The Energy and Economic Impacts of Expanding International Emissions Trading

Tianyu Qi, Niven Winchester, Valerie Karplus and Xiliang Zhang

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Ronald G. Prinn and John M. Reilly
Program Co-Directors

For more information, please contact the Joint Program Office
Postal Address: Joint Program on the Science and Policy of Global Change
77 Massachusetts Avenue
MIT E19-411
Cambridge MA 02139-4307 (USA)
Location: 400 Main Street, Cambridge
Building E19, Room 411
Massachusetts Institute of Technology
Access: Phone: +1.617. 253.7492
Fax: +1.617.253.9845
E-mail: globalchange@mit.edu
Web site: http://globalchange.mit.edu/

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The Energy and Economic Impacts of Expanding International Emissions Trading

Tianyu Qi[*†], Niven Winchester[‡], Valerie J. Karplus[†] and Xiliang Zhang[‡]

Abstract

Emissions trading systems are recognized as a cost-effective way to facilitate emissions abatement and are expected to play an important 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 expanding this international emissions market to include China and the US, which are respectively the largest and second largest carbon dioxide (CO_2) emitters in the world. We find that including China and the US significantly impacts the price and the quantity of permits traded internationally. China exports emissions rights while other regions import permits. When China joins the EU-Australia/New Zealand (EU-ANZ) linked market, we find that the prevailing global carbon market price falls significantly, from $33 per ton of carbon dioxide (tCO_2) to $11.2/$tCO_2$. By contrast, adding the US to the EU-ANZ market increases the price to $46.1/$tCO_2$. If both China and the US join the linked market, the market price of an emissions permit 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 permit trading between all regions is considered, relative to when all carbon markets operate in isolation, 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 around 5% relative to a case without climate policies.

Contents

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 global level. So far, only a few markets for greenhouse gas emissions exist, and these exist at the

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[*] Institute of Energy, Environment and Economy, Tsinghua University, Beijing, China.
[†] Corresponding author (email: qitianyu@mit.edu).
[‡] Joint Program on the Science and Policy of Global Change, Massachusetts Institute of Technology, Cambridge, MA, US.

subnational 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 (DCCEE, 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 emissions trading system in the US was shelved in 2009, several regional carbon markets have already been established (California Environmental Protection Agency Air Resources Board, 2012; Lavelle, 2010; RGGI, 2013), which may accelerate the steps to a national market in the US. Although a multiregion 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 (European Union 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 to link the EU-ETS with California's carbon market (Carus, 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 (Environment News Service, 2013; Guoyi et al., 2012). The impact from linking carbon markets depends in part on the relative quantity of emissions in the two regions. For example, a linkage between the EU-ETS and a hypothetical ETS in the US has a larger impact on the EU carbon price than the linkage between the EU-ETS and a hypothetical ETS in Mexico (Gavard, Winchester, Jacoby and Paltsev, 2011).[1] 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 were 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

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[1] This conclusion is also dependent on the stringency of the constraint and the marginal cost of reducing emissions in each region.

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 supra-national climate proposals. For this analysis, we use a multiregional 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).

The remainder of this analysis is comprised of five sections. Section 2 reviews the relevant literature and summarizes emissions trading programs in China, the US, the EU, Australia and New Zealand. 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

Broadly, the literature concerning linked carbon trading systems represents two areas of inquiry. One focuses on political and institutional barriers, and the other estimates the impacts of linked systems on economic outcomes and emissions. Studies focused on the political and institutional barriers to carbon market integration have identified major challenges. Tuerk et al. (2009) concluded that an OECD-wide carbon market by 2015 was unlikely, because supra-national ETS integration is not a short-term priority in many countries, and that the benefits of such linkages may be offset by the cost of sacrificing other policy objectives, such as domestic CO_2 price control. The authors also suggested that carbon linkages were most likely to begin among countries or regions with strong existing trade ties before expanding further (Tuerk et al., 2009).

