on global cost savings from cooperative mitigation actions.

**Table 1 Literature Review on Global Cost Savings from International Cooperation**

| Source | Regional scope | Target year | Distribution of mitigation efforts across countries | Long-term climate target | Global cost savings from international cooperation (%) | Model |
|---|---|---|---|---|---|---|
| Hof *et al.* (2012) | Global, 26 regions | 2030 | Equal costs per GDP | 450 ppm $CO_2$e | 16% | PBL FAIR/IMAGE/TIMER model |
| | | | Per capita convergence | 450 ppm $CO_2$e | 32% | |
| Fujimori *et al.* (2015) | Global, 17 regions | 2050 | Per capita convergence | 450 ppm $CO_2$e | 16% | AIM/CGE Model |
| | | | Per GDP convergence | 550 ppm $CO_2$e | 35% | |
| Clarke *et al.* (2009) | Global, 10 regions | 2100 | Fragmented action | 450 ppm $CO_2$e and 550 ppm $CO_2$e | 33-67% | Comparison of ten models |
| Böhringer and Welsch (2004) | Global, 12 regions | 2050 | Per capita convergence | 25% below 1990 levels | 59% | CGE model |
| EBRD and GRI (2011) | Economies in transition | 2050 | Uniform: 80% below 2005 levels by all countries | 500 ppm $CO_2$e | 47% | WITCH |
| Dellink *et al.* (2013) | Annex I only | 2020 | Uniform: 20% below 1990 levels by all Annex I countries | n/a | 13% | Global recursive-dynamic computable general equilibrium (ENV-Linkages) |
| | | 2050 | Uniform: 50% below 1990 levels by all Annex I countries | n/a | 7% | |
| World Bank *et al.* (2016) | Global, 14 regions | 2030 | Equal per capita emissions (energy sector) | INDC consistent | 32% | TIAM-Grantham |
| | | 2050 | | 2°C-consistent | 54% | |
| Zhang *et al.* (2017) | Global, 19 regions | 2020 | Copenhagen level | n/a | Varies from region to region | CGE (C-GEM) |
| Qi and Weng (2016) | Global, 19 regions | 2030 | INDC level | n/a | Varies from region to region | CGE (C-GEM) |

## 2.2. *Status of Emissions Trading in Northeast Asia*

To facilitate the transition to a low-carbon community, the three Northeast Asian countries submitted their national emissions reduction target and implemented or planned to implement an emissions trading system in various jurisdictions. Table 2 presents the status of ETSs in Northeast Asia. It includes the jurisdictions involved, the share of ETS coverage to total $CO_2$ emissions, and the sectoral coverages.

In Northeast Asia, Japan was the first country to initiate emissions trading in Tokyo in 2010 and a linkage with the Saitama ETS in 2011. Through a series of discussions in 2012 and 2016, Japan decided that the domestic emissions trading scheme shall be considered carefully by evaluating the burden on industry (Ono, 2017). However, the reported long-term emissions abatement target of Japan beyond 2030 is to reduce 80% of its emissions by 2050 compared to 2005 (MOEJ, 2016). For Japan, it is necessary to consider additional emissions abatement measures for its economy to achieve this ambitious long-term emissions target. Among various barriers is the uncertainty in the utilization of cheaper emissions abatement options such as nuclear power expansion. This is directly related to enlarging abatement potential and lowering high domestic abatement cost in the Japanese economy, which already has implemented high-efficiency technologies in transformation and final energy service sectors. Even though the Japanese government is not actively pursuing a national ETS along with linkage to other countries, it could consider utilizing those policies strategically to enhance its national interest. Through several discussions, the Japanese government considered national ETS implementation, and research has provided support for it as a viable option under international permit utilization that links with China's ETS (Ewing, 2018).

Throughout the 12th and 13th Five Year Plans, the Chinese government implemented pilot ETSs (Government of China, 2016). Currently, seven pilot ETSs and two voluntary ETSs are implemented in China that will be merged into a national level ETS. China's national ETS is going to start formally in 2020 in the power sector first. Also, seven major sectors (petrochemicals, chemicals, building materials, iron and steel, nonferrous metals, paper making, power, and aviation) will be gradually included in the national ETS from 2021 to ensure the peaking of carbon emissions by 2030. For international cooperation, EU ETS, WCI,[1] New Zealand, Japan, and Korea are involved in ETS linkage discussion (ICAP, 2018a).

Korea manages most of its emissions through emissions trading while inducing low-carbonization through energy transformation in its economy. Moreover, a lack of further abatement potentials and a relatively high emissions reduction target impel Korea to actively pursue international carbon market cooperation. According to its emissions trading operation plan, Korea's international cooperation plan in ETS includes Korean-EU cooperation, Korea-China-Japan cooperation, and bilateral cooperation projects through official development assistance channels. The long-term commitment plan of Korea is to secure potential markets through expanding cooperation on linking ETSs with other countries, including China, Japan, and the EU (KEA, 2019).

In Northeast Asia, the three countries have pursued bilateral and trilateral environmental cooperation for more than two decades to resolve regional environmental issues. In 2015, Korea Exchange, the venue of emissions trading in Korea, and China Beijing Environment Exchange, a corporate domestic and international environmental equity public trading platform, signed a Memorandum of Understanding to cooperate on emissions trading development. ETS linkages among the three countries have attracted much attention, and the "Forum on Carbon Pricing Mechanism" was initiated in 2016. In this annual meeting participants share their carbon pricing experience and discuss the possibility of linking each country's ETS.[2]

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[1] WCI represents the Western Climate Initiative, Inc. in North America, including British Columbia, California, Ontario, Quebec, and Manitoba.

