Expanding international GHG emissions trading: The role of Chinese and U.S. participation

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Abstract

Marked-based emission trading systems are a cost effective way to facilitate emissions abatement and are expected to play an essential role in international cooperation for global climate mitigation. Starting from the planned linkage of the European Union's Emissions Trading System with a new system in Australia in 2015, this paper simulates the impacts of extending this international emissions market to include China and the US, which are the largest and second largest CO_2 emitters in the world. We find that including China and the US will have significant impacts on the price and the quantity of permits traded internationally. In most scenarios considered, China exports emissions right while other regions import permits. When China joins the EU-Australia/New Zealand (EU-ANZ) linked market, the prevailing global carbon market price falls from \$33 per ton of carbon dioxide (tCO_2) to \$11.2/tCO_2, while adding the US to the EU-ANZ market increases the price \$46.1/tCO_2. If both China and the US join the linked market, the global price is \$17.5/tCO_2 and 608 million metric tons (mmt) are traded, compared to 93 mmt in the EU-ANZ scenario. The US and Australia would transfer, respectively, 55% and 78% of their domestic reduction burden to China (and a small amount to the EU) in return for a total transfer payment of \$10.6 billion. International trading of emissions permits also leads to a redistribution of renewable energy production. When there is permit trading between all regions considered, relative to when all carbon markets operate in insolation, renewable energy in China expands by more than 20% and shrinks by 48% and 90% in, respectively, the US and Australia-New Zealand. In all scenarios, global emissions are reduced by 5% relative to a case without climate policies.

Key words: Emissions Trading System (ETS); International Permit Trading; Computable General Equilibrium Modeling

1. Introduction

A single global market for greenhouse gas emissions is widely accepted as the most cost-effective path to climate change mitigation. As more nations establish national and regional emissions trading systems, interest has grown in the implications of linking these systems at the

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global level. So far, only a few markets for greenhouse gas emissions exist, and these exist at the sub-national level (e.g., California's cap-and-trade program), the national level (e.g. the New Zealand Emissions Trading System) or at the level of a single economic group (e.g. the EU Emissions Trading System, EU-ETS). Australia currently has a carbon tax, but is planning to establish an ETS that will link to the European Union as early as 2015 (Department of Climate Change and Energy Efficiency, 2011). Meanwhile, China is currently piloting ETS designs at the provincial level with an eye to establishing a trading market at the national level (Guoyi et al., 2012). Although the latest attempt to establish a national emission trading system in the US was shelved in 2009, several regional carbon markets have already been established (California Environmental Protection Agency, 2012; Lavelle, 2010; RGGI, 2013), which may accelerate the steps to a national market in the US. Although a multi-region agreement is yet to materialize, the potential benefits of linking emissions markets across countries and regions are well recognized (Marschinski et al., 2012). Furthermore, the prospects for linking carbon markets in developed and developing countries have been widely discussed and are seen as a way to encourage participation by developing countries in a global climate agreement (EU Commission, 2009; ICAP, 2007).

Ongoing efforts to link the EU-ETS with Australia's ETS represent the first attempt to establish an international emission market since the EU-ETS was established in 2005. There are also plans link the EU-ETS with California's carbon market (Felicity, 2011). Additionally, China has indicated that it would consider participating in an international carbon market, if plans to extend pilot programs to the nation level are successful (Guoyi et al., 2012; Environment News Service, 2013). The impact from linking carbon markets depends on the relative quantity of emissions in the two regions. For example, a linkage between the EU-ETS and a hypothetical ETS in the United States has a larger impact on the EU carbon price than the linkage between the EU-ETS and a hypothetical ETS in Mexico (Gavard et al., 2011). In the setting we consider here, the markets involved have very different emissions levels. Total CO_2 emissions due to the use of fossil fuels in Australia are around 383 million metric tons (mmt) in 2010, compared to 3860 mmt in the EU, 7258 mmt in China and 5762 mmt in the US (International Energy Agency, 2011). Consequently, linking the EU-ETS with a cap-trade program in China and the US is likely to have larger impacts on the EU permit price than linking this system with an ETS in Australia. This paper analyzes the impacts, including changes in carbon prices, emissions and welfare, of the proposed linkage of carbon markets in the EU and Australia, and the impact of China and the US joining this market.

Several benefits from establishing an international ETS are clear. Notably, a global market provides more flexibility for parties to achieve emissions reductions at the lowest marginal cost across all covered sectors and jurisdictions. However, the impact of global trading may not always be positive for all parties. For instance, market distortions or trade effects can affect the relative advantages to each country of participation (Babiker et al., 2004; Flachsland et al., 2009a). Other authors suggest that emissions trading regimes may alter (for the worse in some cases) the way that economic shocks are transmitted through international markets (McKibbin et al., 2008). Therefore, tailored studies that account for the nature of commitments and the structure of each participating economy are required to evaluate super-national climate proposals. For this analysis, we use a multi-regional computable general equilibrium (CGE) model. Such models are well suited to the task at hand, as they capture linkages between energy and economic systems and interactions among regions (Marschinski et al., 2012).

This paper has five further sections. Section 2 reviews the relevant literature and summarizes cap-and-trade programs in China, the United States, the EU, and Australia. The model and data used for the analysis are described in Section 3. Scenarios implemented in the model are described in Section 4 and results are presented in Section 5. The final section concludes.