Flachsland et al. (2009b) assesses the environmental effectiveness and political feasibility of top-down and bottom-up approaches to international carbon trading systems.[2] Challenges identified by the authors include the risk of changing emissions reduction commitments as a result of 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 increase their domestic 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) used a CGE model to test the welfare impact from

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[2] In this literature, top-down and bottom-up approaches refer to two different pathways toward 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 multilaterally.

international 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 interacts with and magnifies these distortions (Paltsev et al., 2004). Marschinski et al. (2012) adopted 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 result in leakage to uncapped sectors. Gavard et al. (2011) simulated a carbon permit linkage between the Chinese electricity sector and an economy-wide cap–and–trade emissions market in the US. In this scenario, the US will purchase more than 46% of its capped emissions from China and pay China $42 billion. Similar to Marschinski et al. (2012), the authors also find internal leakage to non-electricity sectors in China.

2.2 Emission Trading 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 to 2007), the ETS covered approximately 46% of the total CO_2 emissions in 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 by linking compatible emissions trading systems (European Union, 2012b).

The US has also seen efforts to develop emissions trading system designs. A recent effort to establish a national emissions trading market in the US was outlined in the American Clean Energy and Security Act in 2009 (ACES). Under the cap–and–trade system proposed by the bill, a cap was to be placed on national greenhouse gas (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 did not pass in the Senate. Although a US national carbon market has yet to be signed into national law, several regional emission markets have been established. Specifically, an economy-wide emissions trading 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).

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 the EU-ETS will be formed before the middle of 2018 (European Union, 2012b). However, the details of Australia’s emissions trading system, including the size of the emissions cap and definitions of covered sectors, have 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 long-term protection to emissions-intensive, trade-exposed activities, and the inclusion of agriculture was postponed until 2015. Moreover, the New Zealand ETS does not place a hard cap on emissions, 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 carbon market may link to the Australian ETS starting in the middle of 2015, once Australia has established its domestic emissions trading system (MCCEE, 2012). Providing the EU and Australian carbon markets can be successfully 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 five cities and two provinces in order to first establish regional trading markets covering 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 market began in 2013 (ChinaDaily, 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 emissions trading system has been successfully established.

3. MODEL DESCRIPTION

This paper adopts the China-in-Global Energy Model (C-GEM) (Qi, Winchester, Zhang, and Karplus, 2013) to evaluate the energy and CO_2 emissions impacts of 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 developed by the Tsinghua-MIT China Energy and Climate Project, a collaborative effort of 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 processes 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 of 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).

Sector	**Industry included in sector**
Crops	Crops
Forestry	Forestry, logging and related services
Livestock	Livestock
Coal	Mining and agglomeration of hard coal, lignite and peat
Oil	Extraction of crude oil
Gas	Extraction and distribution of natural gas
Petroleum and Coke	Refined oil and petro-chemical products, coke production
Electricity:	Electricity production, collection and distribution
Non-Metallic Minerals	Cement, plaster, lime, gravel and concrete
Iron and 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 and 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 and 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, and pipeline transport
Other Services	Communication, finance, public service, dwellings and other services

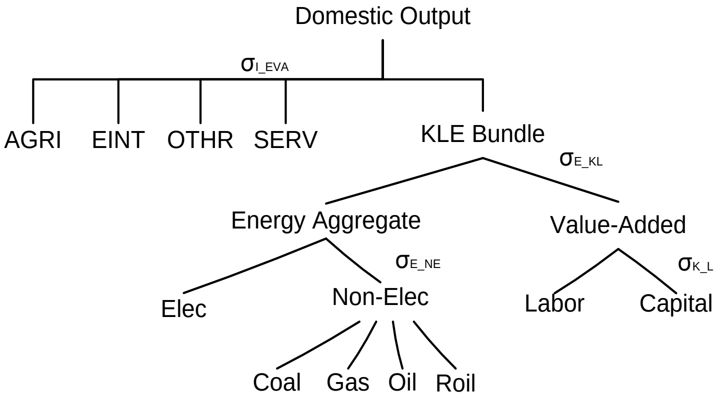

Figure 1. A typical nesting structure for the CES production function in C-GEM.

The 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 the CES nest to control the penetration of each technology (McFarland et al., 2004). Other inputs, including labor, capital and equipment as intermediate inputs, are parameterized based on engineering information for each technology (Qi et al., 2013).