2 The first forum was held in Beijing, China in 2016 and the second was in Seoul, Korea (21-23, Dec. 2017).

**Table 2 ETS and Linkage Status by Jurisdiction in Northeast Asia**

| ETS Name* | Launch | Remarks | Permits Prices ($/tCO$_2$e) | | | | Coverage of ETS (Total, Sector)*** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2017 | 2018 | 2019 | **Avg. | % | P | I | B | T | A | W | F |
| Tokyo (J) | 2010 | Saitama and Tokyo linked | 13.6 | 5.7 | 6.0 | 8.4 | | | X | X | | | | |
| Saitama (J) | 2011 | | | | | | | | X | X | | | | |
| Beijing (C) | 2013 | All pilot ETSs are to be merged into the national ETS | 7.6 | 9.4 | n/a | 8.5 | 45 | X | X | X | X | | | |
| Shenzhen (C) | 2013 | | 5.5 | 6.7 | 2.1 | 4.8 | 40 | X | X | X | X | | | |
| Shanghai (C) | 2013 | | 4.7 | 6.2 | 4.5 | 5.1 | 57 | X | X | X | | X | | |
| Guangdong (C) | 2013 | | 1.9 | 2.3 | 2.9 | 2.4 | 60 | X | X | | | X | | |
| Tianjin (C) | 2013 | | 1.3 | 1.4 | 1.8 | 1.5 | 55 | X | X | | | | | |
| Chongqing (C) | 2014 | | 02. | 3.8 | 1.1 | 1.7 | 40 | X | X | | | | | |
| Hubei (C) | 2014 | | 1.8 | 2.3 | 4.5 | 2.9 | 35 | X | X | | | | | |
| Fujian (C) | 2016 | | 5.3 | 3.2 | 4.4 | 4.3 | 60 | X | X | | | X | | |
| Sichuan (C) | 2016 | First carbon exchange for national ETS | | | | | | | | | | | | |
| Korea | 2015 | ETS linkage talk since 2016 | $18.1^{\S}$ | $20.5^{\S}$ | $22.9^{\S}$ | 20.5 | 68 | X | X | X | X | X | X | |
| China | 2017 | | - | - | - | | n/a | X | | | | | | |
| Japan | under consideration | | - | - | - | | | | | | | | | |

Source: ICAP (2018a), World Bank *et al*. (2017), World Bank (2019)
Note: This table includes permits prices of Tokyo and Saitama Cap and Trade market, China's eight pilot ETSs, and Korean national ETS.
*Capital letter in parenthesis presents a province or city in county (J – Japan, C – China).
** Avg. presents simple arithmetic average of permits prices for three years.
***ETS market size that would be implemented or has been implemented (percentage to total market size). P, I, B, T, A, W, and F represent the Power, Industry, Building, Transportation, Aviation, Waste, and Forest sectors, respectively. § Permit prices obtained from World Bank (2019), as of February 2019.

Since 2017 the nominal carbon permit price level in Korea ETS has been around \$20/tCO$_2$e, which is less than the \$10/tCO$_2$e for China's pilot ETSs and Japan's Tokyo and Saitama integrated ETS. Due to various ETS design elements and different sectors covered, which causes differences among allocation methods applied, specific exemptions and compensation methods, carbon prices are not necessarily comparable between carbon pricing initiatives (World Bank, 2019). If it is found possible to link ETSs of different countries, it is essential to explore the expected impact of ETS linkage to develop the strategic utilization plan of IET market as an economic emissions abatement policy. This paper aims to ask and answer "what would be the impacts of ETS linkage in Northeast Asia?" which would have the largest integrated economy and emissions reduction potential in the world. To make our discussions clear, we focus on analyzing the impact of ETS linkage under the cap-and-trade method including all emission sectors in the economy.

## 3. Methodology

### 3.1. *Global Change Assessment Model (GCAM)*

This study utilizes GCAM, which is an integrated assessment model that links human and earth systems through the representation of socioeconomics, energy, agriculture, land use, and climate models. GCAM divides the world into several regions, and Korea, China, and Japan are categorized as separate regions. For each region, assumptions about population, labor productivity growth, and price and income elasticities are made, which drive the energy and agriculture sectors' final demand. Energy systems in this model are structured as processes of energy production, transformation, and consumption in final energy service sectors with detailed technology representation. Subsequently, a market clearing mechanism determines the whole markets' supply and demand as well as equilibrium prices (Edmonds and Reiley, 1985; Brenkert *et al*., 2003; Kim *et al*., 2006; Eom *et al*., 2012; Mishra *et al*., 2013).

This paper utilizes GCAM 4.0's technology database to construct the energy system. In a no-policy case, the model determines the least-cost method of satisfying the energy needs. In a policy case, energy needs can freely respond to changes in energy prices (Brenkert *et al*., 2003). Under the *ceteris paribus* condition, an introduction of a carbon policy causes changes in fuel prices, which are dependent on the carbon contents and the technology of the fuel employed. That also affects the cost competitiveness of the technology. GCAM determines the market share of a technology in a competitive market using a share equation formulated by technology cost in a logit choice model (Clarke and Edmonds, 1993).[3] Accordingly, the comparison of the no-policy case and policy case (or among policy cases) facilitates the assessment of the impacts of a specific policy on the whole energy system.

## 3.2. *Gains from ETS Linkage*

For the calculation of changes in social welfare through IET, income transfers among participating countries are not considered. For the measurement of gains from trade for each participating countries, however, changes in total abatement cost before and after the linkage (including expenditures for the purchase of the $CO_2$ permits) are required to be considered.

Figure 1 depicts the typical representation of the Marginal Abatement Cost Curve (MACC) for the "No Trade" case on the left and "Trade" case on the right between two countries, X and Y. In the "No Trade" case with domestic carbon cap of $a_X^u$ and $a_Y^u$ for country X and Y, respectively, shaded areas under the MACC up to the carbon cap represent the total carbon abatement costs for each country. The "Trade" case with carbon cap, on the right side of the panel, shows how to measure gains from emissions trading in the linked ETS case.

For a simple explanation, we denote $p^*$ as the equilibrium price of the tradable emission permit, while $a_X^*$ and $a_Y^*$ represent the levels of emission discharge of country X and Y after IET, respectively. In this example, country X imports permits while country Y exports them.

For permit-importing country X,

$\int_{a_X^*}^{a_X^u} MACCda_X$ : Avoided abatement cost for country X

$p^*(a_X^u - a_X^*)$ : Payment made for the purchase of emission permits by country X

it is easy to see that avoided abatement cost is bigger than payment made for the purchase of permits from Eq. (1):

$$\int_{a_X^*}^{a_X^u} MACCda_X > p^*(a_X^u - a_X^*) \qquad (1)$$

For permit-exporting country Y,

$p^*(a_Y^* - a_Y^u)$ : Revenue from the sales of emission permits by country Y

$\int_{a_Y^u}^{a_Y^*} MACCda_Y$ : Additional abatement cost for country Y

revenue from the sales of emission permits is bigger than additional abatement cost as shown in Eq. (2):

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[3] Muratori et al. (2017) presents the structure of technology cost with an example of power sector case.

$$p^*(a_Y^* - a_Y^u) > \int_{a_Y^u}^{a_Y^*} MACCda_Y \tag{2}$$

Therefore, gains from emissions trading for each country X and Y denoted as $G_X$ and $G_Y$, using Eq. (3) and (4), respectively, can be measured as follows:

$$G_X = \int_{a_X^*}^{a_X^u} MACCda_X - p^*(a_X^u - a_X^*)\,, \tag{3}$$

$$\begin{aligned} G_Y &= p^*(a_Y^* - a_Y^u) - \int_{a_Y^u}^{a_Y^*} MACCda_Y \\ &= \int_{a_Y^*}^{a_Y^u} MACCda_Y - p^*(a_Y^u - a_Y^*) \end{aligned} \tag{4}$$

In Eq. (3) and (4), gains from emissions trade can be further simplified for any country participating in IET as follows:

$$\begin{aligned} G &= \int_{a^*}^{a^u} MACCda - p^*(a^u - a^*) \\ &= \left( \int_0^{a^u} MACCda \right) - \left( \int_0^{a^*} MACCda \right) - p^*(a^u - a^*) \end{aligned},$$

Three terms found on the right-side of the equation above implies total abatement cost (TAC) before IET applies, TAC after IET applies and capital outflow for the purchase of emissions permit (CF). Total abatement cost before IET applies can be denoted as $TAC^u$. TAC and capital outflow after IET applies can be denoted as $TAC^a$ and $CF^a$, respectively, $a$ noting alternative IET scenario.