2. Background

2.1 Literature review

Two strands of literature concerning linked carbon trading systems have emerged. One focuses on political and institutional barriers, and the other estimates the impacts of linked systems on economic outcomes and emissions. In the first category, Tuerk et al. (2009) evaluate the feasibility of establishing an OECD-wide carbon market by 2015 and concluded that it is a highly ambitious goal. A major barrier is that super-national ETS integration is not a short-term priority in many countries, and the benefits of such linkages may be offset by the cost of sacrificing other policy objectives, such as domestic CO_2 price control. Though some regions like the EU prioritizes the achievement of a defined reduction target, several regions wish to ensure that short-term carbon prices are not too high. The authors conclude that, it is more likely that carbon markets will begin to be linked in 2015 rather than a fully integrated OECD market operating by this date. The authors also suggest that carbon linkages will begin among countries or regions with strong existing trade ties before spreading elsewhere.

Flachsland et.al (2009) assesses the environmental effectiveness and political feasibility of top-down and bottom-up approaches to international carbon trading systems [1]. Challenges identified by the authors include the risk of changing emissions reduction commitments under political volatility, and the environmental impacts of individual commitments without global cooperation. Additionally, if participants in an integrated market determine their own emissions reduction targets, as is currently the case, international permit trading may reduce or neutralize environmental improvements. Such a situation will occur if member regions reduce their emissions targets to enable greater exports of permits. (Carbone et al., 2009; Flachsland et al., 2009a; Helm, 2003; Rehdanz and Tol, 2005) .

Most studies that investigate the impacts of international permit trading employ CGE frameworks. Babiker et al. (2004) use a CGE model to test the welfare impact from international

[1] In this literature, top-down and bottom-up approaches refer to two different pathways towards establishing an emission trading system. The top-down approach is characterized by a centralized multilateral decision-making process, as embodied in the UNFCCC negotiations, while the bottom-up approach is associated with decentralized decision-making of individual nations or sub-national entities that implement emission trading systems uni-, bi- or pluri-laterally.

emission trading. They find that, although international permit trading generally reduces the welfare costs of meeting emissions targets, trading can cause welfare losses in permit exporting countries. This situation occurs when there are pre-existing tax distortions and permit trading increases distortions due to these taxes. Marschinski et.al. (2012) adopt a Ricardo-Viner general equilibrium model to study the impact of sectoral carbon market linking on emissions, industrial competitiveness, and economic welfare. The authors find that global emissions can increase if the emission cap is not economy-wide in one of the "linked" countries, as changes in energy prices cause leakage to uncapped sectors. Gavard et al. (2011) simulate a carbon permit linkage between the Chinese electricity sector and United States economy-wide cap-and-trade emission market. In this scenario, the US will purchase more than 46% of its capped emissions from China and pay China $42 billion USD. Similar to Marschinski et.al. (2012), the authors also find internal leakage to non-electricity sectors in China.

2.2 Emission Trading s in China, the EU, the US, Australia and New Zealand

Launched in 2005, the EU-ETS is a cornerstone of the EU's policy to combat climate change. The EU-ETS is the largest emissions trading scheme created to date, covering around 11,000 power stations and industrial plants in 30 countries (European Union, 2003; European Union, 2012a). In its first phase (2005 – 2007), the ETS covered approximately 46% of the total CO_2 emissions of EU countries. Phase III of the EU-ETS began in January 2013 and will end in 2020. Phase III targets emissions reductions of 20% below 1990 levels by 2020 (European Union, 2012c; Kopsch, 2012). The EU-ETS also expects to develop an international carbon market through "bottom-up" linking of compatible emission trading systems (European Union, 2012b).The EU especially hopes to form a global emissions trading system, which goes beyond current policies that allow purchasing offsets from developing countries, primarily through the Clean Development Mechanism (CDM). Linking carbon programs in the EU and Australia would be a major step towards the creation of an international emissions market (European Union, 2012b).

A recent effort to establish a national emission market in the US was outlined in the American Clean Energy and Security Act in 2009 (ACES), which was an energy bill to establish a variant of an emissions trading plan. Under the cap-and-trade system proposed by the bill, a cap was to be placed on national GHG emissions so that, relative to 2005 levels, emissions fell by 17% by 2020 and 83% by 2050. (Waxman and Markey, 2009). The bill was approved by the House of Representatives, but was defeated in the Senate. Although a US national carbon market is yet to be signed into law, several regional emission markets have been established. Specifically, an economy-wide cap-and-trade program operates in California (California Environmental Protection Agency, 2012), and the Regional Greenhouse Gas Initiative (RGGI, or ReGGIe) caps emissions from power plants in several states in the eastern US (RGGI, 2013). Additionally, established in 2003, the Chicago Climate Exchange (CCX) is one of North America's only voluntary and legally binding greenhouse gas (GHG) reduction and trading systems (Lavelle, 2010).

In 2003, Australia was home to the first regional pilot (baseline and credit) emissions trading market in the world (the New South Wales Greenhouse Gas Abatement Scheme) but this regional market was not extended to a national market (Australia Greenhouse Gas Reduction Scheme Administrator, 2012; Nelson et al., 2012). However, in 2011, the Australian Government passed the Clean Energy Act of 2011, which imposed a fixed carbon price of AU$23 per metric ton of carbon dioxide equivalent (CO_2e) emitted from certain industries from July 1, 2012 (Australian government, 2011). On July 1, 2015, the "carbon price" mechanism in Australia will switch to an "emissions trading scheme" (Department of Climate Change and Energy Efficiency, 2011), and a two-way link with EU-ETS will be formed before the middle of 2018 (European Union, 2012b). However, the details of Australia's emission trading system, including the size of the emissions cap and definitions of covered sectors, are yet to be finalized.