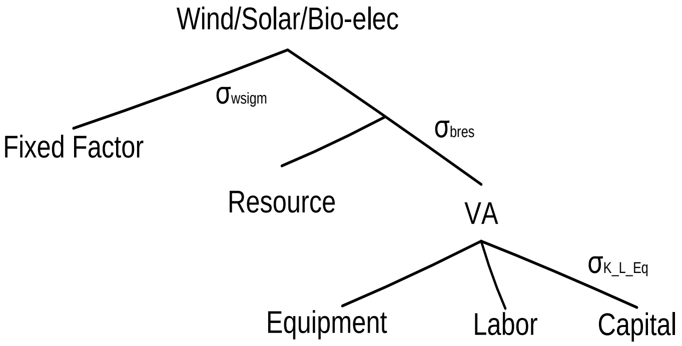

Figure 2. CES production structure for wind, solar and biomass power.

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 inputs from different regions.

The C-GEM 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 data set includes consistent national accounts for production and consumption activities (input–output tables) integrated together with bilateral trade flows for 57 sectors and 129 regions for the year 2007 (Narayanan et al., 2012a; Narayanan et al., 2012b). The C-GEM replaces GTAP 8 observations for China 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 database 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).

Region name	**Countries in region**
China	Mainland China
United States	United States
Canada	Canada
Japan	Japan
South Korea	South Korea
Developed Asia	Hong Kong, Taiwan and Singapore
Europe Union	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	India
Developing Southeast Asia	Indonesia, Malaysia, Philippines, Thailand, Vietnam, Cambodia, Laos and the rest of Southeast Asia
Rest of Asia	Rest of Asia Rest of Asia countries.
Mexico	Mexico
Middle East	Middle East Iran, United Arab Emirates, Bahrain, Israel, Kuwait, Oman, Qatar and Saudi Arabia
South Africa	South Africa
Rest of Africa	Rest of Africa countries
Russia	Russia
Rest of Europe	Albania, Croatia, Belarus, Ukraine, Armenia, Azerbaijan, Georgia, Turkey, Kazakhstan, Kyrgyzstan and the rest of Europe
Brazil	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).[3] 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 among the EU, the US, China and 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 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 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 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 originates 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

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[3] 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 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 originates from renewable sources and there is a 20% improvement in energy efficiency (European Union, 2012c).
US	A 4% efficiency improvement is achieved by 2020 (ACEEE, 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.[a]
Australia and New Zealand	By 2020, at least 20% of energy consumption is from renewable sources (Australian Government, 2012).

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

4.2 Assumptions for the Emissions Trading System in Each Region

The EU and New Zealand already have existing emissions trading systems, but Australia, China and the US have not yet finalized the structure of their domestic carbon market. In this paper, we make assumptions about the coverage of the emissions trading systems 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 all the sectors. Though New Zealand holds an intensity target rather than an explicit reduction target, we apply a 5% reduction to the composite ANZ region. 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). The combined emissions caps in the four regions reduce global emissions by around 5%.

Table 6. Emissions allowance totals for the 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[a]	7%	16%	29%	7%

[a] Proportional reductions are relative to 2020 emissions in the No Policy Scenario.

5. RESULTS

5.1 Emission Reductions in the Separate Emissions Markets Scenario

We begin by examining the impact of separate (unlinked) emissions trading systems in each region. The carbon price is significantly different in each of the markets, as shown in **Table 7,** in large part due to the differences in the emissions caps applied. 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 prices and emissions reductions results in the Separate Scenario**.**

	EU	**US**	**ANZ**	**China**
Emissions reduction (mmt)	134	913	141	764
Carbon price ($/ton)	12	38	132	7
Welfare change (%)	-0.01	-0.05	-0.58	-0.01

The lower carbon price in China relative to other capped regions reflects the relative abundance of low-cost abatement options in this country and the small proportional reduction in emissions (although it is large in absolute terms compared to other regions). These differences are driven by (i) production technologies in China being on average older than those 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 attributes 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\$, which is six times higher than the EU (0.22 kg CO_2/US\$) and three times higher than Australia-New Zealand (0.39 kg CO_2/US dollar). The 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 or improving energy efficiency.