Then, above equation is presented as following:

$$G^a = TAC^u - TAC^a - CF^a \tag{5}$$

The size of the gains from emissions trading via market linkage depends on the size of reduction target, and the gap between marginal abatement cost (MAC) of each participating country before ETS linkage. Graphs at the bottom of Figure 1 illustrate the case with a bigger gap between MAC before trade with the size of target emission reduction unchanged.

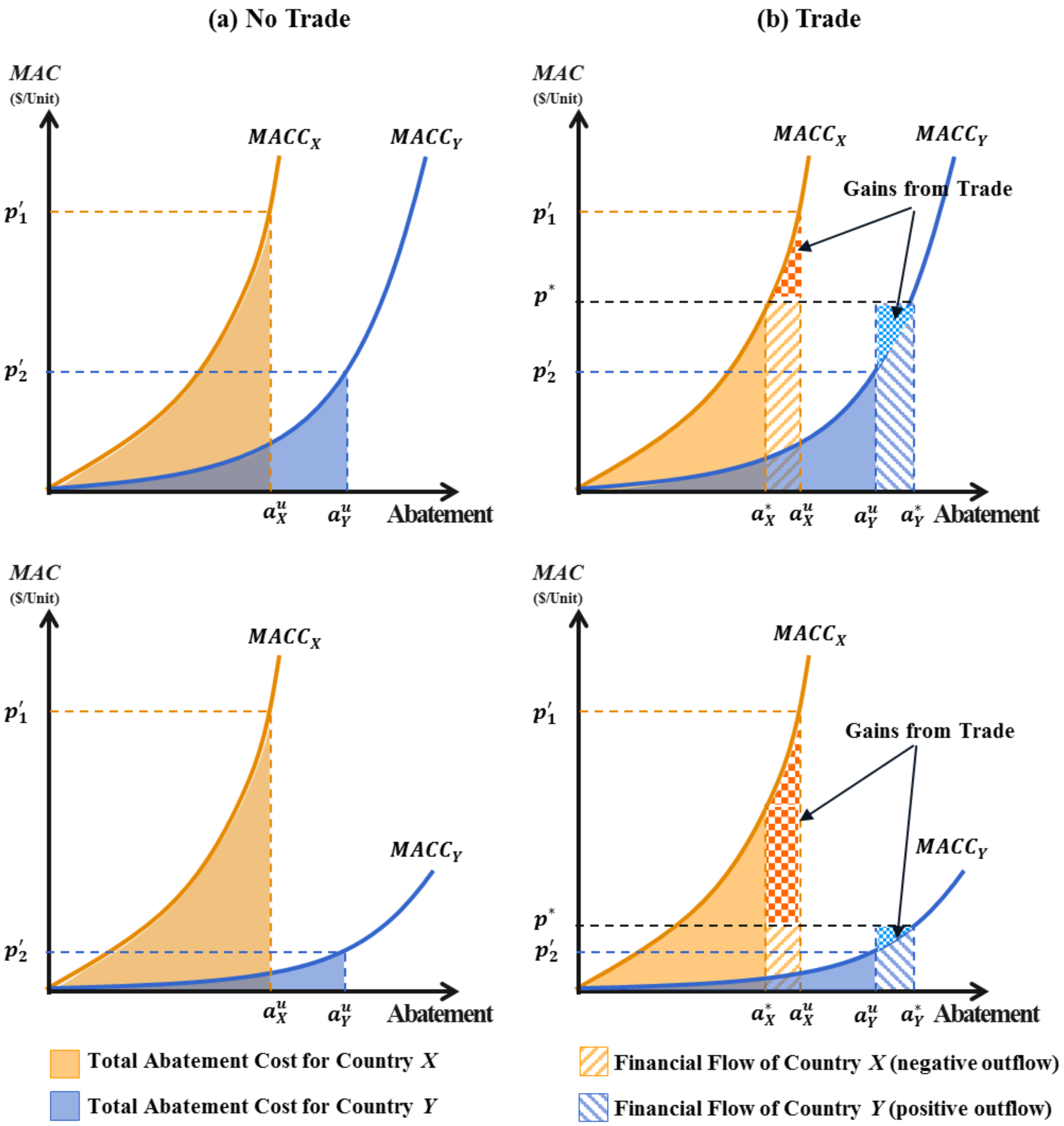

**Figure 1 Gains from Emissions Trading between Two Countries (Steeper vs. Flatter MAC)**
Source: Modified based on Ellerman and Decaux (1998) and Lépissier *et al*. (2015)

Let $STAC^a$ be defined as $STAC^a = TAC^u - TAC^a = \int_{a^*}^{a^u} MACC da$, and it can be seen that $STAC^a$ will be positive for country X and negative for country Y in the above figure. Rectangular areas below $P^*$ and in between $a^*$ and $a^u$ on the right hand side of the figure above show the size of capital flows for the purchase of emissions permits. Now let $CF^a$ and $G^a$ represent capital outflow for CO$_2$ permits import, and gains from emissions trading under scenario $a$, respectively. Comparing the area for $TAC^u$ on the left side of figure 1 with the same area on the right, following relationship is seen to hold for country X and Y:

For country X, $TAC^u = TAC^a + G^a + CF^a$ holds. For country Y, $TAC^a = TAC^u - G^a - CF^a$ holds, since capital inflow to this country after IET is noted as $-CF^a$ and gains from trade $G^a$ should be subtracted from this rectangular area to properly represent the area underneath MAC up to $a_Y^*$ as $TAC^a$.

For both cases, following relationship holds:

$$TAC^u - G^a = TAC^a + CF^a ,$$

If net abatement cost after IET is defined as reduced total abatement cost after IET application, it can be defined as $TAC^u - G^a$, implying reduced total abatement cost by gains from emissions trading.