Plans for a carbon market in New Zealand were first framed in 2007 (New Zealand Government, 2007) and outlined in 2008 (New Zealand Parliament, 2009). The 2008 Act provided for a comprehensive ETS, ultimately to cover all sectors (including agriculture and forestry) and all GHGs under the Kyoto Protocol (Lennox and van Nieuwkoop, 2010; New Zealand Parliament, 2008). This act was subsequently amended to provide greater protection to emissions-intensive, trade-exposed activities over a longer period, and also the inclusion of agriculture was postponed until 2015. Moreover, there is no emissions cap in New Zealand ETS, as the number of permits required to be surrendered by covered entities is based on emissions intensity (New Zealand Government, 2007). The New Zealand government has suggested that the NZ-ETS may link to the Australian ETS from the middle of 2015, once Australia has established its domestic emissions trading system (Minister for Climate Change and Energy Efficiency, 2012). Providing the EU and Australian carbon markets are integrated, such an extension would effectively link the New Zealand ETS with the EU-ETS.

Since 2011, China has taken steps to establish its domestic emissions market. In its Twelfth Five Year Plan (covering 2011–2015), the Chinese government announced its intention to establish a national carbon trading system by 2015. As the first step, the National Development and Reform Commission of China has initiated carbon trading pilots in seven provinces and cities in order to first establish regional trading markets that cover over 2000 firms (Guoyi et al., 2012; Qi et al., 2012). Some regional markets, such as those in Shanghai and Guangdong, are already established and a pilot trading will begin in 2013 (ChinaDaily, 2012; Environmental Finance, 2012). The success or failure of those experiments will to a large extent determine the future (at least in the near term) of carbon market developments in China. China has also signaled its intent to join an international ETS, once a domestic emission trading system has been successfully established (Economic Information, 2012; Wang, 2013).

3. Model Description

This paper adopts the China-in-Global Energy Model (C-GEM) (Qi et al., 2013) to evaluate the energy and CO_2 emissions impacts linking carbon markets in China, the EU, the US and Australia-New Zealand (ANZ). The C-GEM is a recursive-dynamic general equilibrium model of the world economy that has been developed collaboratively by the Tsinghua Institute of Energy, Environment, and Economy and the MIT Joint Program on the Science and Policy of Global Change. In the model, there are 18 production sectors, which are listed in **Table 1.** These sectors are classified into six types of production processes: extraction of primary fuels (crude oil, coal and gas), production of electricity, refined oil production, energy intensive industries, agriculture and other production activities including other manufacturing industries, transportation and services. Each of the production process is captured by a nested constant elasticity of substitution (CES) function. A typical detailed nesting structure for the six production activities is portrayed in **Figure 1**, where σ is used to denote the elasticity of substitution between inputs. An important feature of the nesting structure is the ability for firms to substitute among fossil fuels and between aggregate energy and value added, based on their cost competitiveness which is influenced by energy and climate policies.

Table 1. Sectors in the China-in-Global Energy Model (C-GEM).

Crops
Forestry: Forestry, logging and related services
Livestock
Coal: Mining and agglomeration of hard coal, lignite and peat
Oil: Extraction of crude oil
Gas: Extraction and distribution of natural gas
Petroleum & Coke: Refined oil and petro- chemical products, coke production
Electricity: Electricity production, collection and distribution
Non-Metallic Minerals: Cement, plaster, lime, gravel, concrete
Iron & steel: Manufacture and casting of basic iron and steel
Non-Ferrous Metals: Production and casting of copper, aluminum, zinc, lead, gold, and silver
Chemical, Rubber & Plastics: Basic chemicals, other chemical products, rubber and plastics products
Fabricated Metals: Sheet metal products (except machinery and equipment)
Mining: mining of metal ores, uranium, gems. other mining and quarrying
Food & Tabaco: Manufacture of foods and tobacco
Equipment: Electronic equipment, other machinery and Equipment
Other industries: Industries not included elsewhere
Transportation Services: Water, air and land transport, pipeline transport
Other Services: Communication, finance, public service, dwellings and other services

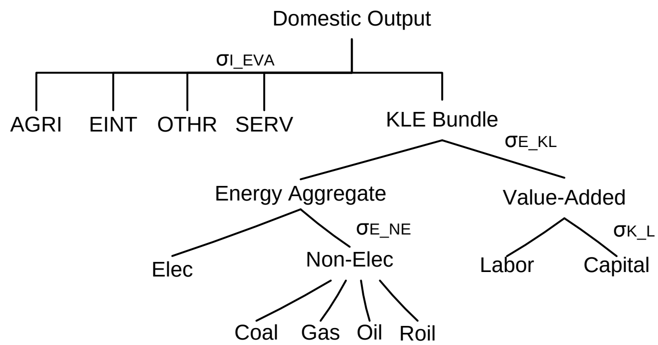


Figure 1. A typical nesting structure for the CES production function in C-GEM

C-GEM also represents 11 types of advanced technologies, which are listed in **Table 2**. Three technologies produce perfect substitutes for conventional fossil fuels (crude oil from shale oil, refined oil from biomass, and natural gas from coal gasification). The remaining eight technologies are electricity generation technologies. Wind, solar, and biomass electricity technologies are treated as imperfect substitutes for other sources of electricity due to their intermittency. The final five technologies—NGCC, NGCC with CCS, IGCC, IGCC with CCS, and advanced nuclear—all produce perfect substitutes for electricity output.