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 economic activity 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%), as compared to more moderate reductions in the EU (9%) and China (8%). In terms of absolute numbers, the largest reduction in coal consumption occurs in China (8.9 EJ or 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 the US, electricity generation from wind increases from 6 mtoe to 16 mtoe, and solar power doubles. In the EU, renewable energy production increases by more than 20% (from 20 to 24 mtoe) and in China generation from these technologies increases by more than 25% (from 43 to 54 mtoe).

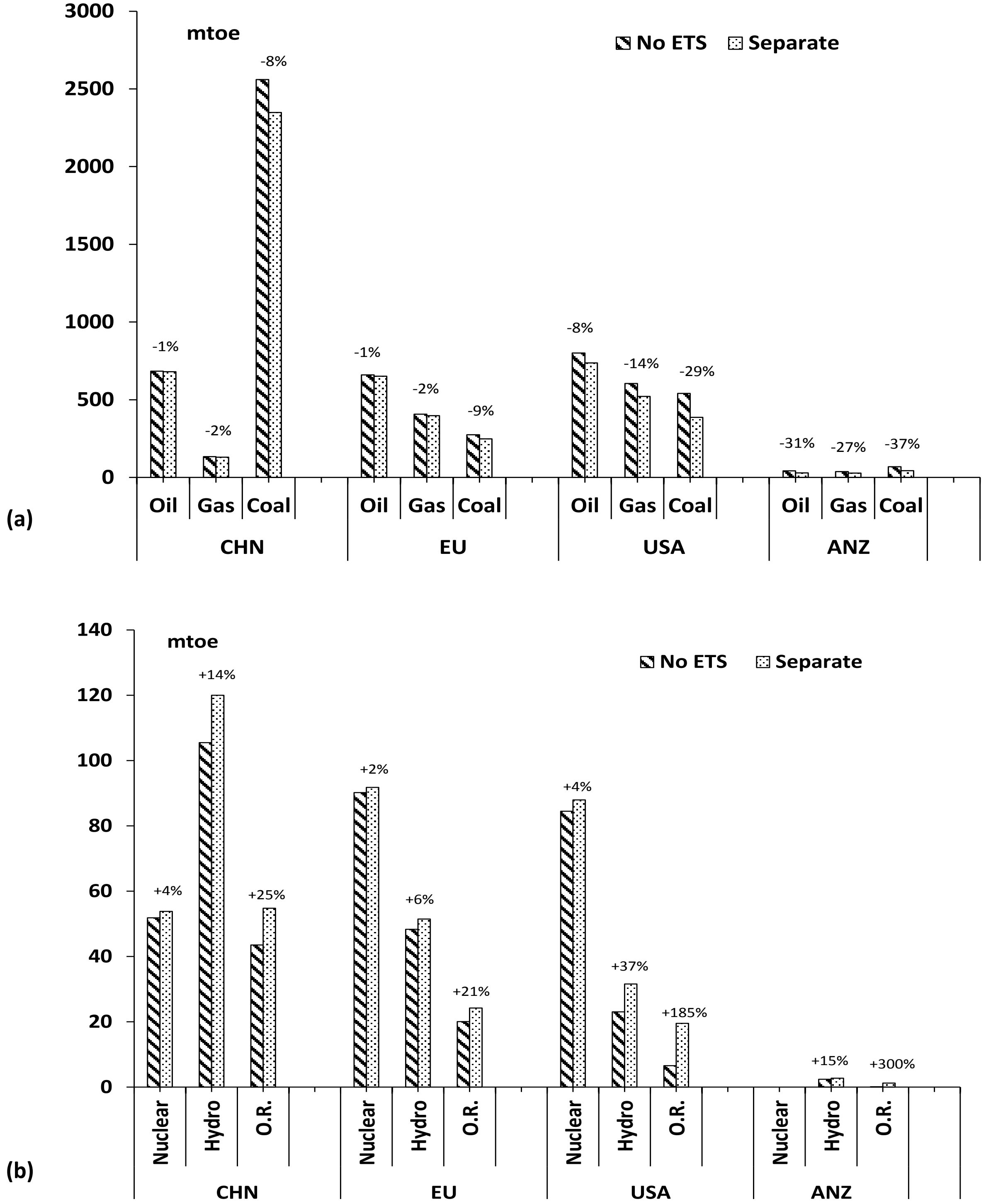

Figure 3. Fossil fuel consumption (a) and renewable energy production (b) in the No ETS and Separate scenarios in 2020.