Therefore, net abatement cost after IET noted as $NAC^a$ shows following relationship:

$$NAC^a = TAC^u - G^a = TAC^a + CF^a \tag{6}$$

Discussions above can be shown to be consistent with Eq. (5).

$$\begin{aligned} G^a &= TAC^u - TAC^a - CF^a = STAC^u - CF^a \\ &= TAC^u - \left(TAC^a + CF^a\right) \\ &= TAC^u - NAC^a \end{aligned} \tag{7}$$

Using subscript $i$ to denote participating country, Eq. (9) shows the relationship from the whole region's perspective.

$$\begin{aligned} TAC_i^u &= NAC_i^a + G_i^a \\ &= \left(TAC_i^a + CF_i^a\right) + G_i^a \end{aligned} \tag{8}$$

$$\begin{aligned} \sum_i G_i^a &= \sum_i TAC_i^u - \sum_i NAC_i^a \\ &= \sum_i TAC_i^u - \sum_i \left(TAC_i^a + CF_i^a\right) \\ &= \sum_i \left(TAC_i^u - TAC_i^a\right) - \sum_i CF_i^a \\ &= \sum_i STAC_i^a \end{aligned} \tag{9}$$

It is obvious to note that the sum of the region's capital outflows will be zero, or $\sum_i CF_i^a = 0$.

Eq. (9) implies that aggregated gains from emissions trading of all participating countries is the same as the sum of the differences between each country's total abatement cost before ETS and the other alternative ETS. However, the difference between the total abatement cost and net abatement cost after ETS for each country will not be the same if capital outflow is not zero. Various measures discussed above such as $G$, $TAC$, $STAC$, $CF$ and $NAC$ will be presented for each case of alternative IET scenario and shown to be consistent with the equations given above.

### 3.3. *Economic Growth and Emissions Abatement Pathway*

In this paper, socioeconomic pathway, historical emissions, and reduction target presented in INDC are considered for scenario building for further analysis. For Korea and Japan, nuclear power plans are also considered to reflect each country's policy.[4]

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[4] Even though nuclear power is a significant emissions mitigation source for both Korea and Japan, the public acceptance of nuclear power has decreased after the Fukushima Daiichi nuclear accident in 2011. For this reason, nuclear power capacity is assumed to be fixed according to construction plans proposed by each government as of 2017 (WNA, 2017). The lifespan of

Figure 2 summarizes three countries' historical trends and future pathways of GDP and emissions. Solid blue lines show the historical relationship between GDP (World Bank, 2017b) and emissions (World Bank, 2017a). Future GDP projection is made based on GDP growth rate reported in OECD's forecast (OECD, 2014). The GDP growth rates assumed in this paper reflect a slowdown of economic growth, with annual growth rates of around 4% for China, 2% for Korea, and 1% for Japan by 2030. The data referenced in Figure 2 yield the initial GCAM simulation's results with $CO_2$ emissions. In this case, economic pathway and nuclear power policy assumptions are utilized as inputs. Table 3 summarizes the reference $CO_2$ emissions pathways.

**Table 3 Economic Pathway and Reference $CO_2$ Emissions**

| Year | GDP (Growth Rate, %) | | | Reference Emissions ($CO_2$ Only, $MtCO_2$) | | |
|---|---|---|---|---|---|---|
| | China | Korea | Japan | China | Korea | Japan |
| 2015 | 16,597 | 1,267 | 5,986 | 10,268.3 | 649.5 | 1,117.6 |
| 2020 | 22,057(5.7) | 1,493(3.3) | 6,223(0.8) | 11,356.4 | 676.9 | 1,153.1 |
| 2025 | 27,386(4.3) | 1,717(2.8) | 6,586(1.1) | 12,260.4 | 720.1 | 1,160.8 |
| 2030 | 32,766(3.6) | 1,930(2.3) | 7,031(1.3) | 12,862.0 | 752.9 | 1,202.2 |

Note: the GDP growth rates in parenthesis are based on the OECD (2014) in billions of 2010 constant dollars

Red lines in Figure 2 show future emission target reported in each country's INDC. It also presents the emissions management pathway to be achieved through domestic mitigation efforts alone.

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nuclear power plants is also assumed fixed to its design lifetime. Nuclear power plants, therefore, will be phased out sequentially in our scenario after each unit's design lifetime is over for Korea and Japan.