Table 2. Advanced technologies in the C-GEM model.

Technology	Description
Wind	Converts intermittent wind energy into electricity
Solar	Converts intermittent solar energy into electricity
Biomass electricity	Converts biomass into electricity
IGCC	Integrated gasification combined cycle (coal) to produce electricity
IGCC-CCS	Integrated gasification combined cycle (coal) with carbon capture and storage to produce electricity
NGCC	Natural gas combined cycle to produce electricity
NGCC-CCS	Natural gas combined cycle with carbon capture and storage to produce electricity
Advanced nuclear	Nuclear power beyond existing installed plants
Biofuels	Converts biomass into refined oil
Shale oil	Extracts and produces crude oil from oil shale
Coal gasification	Converts coal into a perfect substitute for natural gas

Wind, solar, and biomass electricity have similar production structures as shown in **Figure 2**. As they produce imperfect substitutes for electricity, a fixed factor is introduced in the top level of CES nest to control the penetration of each technology (McFarland et al., 2004). Other inputs, including labor, capital, and equipment are intermediate inputs, are organized based on the engineering information for each technology (Qi et al., 2013).

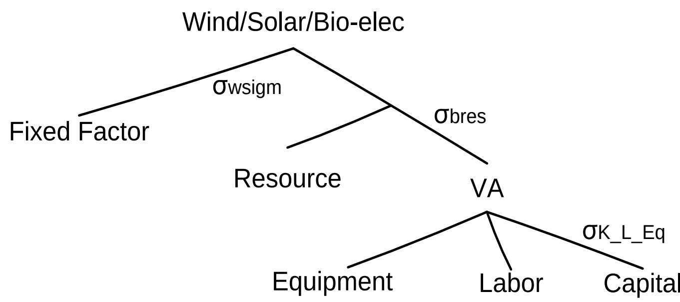


Figure 2. CES production structure for wind and solar power.

Bilateral trade is specified using the Armington assumption that domestic and imported goods are imperfect substitutes and are distinguished by region of origin (Armington, 1969). That is, each commodity purchased in a region is a CES composite of a domestic variety and an imported variety, where the imported variety is a further CES composite of varieties from different regions.

The C-GEM model is calibrated based on the Global Trade Analysis Project Version 8 (GTAP 8) global database (Badri et al., 2012) and China's official statistical publications, using 2007 as the base year. The GTAP 8 dataset includes consistent national accounts on production and consumption (input-output tables) together with bilateral trade flows for 57 sectors and 129 regions for the year 2007 (Narayanan et al., 2012b; Narayanan et al., 2012a). The C-GEM replaces the GTAP 8 observations with data from China's official data sources, including national input-output tables and energy balance tables for 2007. To maintain consistency between these two datasets, the revised global database is rebalanced using least-squares techniques (Rutherford and Paltsev, 2000). The C-GEM aggregates the GTAP data to 19 sectors and 19 regions as shown in **Table 1** and **Table 3** below.

Table 3. Regions in the China-in-Global Energy Model (C-GEM).

China: Mainland China
United States
Canada
Japan
South Korea
Developed Asia: Hong Kong, Taiwan, Singapore
Europe Union: Includes EU-27 plus Countries of the European Free Trade Area (Switzerland, Norway, Iceland)
Australia-New Zealand: Australia, New Zealand, and rest of the world (Antarctica, Bouvet Island, British Indian Ocean Territory, French Southern Territories)
India
Developing South-East Asia: Indonesia, Malaysia, Philippines, Thailand, Vietnam, Cambodia, Laos, rest of South-East Asia.
Rest of Asia: Rest of Asia countries.
Mexico
Middle East: Iran, United Arab Emirates, Bahrain, Israel, Kuwait, Oman, Qatar, Saudi Arabia
South Africa
Rest of Africa: Rest of Africa countries.
Russia
Rest of Europe: Albania, Croatia, Belarus, Ukraine, Armenia, Azerbaijan, Georgia, Turkey, Kazakhstan, Kyrgyzstan, rest of Europe.
Brazil
Latin America: Rest of Latin America Countries

The C-GEM is solved recursively in five-year intervals, starting with the year 2010. The model is written in the General Algebraic Modeling System (GAMS) software system and solved using Mathematical Programing System for General Equilibrium analysis (MPSGE) modeling language (Rutherford, 2005).

In C-GEM, CO_2 emissions are calculated by applying constant emission factors to the fossil fuel energy flows of coal, refined oil, and natural gas based on the 2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories (IPCC, 2006)[2]. The emission factors are assumed to remain constant across regions and over time. CO_2 emissions are introduced as a Leontief input together with fuel consumption. This implies that the reduction of emissions in production sectors can only be achieved by reducing the use of carbon-intensive fuels. In the current version of C-GEM, only fossil-fuel-related CO_2 emissions are projected.

4. Modeling Scenarios

We develop five scenarios to examine the impact of international permit trading between the EU, the US, China, Australia and New Zealand, which are outlined in **Table 4**. Based on the expectation that New Zealand will link its market with Australia in 2015, we have represented a fully integrated Australia/New Zealand (ANZ) emissions trading market in this paper.