5.2 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 ANZ and China (AC) results in a carbon price of \$10.6/tCO_2, which is a significant reduction compared to the ANZ price (\$132/tCO_2) in the Separate Scenario. As the linked emission price is still lower than the carbon price in the EU market (\$12/tCO_2), the EU and ANZ both purchase permits from China in the ACE scenario, resulting in an international emission price of \$11.2/tCO_2. In this scenario, China sells permits for 164 mmt of CO_2 emissions, 119 mmt to ANZ and 45 mmt to the EU. 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.

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

Scenario/ Region		2020 emissions reduction [a]		Change in abatement (mmt) [b]	Carbon price (USD/t)	International Transfer (billion USD)	Welfare change (%)
		mmt	%				
AE	USA	913	16	-	38.5	-	0
	EU	228	11	93	33	3.07	-0.02
	ANZ	48	10	-93	33	-3.07	0.38
	CHN	764	7	-	7.2	-	0
ACE	USA	913	16	-	38.2	-	0
	EU	89	4	-45	11.2	-0.5	0.01
	ANZ	23	5	-119	11.2	-1.33	0.56
	CHN	928	8	164	11.2	1.83	0.02
AEU	USA	837	15	-76	46.1	-3.51	-0.01
	EU	291	15	157	46.1	7.25	-0.03
	ANZ	60	12	-81	46.1	-3.74	0.29
	CHN	764	7	-	7.2	-	0
ACEU	USA	416	7	-498	17.5	-8.7	-0.01
	EU	141	7	8	17.5	0.1	-0.01
	ANZ	31	6	-110	17.5	-1.9	0.48
	CHN	1364	12	600	17.5	10.5	0.13

[a] Emissions reductions are expressed relative to the No Policy Scenario

[b] Changes in emissions abatement and welfare are relative to the Separate Scenario.

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. The observation that the EU is a net exporter of permits is perhaps surprising, but it is worth noting that existing renewables and other mandates essentially offer reductions towards the EU's goal that are pursued regardless of the carbon price, making the EU an attractive source of emissions reductions.

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 from permit trading. This is due to the interaction between existing distortions (for instance, fuel taxes as well as existing sectoral policies within regions) and permit trading, as discussed in Babiker et al. (2004).

5.3 Impact on Energy Production

International permit trading minimizes the overall abatement cost within the covered regions. As a result, emission reductions may occur in different locations relative to the case in which cap–and–trade programs operate separately. Permit exporters will face a tighter emission constraint, which in return will require them to consume more low-carbon energy. On the other hand, permit importers will be able to use more fossil fuels and the development of clean energy will be postponed. Changes in fossil fuel consumption and electricity generation in the Separate and ACEU Scenarios are displayed in **Figure 4**. Coal consumption in China decreases in the ACEU scenario (by 7%), relative to the Separate Scenario. There is also a small reduction in oil and gas consumption in China in these scenarios. Reductions in fossil fuel use are driven by a combination of lower 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 over 20%. The US, a permit importer, on the other hand, consumes 19% more coal, 11% more gas and 6% more oil than in the ACEU scenario relative to the Separate Scenario. Also in this scenario in the US, electricity from hydro and other renewables falls by 14% and 48% respectively. 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 compared to the Separate Scenario. Thus international permit trading redistributes production of renewable energy from permit importers (mainly developed economies) to permit exporters (mainly developing regions).