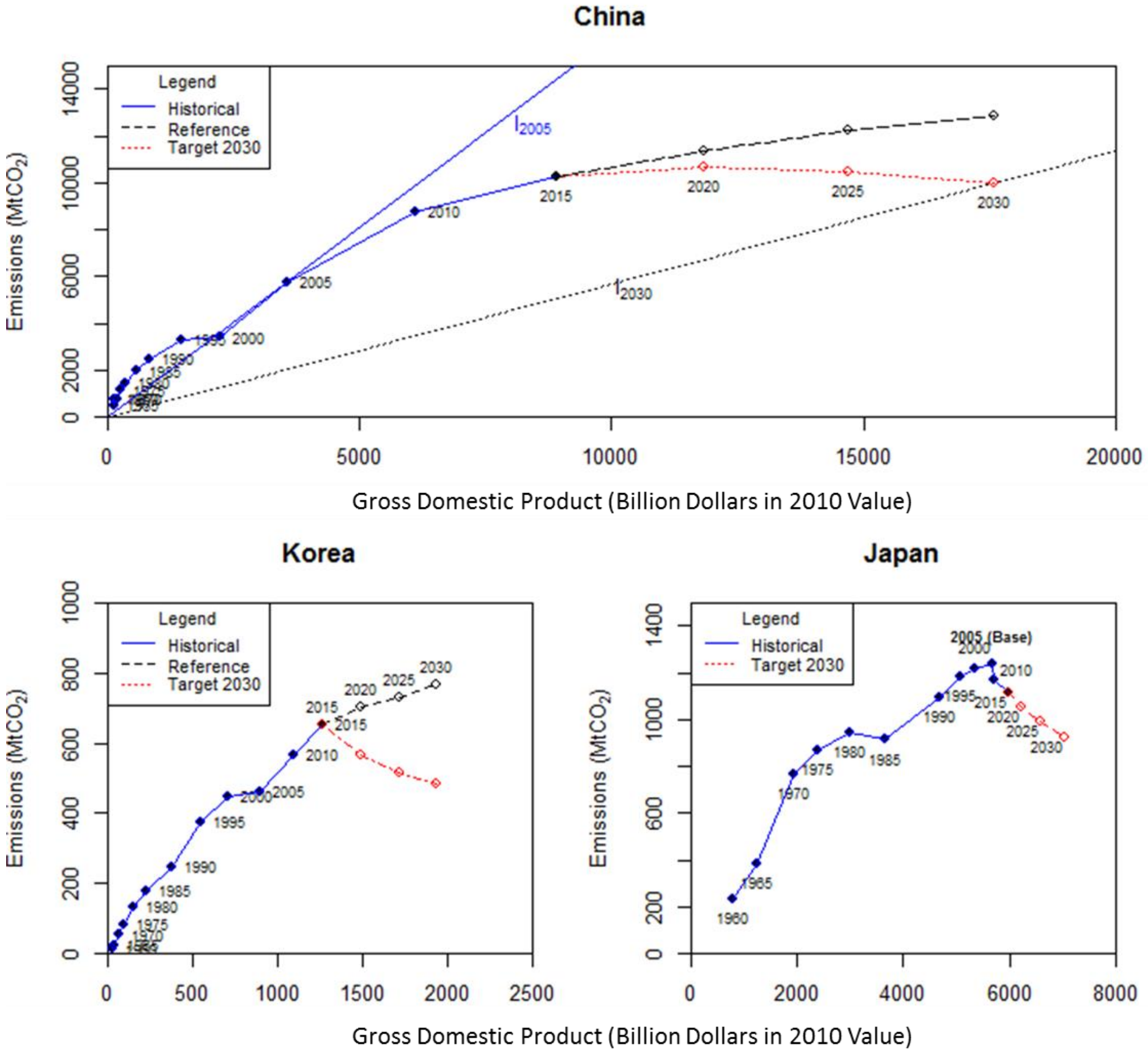

**Figure 2 The Historical and Long-term Pathway of GDP and Emissions**

Source: Historical emissions – World Bank (2017a), GDP - World Bank (2017b), GDP Growth Rate - OECD (2014), Long-term emissions target by country - Government of China (2015); Government of Korea (2015); Government of Japan (2015), non-$CO_2$ share of Korea – World Resource Institute (2015), the share of carbon credits utilization - Government of Korea (2015a).

For the long-term emissions pathway, we take emissions management targets reported in the INDCs for each country, although each country expressed its mitigation target somewhat differently. In the case of China, it provided its mitigation target in terms of $CO_2$ emission per unit of GDP (or $CO_2$ intensity). According to the INDC of China, a 65% improvement of $CO_2$ per unit of GDP from the 2005 level is the target by 2030 (Government of China, 2015).

Let $CO_2$ emission per unit of GDP be noted as $I_t = CO_{2_t} / GDP_t$. The differentiation of the equation with respect to time after taking logarithms yields the following Eq. (10):

$$\dot{I} = \dot{CO}_2 - G\dot{D}P \qquad (10)$$

where, $\dot{I}$, $\dot{CO}_2$, and $G\dot{D}P$ are $\frac{\partial I}{\partial t} / I$, $\frac{\partial CO_2}{\partial t} / CO_2$ and $\frac{\partial GDP}{\partial t} / GDP$, respectively.

That is, $CO_2$ intensity can be improved either by decreasing $CO_2$ emissions or by achieving faster GDP growth relative to $CO_2$ emissions growth. According to historical GDP and emissions trends of China, $CO_2$ intensity in 2005 was 1.622 $tCO_2$/\$1000, and its target of 65% improved $CO_2$ intensity in 2030 would be 0.568 $tCO_2$/\$1000.

For Japan, it is relatively simple to identify its emissions pathway since its mitigation target is provided in terms of absolute emissions reduction. The INDC emissions target is a 25.4% reduction from the 2005 emissions level by 2030 (Government of Japan, 2015), and 80% reduction by 2050 is the longer term target (MOEJ, 2016). According to historical data, $CO_2$ emission in 2005 was 1,239 $MtCO_2$, and the emission target by 2030 becomes 924.3 $MtCO_2$.

The Korean government proposed "to reduce its greenhouse gas emissions by 37% from the business-as-usual (BAU, 850.6 $MtCO_2eq$) level by 2030 across all economic sectors." Also, it plans to "partly use carbon credits from international market mechanisms to achieve its 2030 mitigation target, in accordance with relevant rules and standards" (Government of Korea, 2015b). On the same day of INDC submission to the United Nations Framework Convention on Climate Change, the Korean government publicly announced that 11.3% of the BAU emissions reduction would be achieved through an International Market Mechanism (IMM) by 2030 (Government of Korea, 2015a). In Figure 2, the BAU emissions forecast is presented as the reference case based on $CO_2$ emissions quantity.

### 3.4. *Carbon Market Linkage Scenarios*

This section describes the ETS linkage scenario-building in the three Northeast Asian countries. Li and Zhang (2018) present various combinations regarding the conceptual design of ETS linkage among these three countries. They describe the structure of unilateral, cross-regional, chained-bilateral, and full multilateral linkage cases assuming the launch of Japan's national ETS. As Korea plans to utilize international emission permits, the partial linkage should be considered as an additional dimension of ETS linkage. Figure 3 presents ETS linkage scenarios explored in this paper that have emission targets based on each country's NDC. From left to right, it shows the unlinked carbon markets (uETS) case, partial-linked carbon markets (pETS) case, and (fully-linked) regional carbon market (rETS) case. Even though the aggregated emissions target for all countries is the same for each scenario, market conditions are different based on the type of cooperation. For the uETS case, the three countries have three independent domestic ETSs. In pETS case, the three countries construct two carbon markets. One is a unified carbon market of Korea, China and Japan with the predetermined international permits demand by Korea, and the other is the Korea domestic carbon market. This scenario simulates the Korean government's decision to mitigate 25.7% of GHG domestically and 11.3% of GHG through IMM. In this case, Korea will face two different equilibrium carbon prices. In rETS case, the three countries formulate one unified carbon market. As indicated, all three different types of ETS linkages are presented in Figure 3, with uETS on the left, pETS in the middle, and rETS on the right.