[2] In this inventory, 94.6 metric tons of CO_2 are emitted per exajoule from coal, while corresponding numbers for oil and natural gas are, respectively, 73.3 and 56.1.

In order to understand the impacts of expanding the size of the emissions market, we first simulate the model with no controls on CO_2 emissions (No ETS) to observe "business-as-usual" emissions in each region. We then consider four policy scenarios: 1) a separate market scenario (Separate) that simulates the four regional emissions markets separately, 2) an EU-ANZ scenario (AE) that links the EU-ETS to the ANZ ETS, 3) a scenario that links carbon markets in the EU, ANZ and China (ACE), 4) a scenario that links carbon markets in the ANZ, EU, and USA (AEU), and 5) a scenario that links the markets in the ANZ, EU, USA and China (ACEU).

Table 4. Description of scenarios.

Scenario	Countries/regions with a separate ETS	Countries/regions with linked ETSs
No ETS	None	None
Separate	EUR, USA,ANZ, CHN	None
AE	CHN, USA	ANZ, EUR
ACE	USA	EUR, ANZ, CHN
AEU	CHN	ANZ, EUR, USA
ACEU	None	ANZ, CHN, EUR, USA

4.1 Policy Assumptions

To accurately assess the impacts of linking the three candidate trading systems, it is important to consider existing complementary policies that promote energy savings and renewable energy deployment through direct regulatory measures or other channels. For example, the EU and Australia have legislation to ensure that 20% of energy consumption is from renewable sources by 2020, while China plans to accelerate the deployment of nuclear, hydro, and renewable energy through 2020. Given that the cost of deploying renewable energy is different in each region, emissions abatement costs and ultimately the distribution of emissions reductions in a linked system will be influenced by renewable directives in each region. These "current policies" are included in all scenarios (including the No ETS scenario) and are summarized in in **Table 5**.

Table 5. Current Policies and Plans Included in all Scenarios.

Regions	Policy Description
EU	By 2020, at least 20% of energy consumption is from renewable sources and there is a 20% improvement in energy efficiency (European Union, 2012c).
United States	A 4% efficiency improvement target by 2020 (American Council for an Energy-Efficiency Economy, 2013).
China	Targets for nuclear, hydro and renewable energy in 2020 set out in China's Twelfth Five-Year Plan and Medium-Term Plan for Renewable Energy[3].
Australia & New Zealand	By 2020, at least 20% of energy consumption is from renewable sources (Australian government, 2012).

[3] The government plan for the installed capacity of nuclear is 40GW in 2015 and 70GW in 2020; for hydro it is 290GW in 2015 and 420GW in 2020 (State Council of China, 2013; China electricity council, 2012); for wind it is 100GW in 2015 and 200GW in 2020; for solar it is 21GW in 2015 and 50 GW in 2020 (National Development and Reform Commission of China, 2007; National Energy Admistration, 2012).

4.2 Assumptions for the Emissions Trade System in each Region

The EU and New Zealand already have existing emissions trading systems, but Australia, China and the US have not finalized the structure of their domestic carbon market yet. In this paper, we make assumptions about the coverage of the emissions trading system in Australia, China and the US based on available information and focus on the effects of linking carbon markets in different regions. The EU-ETS covers the power generation and energy intensive sectors (European Union, 2012a). For ANZ, China and the US, we assume that all sectors except agriculture are included in emissions trading.

CO_2 emissions allowances allocated to regional markets are based on their national reduction targets in 2020, as listed in **Table 6**. For the EU, the 2020 target is a 21% reduction in GHG emissions from 2010 levels (European Union, 2012a). In this analysis, we only consider CO_2 emissions. For the US, we use the 17% emission reduction target from 2005 levels by 2020 stated in the American Clean Energy and Security Act of 2009 (Waxman and Markey, 2009). For Australia, we employ their 2020 unconditional 5% reduction target below 2000 emissions level in the power and energy intensive sectors. Though New Zealand holds an intensity target rather than an explicit reduction target, we apply the same 5% reduction assumption to New Zealand. For China, the national target for 2020 is a 40%-45% reduction of emission intensity based on 2005 levels (which equates to a 27% reduction in CO_2 emissions intensity relative to 2010 levels).

Table 6. Emissions allowance of EU, US, ANZ and China.

	EU	US	ANZ	China
No Policy 2020 emissions (mmt)	1994	5703	492	11092
2020 emissions cap (mmt)	1860	4790	351	10328
Proportional reduction in emissions*	7%	16%	29%	7%

(*These proportional reductions here are relative to no policy 2020 emissions.)

5. Results

5.1 Emission Reductions in the Separate Emissions Markets scenario

We begin by examining the impact of separate cap-and-trade policies in each region. With different emission caps applied in the individual carbon market, the carbon price is significantly different in each of the markets, as shown in **Table 7**. ANZ has the highest carbon price at \$132/tCO_2, followed by the US, (\$38/tCO_2), the EU (\$12/tCO_2) and China (\$7/tCO_2).