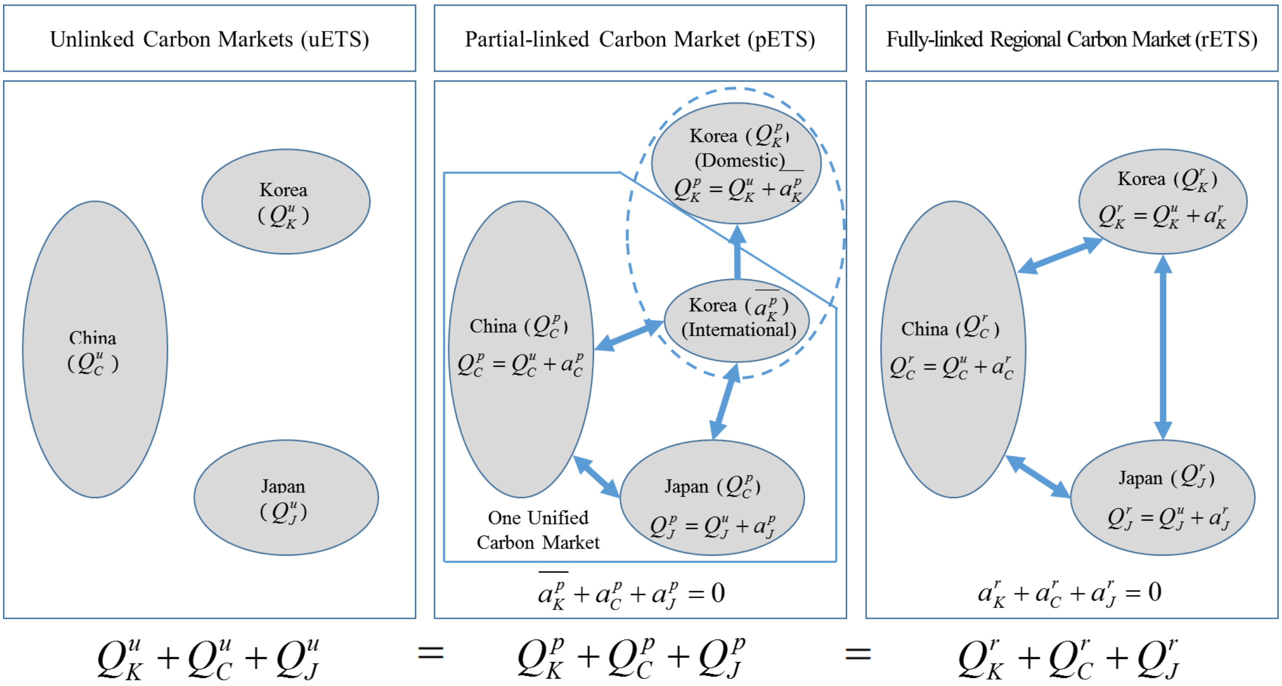

**Figure 3 ETS Linkage Scenarios Representation**

In Figure 3, $Q_i^j$ represents each country's emissions after ETS applies, where $i$ denotes countries (K for Korea, C for China, and J for Japan) and $j$ denotes types of ETS linkage ($u$ for unlinked, $p$ for partially linked, and $r$ for fully-linked regional ETS). For all ETS types, it is easy to show that total emissions in the three Northeast Asian countries after ETS application must be the same. This is presented as Eq. (11):

$$\sum_{i \in \{K,C,J\}} Q_i^u = \sum_{i \in \{K,C,J\}} Q_i^p = \sum_{i \in \{K,C,J\}} Q_i^r \qquad (11)$$

Let $a_i^p$ and $a_i^r$ represent the quantity of emissions permit supplied at pETS and rETS, respectively. It is easy to $a_i^r$ show that $a_i^p = Q_i^p - Q_i^u$ and $a_i^r = Q_i^r - Q_i^u$. Then it can be shown that $\sum_{i \in \{K,C,J\}} a_i^p = \sum_{i \in \{K,C,J\}} a_i^r = 0$ holds from Eq. (11). When $a_i^p$ or $a_i^r$ is negative, country $i$ will abate more emissions after ETS applies, implying that $i$ country becomes a supplier of emissions permits. If it is positive, country $i$ will demand emissions permits. One additional thing to note is that $\overline{a_K^p} = Q_K^p - Q_K^u$ is a predetermined quantity of emissions permits demanded by Korea, which equals the absolute value of $a_C^p + a_J^p$.

Table 4 displays the emission quantities according to market linkage scenarios for the period 2020-2030. Consistent with the equations featured at the bottom of Figure 3, the aggregate emission of the three countries is the same in each scenario. Moreover, each scenario is also commensurate with the attainment of each country's emission abatement targets.

Table 4 Emissions Market Linkage Scenarios (Unit: $MtCO_2$)

| Year | uETS Emissions | | | | pETS Emissions | | | | rETS Emissions |
|---|---|---|---|---|---|---|---|---|---|
| | China ( $Q_C^u$ ) | Korea ( $Q_K^u$ ) | Japan ( $Q_J^u$ ) | Total | Korea ( $Q_K^p = Q_K^u + \overline{a_K^p}$ ) | Pred* ( $\overline{a_K^p}$ ) | China and Japan Unified ( $Q_C^p + Q_J^p - \overline{a_K^p}$ ) | Total | Total (All unified) |
| 2020 | 10,660.6 | 563.4 | 1,053.4 | 12,277.4 | 651.8 | 88.4 | 11,625.6 | 12,277.4 | 12,277.4 |
| 2025 | 10,502.8 | 521.0 | 991.4 | 12,015.2 | 612.6 | 91.5 | 11,402.7 | 12,015.3 | 12,015.2 |
| 2030 | 9,971.5 | 482.3 | 927.0 | 11,380.7 | 578.4 | 96.1 | 10,802.4 | 11,380.8 | 11,380.7 |

Note: Pred* presents Predetermined permits demand of Korea

## 4. Results and Discussions

### 4.1. *Carbon Market and Trade*

Even though individual country emission abatement targets (as well as the aggregated emissions abatement target) are reached in each scenario, the details of scenario results vary depending on the type of carbon market linkage. This section outlines scenario results, including equilibrium $CO_2$ price, tradable emissions permits, and costs and potential benefits from the introduction of different ETS types. The results are presented by comparing the outcomes of the uETS scenario with the pETS and rETS scenarios.

Figure 4 summarizes the three scenarios' ETS market outcomes to facilitate ease of understanding. Figures in the diagram represent scenario results for the year 2030. All the numbers in green and green circles in this figure represent uETS results prepared for comparison with other scenarios (with one exception marked *** as explained in the figure's note). Numbers in purple represent the results of the pETS and rETS scenarios. Curved arrows attached to letters represent the $CO_2$ permit price change, while straight arrows represent emission permits movement from one country to another. Numbers in the purple circles represent the quantity (in $MtCO_2$) of emissions permits. Solid arrows show the tradable permits flow (in terms of $MtCO_2$) from China to Korea and Japan, while the dotted arrows show the capital outflows[5] in return from Korea and Japan to China (valued in terms of constant 2010 dollars). Finally, the light blue cylinders represent the gains from emissions trading. Larger circles (and cylinders) represent a larger quantity of emissions or permits traded (and size of the gains from emissions trading).

The uETS simulation results show how each country's emission target is achieved. Domestic emissions targets for China (9,971.5 $MtCO_2$), Korea (482.3 $MtCO_2$) and Japan (927.0 $MtCO_2$) are achieved without any international cooperation. It should be noted that large differences in domestic emission prices among the three countries exist: China ($28.8 per $tCO_2$), Korea ($73.1) and Japan ($35.9).

The pETS market has a predetermined constraint of 11.3% of 2030 BAU emissions of Korea, or 96 $MtCO_2$, that the Korean government decided to procure from IMM. Even if the pETS type is allowed in Northeast Asian ETS, Korea still needs to have its own domestic ETS and there is no guarantee that these two markets will generate the same equilibrium prices. Indeed, the simulation results show that the Korean domestic equilibrium emission price ($47.6/ $tCO_2$) becomes much lower than that of the uETS case ($73.1/ $tCO_2$) since the domestic emission reduction target now becomes around 30% lower than before due to this 96$MtCO_2$. At the same time, the pETS equilibrium price in the international market ($30.1/ $tCO_2$) is even lower than Korean domestic equilibrium emission price. Emissions discharge by China, Korea and Japan are (9,971.5 – 140) $MtCO_2$, (482.3 + 96) $MtCO_2$ and (927.0 + 44) $MtCO_2$, respectively. That is, emission permits supplied by China, Korea and Japan are (140) $MtCO_2$, (-96) $MtCO_2$ and (-44) $MtCO_2$, respectively.

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[5] Instead of denoting this as a cash flow or transfer income, it is denoted as capital outflow following Asian Development Bank (2016).

The rETS with no such constraint as pETS exhibits an equilibrium permits price of $\$30.7/\text{tCO}_2$, which is just a little bit higher equilibrium price than that of pETS, or $\$30.1/\text{tCO}_2$. Emissions discharge by China, Korea and Japan are (9,971.5 – 185) MtCO$_2$, (482.3 + 144) MtCO$_2$ and (927.0+41) MtCO$_2$, respectively. That is, emission permits supplied by China, Korea and Japan are (185) MtCO$_2$, (-144) MtCO$_2$ and (-41) MtCO$_2$, respectively.

When ETS market types are considered, it can easily be seen that several important issues are expected. In the uETS case, there will be three different domestic carbon markets; therefore, it is natural to have three different emissions equilibrium prices. For rETS, there will be a single equilibrium price since there is one internationally linked market. For the partially linked market or pETS in this study, there are two markets created with the quantity of Korean participation in IET arbitrarily determined.

When rETS and uETS are compared, only a mere 6.4% increase in the emissions price is expected for China, while a 58.0% and a 14.5% decrease is expected for Korea and Japan, respectively. In this process of equilibrium emissions price change, China reduces its emissions by an additional 185 MtCO$_2$ and creates the same amount of tradable emission permits, while Korea and Japan purchase 144 MtCO$_2$ and 41 MtCO$_2$ from China at the equilibrium price of $\$30.7/\text{tCO}_2$, respectively. The dollar value of purchases is equivalent to $\$4.42$ billion and $\$1.27$ billion for Korea and Japan, respectively. Thus, China's revenue is $\$5.69$ billion.

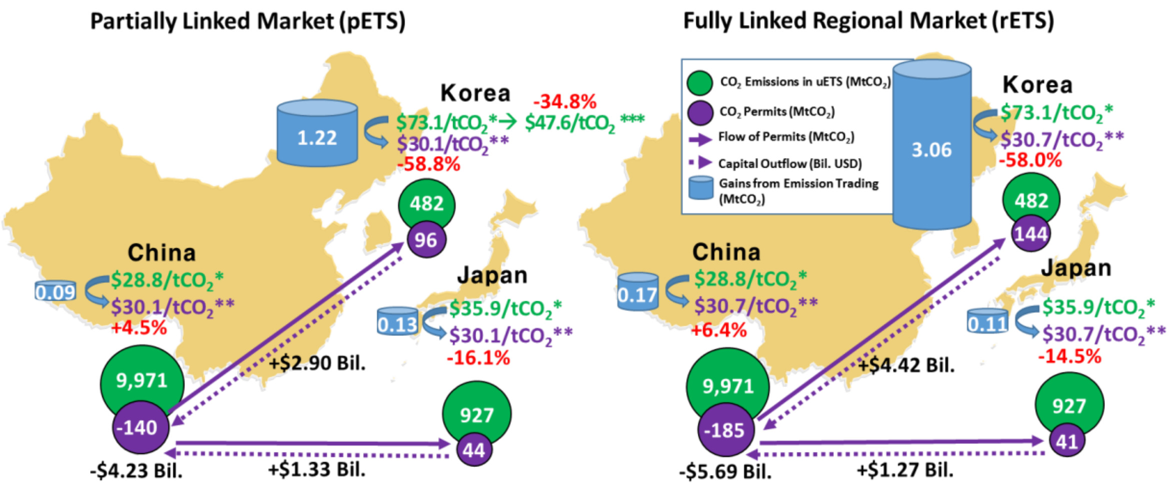


**Figure 4 Northeast Asian Emissions Trading Market Status Expected in 2030**

Note: * indicates equilibrium emission prices for uETS. ** indicates equilibrium emission prices for pETS on the left side of the figure and that of rETS on the right. *** is Korea's domestic equilibrium emission price for pETS. The quantities of emissions and permits are rounded up to first decimal point.

Table 5 summarizes additional details regarding the alternative ETS schemes. In the following table, the above equation is confirmed numerically through scenario analysis results.

**Table 5 Cost of Abatement, Capital Flows, and Gains from Emission Trading in 2030 (2010 constant Billion USD).**

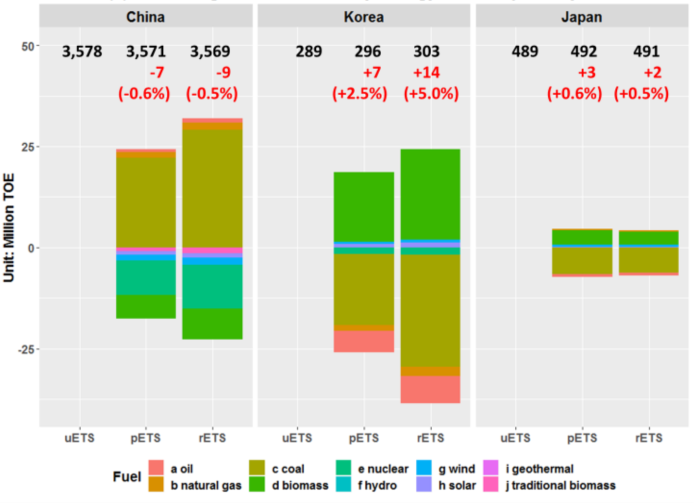
| Country | uETS | pETS | | | | | rETS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $TAC^u$ | $TAC^p$ | $STAC^p$ (%) | $CF^p$ | $G^p$ | $NAC^p$ | $TAC^r$ | $STAC^r$ (%) | $CF^r$ | $G^r$ | $NAC^r$ |
| China | 41.67 | 45.81 | -4.14<br>(-9.9) | **-4.23** | 0.09 | 41.58 | 47.19 | -5.52<br>(-13.2) | **-5.69** | 0.17 | 41.50 |
| Korea | 9.89 | 5.77 | 4.12<br>(41.7) | 2.90 | 1.22 | 8.67 | 2.41 | 7.48<br>(75.6) | 4.42 | 3.06 | 6.83 |
| Japan | 4.94 | 3.48 | 1.46<br>(29.6) | 1.33 | 0.13 | 4.81 | 3.56 | 1.38<br>(27.9) | 1.27 | 0.11 | 4.83 |
| Total | 56.50 | 55.06 | 1.44<br>(2.5) | 0.00 | 1.44 | 55.06 | 53.16 | 3.34<br>(5.9) | 0.0 | 3.34 | 53.16 |

Note: $TAC$, $STAC$, $CF$, $G$, and $NAC$ represent Total Abatement Cost, Savings in Total Abatement Cost, Capital Inflows, Gains from Emissions Trading, and the Net Abatement Cost, respectively. The subscripts $u, p, r$ represent uETS, pETS, and rETS, respectively.