Table 7. Carbon price and emissions reduction results under No ETS and Separate scenarios

	EU	US	ANZ	CHN
Emissions reduction (mmt)	134	913	141	764
Proportion reduction in emissions (%)	7	16	29	7
GDP change (%)	-0.02	-0.15	-0.92	-0.09
Carbon price ($/ton)	12	38	132	7
Welfare change (%)	-0.01	-0.05	-0.58	-0.01

The lower carbon price in China than elsewhere reflects the relative abundance of low-cost abatement options in China. These differences are driven by (i) production technologies in China being, on average, older than in the EU, the US and ANZ, and (ii) a large share of coal in total energy production in China relative to other regions. These differences drive differences in CO_2-intensity (CO_2 emissions per unit of GDP) across regions. Specifically, in 2010, the emissions intensity of output in China was 1.59 kg CO_2/US dollar, which is six times higher than the EU (0.22 kg CO_2/US dollar) and three times higher than Austria- New Zealand (0.39 kg CO_2/US dollar). Older, less efficient technologies in China mean that a greater reduction in emissions is achieved by adopting advanced technologies, and large use of coal in this region provides greater scope for reducing emissions by substituting away from this input towards cleaner fossil fuels.

Changes in electricity generation from advanced technologies and primary energy use are presented in **Figure 3**. Due to the carbon caps, less energy is consumed to support a similar scale of economy in the US (13% less), the EU (2% less), ANZ (31% less) and China (5% less). Significant proportional reductions in coal consumption are achieved in the US (29%) and ANZ (37%), and more moderate reductions in the EU (9%) and China (8%). In terms of absolute numbers, the largest reduction in coal consumption occurs in China (212 million tons of oil equivalent, mtoe), which is about 70% of the EU's total coal consumption in 2010. Carbon prices also increase the cost competitiveness of renewable electricity. In US, electricity generation from wind increases from 6 mtoe to 16 mtoe, and solar power doubles. In EU, both wind and solar increase by more than 20% and in China generation from these technologies increase by more than 25%.

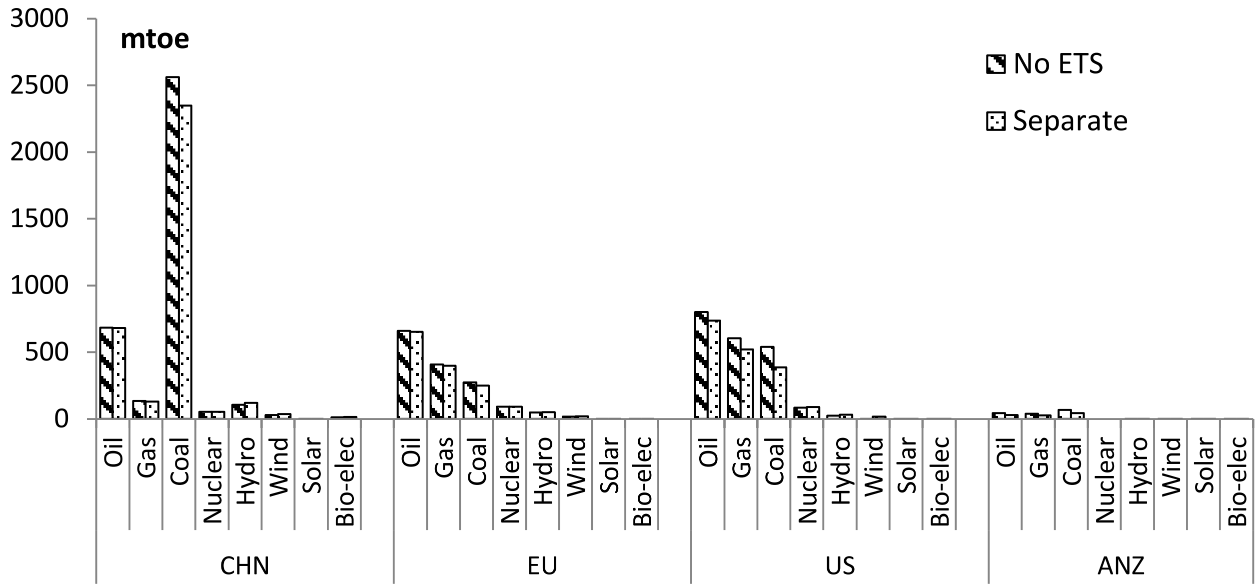


Figure 3. Primary energy consumption under No ETS and Separate scenarios.

5.2 The Impact of Linking Emissions Markets

We now consider what happens when emissions markets are linked with each other. Results for the AE, ACE, AEU, and ACEU scenarios are presented in **Table 8**. Linking carbon markets in Australia and China (AC) results in a carbon price of \$10.6/tCO_2, which is a significant reduction compared to the price (\$132/tCO_2) in the separate market in ANZ. As the linked emission price is still lower than the carbon price in EU market (\$12/tCO_2), the EU and ANZ both purchase permits from China in the AC scenario, resulting in an international emission price of \$11.2/tCO_2. In this scenario, China exports permits for 164 mmt of CO_2 emissions, 119 mmt to ANZ and 45 mmt the EU.

Table 8. Carbon prices and emissions reductions under AE, ACE, AEU, and ACEU scenarios.