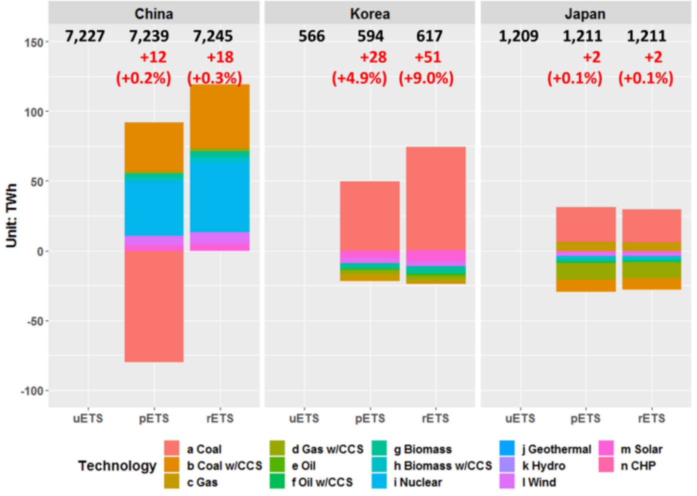
## 4.2. *Changes in Energy System*

ETS linkage transforms energy systems by causing fuel switching between fossil and low-carbon or non-fossil fuels**.** Figure 5 summarizes expected changes in total primary energy consumption (TPEC, Panel (a)) and total power generation (Panel (b)) after ETS linkage. Red letters in the figure denote net changes in TPEC or total power generation after ETS linkage as compared to uETS (with net changes also expressed in percentage terms).

China's TPEC associated with pETS and rETS decreases marginally overall, with fossil fuel energy consumption decreases outweighing the increase in low-carbon or non-fossil fuel consumption, while those changes are limited to -0.6% (-7.0 MTOE) with pETS and -0.5% (-9.0 MTOE) with rETS (compared to the uETS case). Even though China's TPEC decreases after ETS linkage, the country is expected to experience a slight increase in the power supply (0.2% for pETS (12.0 TWh) or 0.3% for rETS (18.0 TWh)). In the power sector, increases in power generation from low-carbon technologies (including CCS-attached, nuclear, and renewable technology) outweigh decreases in conventional fossil fuel power generation. This implies that IET will help China make its power system cleaner by substituting conventional power technologies with low-carbon technologies.



(a) Net Changes in Total Primary Energy Consumption by Fuel



(b) Net Changes in Total Power Generation by Technology

**Figure 5 Energy Sector Changes after ETS Linkage**

Note: Figures in parentheses present percentage change in total primary energy consumption or total power generation compared to those of uETS case. Upper and lower panels show net changes in total primary energy consumption and net changes in total power generation compared to uETS case.

Korea’s TPEC increases by 2.5% (7.0 MTOE) or 5% (14.0 MTOE) after pETS or rETS linkage, respectively. Due to the purchase of emission permits, the country can consume more fossil fuel. Power generation increased by 4.9% (28.0 TWh) in pETS and 9.0% (51.0 TWh) in rETS cases due to an increase in conventional fossil power generation coupled with decreased renewable and CCS-attached technologies. Since Japan utilizes a relatively smaller number of $CO_2$ permits compared to its $CO_2$ emissions in uETS, ETS linkage impact on TPEC and total power generation is limited. Japan’s TPEC and total power generation rise with internationally linked ETS with their impact less than 1% and around 0.1% for both pETS and rETS, respectively. However, it is noted here that net changes in Korea and Japan’s TPEC and power generation are different. From Figure 5, it is seen that Japan’s net change in power generation is around 1/5 of its net change in TPEC, while for Korea, its net change in power generation is about two times larger than its net change in TPEC.

Unlike China’s case, the import of permits lowers Korea and Japan’s marginal domestic $CO_2$ abatement costs and it, in turn, induces higher use of conventional fossil fuel power generation rather than low-carbon power generation. It indicates that this region’s international ETS linkage could slow down the speed of Korea and Japan’s power sector de-carbonization. It will be another very important issue to examine carefully before actual implementation of internationally linked ETS market.

## 5. Concluding Remarks

Emissions trading is an incentive-based, cost-effective policy option for greenhouse gas reduction. This article discusses the impact of ETS linkage for achieving the same aggregate $CO_2$ emissions target in Northeast Asia. The results indicate that ETS linkage reduces the abatement cost and provides gains from emissions trading for all participating countries. For a permit-exporting country, negative capital outflow is sufficient enough to compensate extra abatement cost. For a permit-importing country, the abatement cost savings through permit imports outweigh capital outflows required to purchase permits. The net abatement cost for linked ETS is lower than the unlinked case.

One important thing to note here is that the application of ETS is expected to affect the structure of the energy systems in all participating countries. For the permit-exporting country, the de-carbonization of the energy system is accelerated by the substitution of fossil fuels with low-carbon content fuels for primary energy consumption. In particular, the increase in low-carbon power generation exceeds the decrease in conventional coal power generation in China, indicating that it shifts to a low-carbon power system while satisfying electric power demand. On the other hand, the energy system of permit-importing country moves in the opposite direction of that of permit-exporting country, which means that the transition to a clean energy system would be hampered by losing opportunity to use low-carbon energy sources and clean power technologies. In this process, permit-importing countries could face a dilemma whether to construct a cleaner energy system at the higher cost or to get more economic benefit by the procurement of international emissions permits to reduce domestic emissions. The result from pETS scenario shows that there will be two different equilibrium prices - domestic carbon market price and that of international permits market. In this case, domestic permit price is much higher than that of international permit market. Two different market prices of emission permits in Korea would require additional measures for the allocation of permits. Economic benefits are also found to fall short of expectation due to this under-utilization of IET. These expected impacts, therefore, must be carefully examined before actual ETS is implemented as a policy option in permit-importing country.

Despite being a practical policy option to reduce abatement cost for all participating countries, it is expected that there would be many obstacles in actual implementation of international emissions trading in the future. To resolve the potential problems of ETS linkage, it is essential to have international joint research among participating countries by the construction of an expert network for capacity building and cooperation.

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