	AE				ACE				AEU				ACEU			
	USA	**EU**	**ANZ**	**CHN**	**USA**	**EU**	**ANZ**	**CHN**	**USA**	**EU**	**ANZ**	**CHN**	**USA**	**EU**	**ANZ**	**CHN**
No Policy 2020 emissions (mmt)	5703	1994	492	11092	5703	1994	492	11092	5703	1994	492	11092	5703	1994	492	11092
2020 emissions (mmt)	4790	1766	444	10328	4790	1905	470	10164	4866	1703	432	10328	5288	1853	461	9728
Emissions reduction (mmt)	913	228	48	764	913	89	23	928	837	291	60	764	416	141	31	1364
Emissions reduction (%)	16	11	10	7	16	4	5	8	15	15	12	7	7	7	6	12
Carbon price (USD/t)	38.5	33	33	7.2	38.2	11.2	11.2	11.2	46.1	46.1	46.1	7.2	17.5	17.5	17.5	17.5
Change in CO_2 abatement	-	93	-93	-	-	-45	-119	164	-76	157	-81	-	-498	8	-110	600
International Transfer US dollar (billion $)	-	3.07	-3.07	-	-	-0.5	-1.33	1.83	-3.51	7.25	-3.74	-	-8.7	0.1	-1.9	10.5
GDP change relative to the Separate scenario (%)	0.00	-0.04	0.71	0.00	0.00	0.02	0.82	-0.02	0.02	-0.08	0.64	0.00	0.10	-0.01	0.76	-0.08
Welfare change relative to Separate scenario (%)	0.00	-0.02	0.38	0.00	0.00	0.01	0.56	0.02	-0.01	-0.03	0.29	0.00	-0.01	-0.01	0.48	0.13

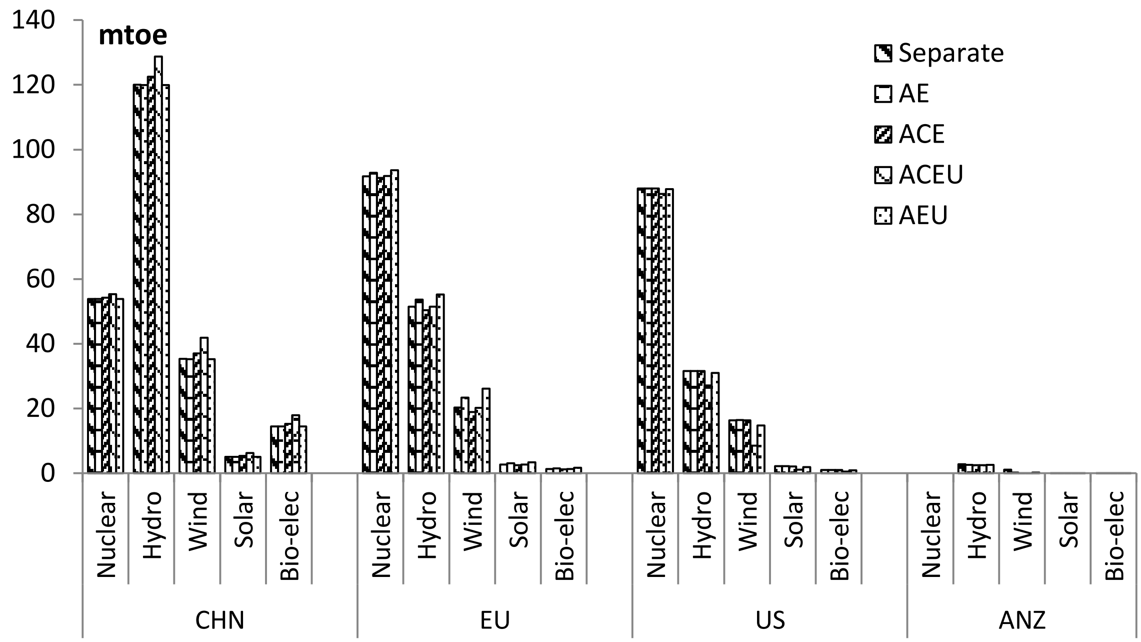
If China is not involved in the international carbon market, as the case in the AEU scenario, the global carbon price is \$46.1/tCO_2 and permits for 157 mmt of emissions are traded. In this scenario, permits are sold by the EU to the US and ANZ.

In the ACEU scenario, linking all carbon markets considered results in a permit price of \$17.5/tCO_2 and 608 mmt of permits are traded (compared to 164 mmt in the ACE scenario). The US buys 498 mmt of the emission permits, accounting for 55% of its reduction target and ANZ purchases permits for 110 of emissions, accounting for 78% of its reduction target. Most of the permits are supplied by China and a small amount (1% of total supply) by the EU. Turning to financial transfers, the US pays \$8.7 billion to permit suppliers and ANZ pays \$1.9 billion, and the EU and China receive, respectively, \$0.1 billion and \$10.5 billion. The transfer to China is equivalent to 0.23% of China's 2010 GDP.

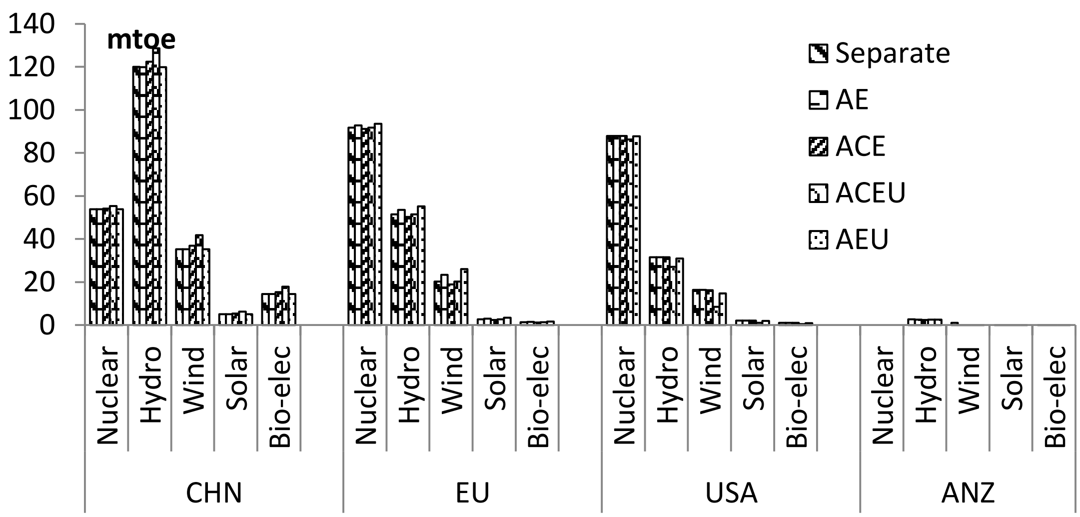
Welfare changes for each scenario are also reported in **Table 8.** In general, ANZ experiences the largest welfare gain (in proportional terms) due to international permit trading, reflecting relatively high abatement costs in this region. Global welfare increases by 0.02% in the ACEU scenario. Interestingly, not all participating regions gain due to permit trading. This is due to the interaction between existing distortions and the impact of permit trading, as noted by Babiker et al., (2004).

5.3 The Impact on Energy Production

When there is international permit trading, to minimize the overall abatement cost in covered regions, emission reductions are reallocated among all covered regions relative to when cap-and-trade programs operate separately. Permit exporters will have tighter emission constraint, which in return will require them consume more low-carbon energy. On the other hand, permit importers are able to emit more fossil fuels and the development of clean energy will be postponed. Changes in fossil fuel consumption and electricity generation by source are displayed in **Figure 4**. Coal consumption in China decreases in the ACE (by 2%) and ACEU scenarios (by 7%), relative to the Separate scenario. There also small reduction in oil and gas consumption in China in these scenarios. Reductions in fossil fuel use are driven by a combination of reduced demand (due to higher prices), improved energy efficiency, and expansion of low-carbon energy sources. In the ACEU scenario, renewable energy in China expands by just over 20%, resulting in 5% of the overall energy savings. The US, a permit importer, on the other hand, consumes 19% more coal, 11% more gas and 6% more oil in the ACEU scenario relative to the Separate scenario. Also in this scenario in the US, electricity from hydro and other renewables falls by, respectively, 14% and 48%. Changes in energy production due to permit trading are largest in the ANZ region. This region consumes 41% more coal, 35% more gas, 40% more oil and 90% less renewable energy in the ACEU scenario than the Separate scenario. Thus, international permit trading redistributes production of renewable energy from permit importers (mainly developed economy) to permit exporters (mainly developing regions).



(a)



(b)

Figure 4. Fossil fuel consumption (a) and renewable energy consumption (b) results under AE, ACE, AEU, and ACEU scenarios

6. Conclusion

A market-based emission trading system is a cost-effective way to facilitate abatement and is expected to play an essential role in global climate change mitigation. Though an international emission trading system is yet to establish, some national and regional emissions markets have already operating. The EU-ETS has moved to its third phases of operation and China is also piloting emission trading system in sub-national level to build up the capacity to establish a national ETS. Australia also announced that it will build up a national emission market in 2015 and link this market to the EU-ETS in 2018. Against the background of the rapidly growing global emission market, this paper analyzed the impact of form and expand a global carbon market to include the EU, the US, Australia, New Zealand and China.

Applying an emission constraint will leads to an adoption of new technologies to improve the energy efficiency and replace the fossil fuel consumption with renewable energy and other sources of clean energy. We find that due to the carbon caps in the separated emission market, less energy is consumed to support a similar scale of economy in the US, the EU, Australia/New Zealand and China. At the same time, a significant reduction in coal consumption is achieved. China reduced its coal use by 212 mtoe, which nearly accounts for 70% of the EU's total coal consumption in 2010. Emissions prices also stimulated the production of renewable energy. In the US, the wind power grows from 6 mtoe to 16 mtoe, and solar power scale is also twice enlarged. In China, renewable energy production increased by more than 25%, making China the largest producer of electricity from wind and solar in the world.

Linking the separated carbon programs to form an international market resulted in large changes in the distribution of emissions reductions and renewable electricity production in included regions. When included in international carbon markets, China is a large exporter of emissions permits and the US is large importer. When China joins the EU-ANZ linked market, the per ton carbon price falls from price $33to $11.2, while adding the US to EU-ANZ carbon markets results in a carbon price of $\$46.1/tCO_2$. If both China and the US join the EU-ANZ carbon market, the price is $\$17.5/tCO_2$ and the trading permit will be as much as 608 mmt (compared to 93 mmt in the EU-ANZ scenario). The US and Australia transfer, respectively, 55% and 78% of their domestic reduction burden to China (and a very small amount to the EU) in return for a total transfer payment of $10.6 billion. The reallocation of emissions permits also leads to a global redistribution of the renewable energy industry. When carbons markets in the four regions are linked, relative to when the carbon markets operate independently, renewable energy in China expands by more than 20% while in the US and ANZ shrink by, respectively, 48% and 90%. In all simulations, there is a 5% reduction in global emissions.

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