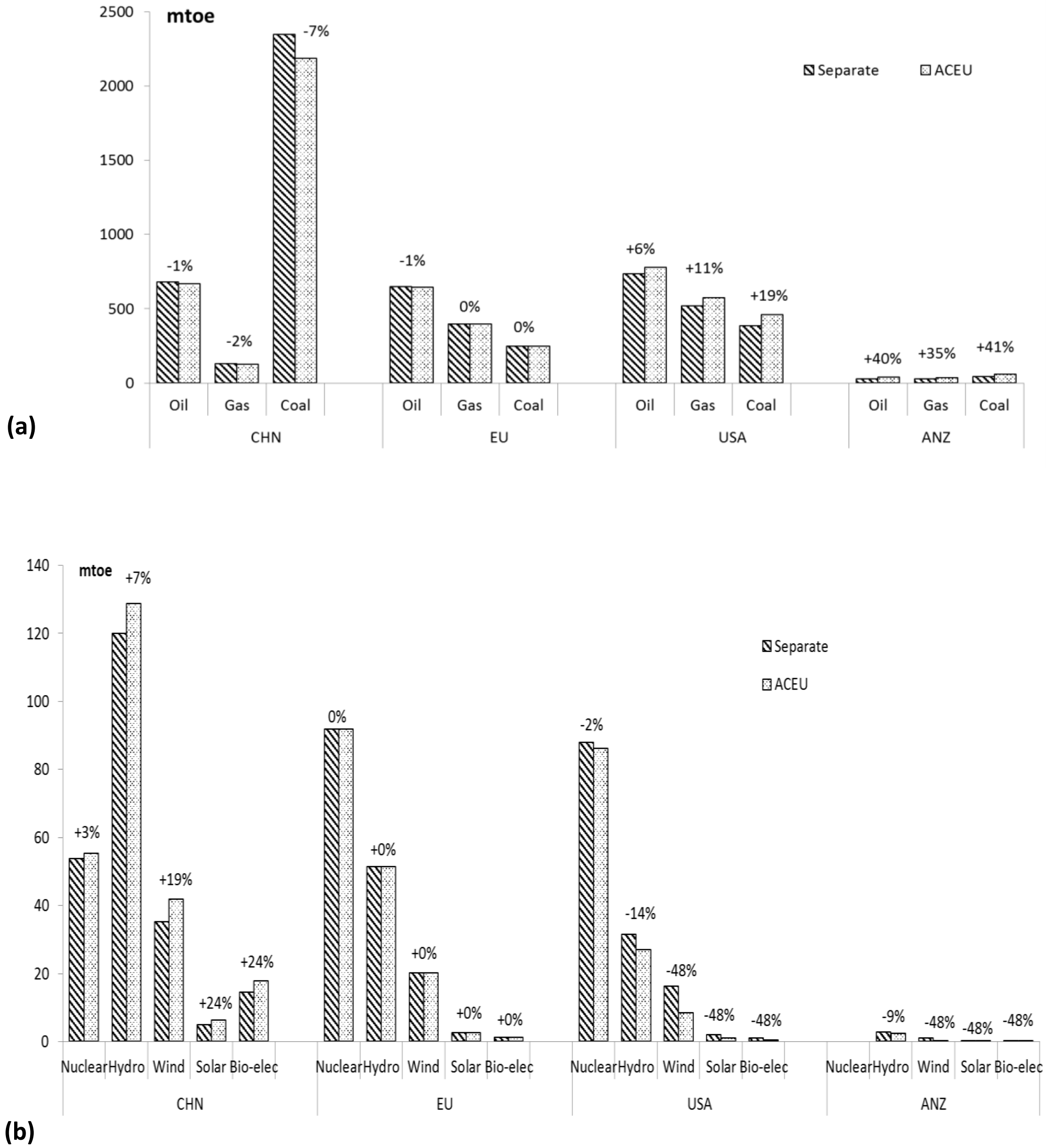

Figure 4. Fossil fuel consumption (a) and renewable energy production (b) in the Separate and ACEU scenarios.

6. CONCLUSION

In this analysis, we study a hypothetical expansion of an international market for CO_2 emissions and simulate the resulting changes in energy use, CO_2 emissions, financial transfers, carbon price, regional welfare and trade flows. We start from the planned linkage of the EU and Australian trading systems, and consider a full range of possible trading system combinations. Our results provide a plausible first assessment of the effects of linking trading systems based on currently announced emissions reduction goals through 2020. We find that introducing the EU and the US into an ETS in particular has a large impact on outcomes in a linked system. We explain these outcomes as a function of the stringency of the cap (and the associated quantity of emissions reductions), the marginal cost of abatement opportunities in each market, and the interaction between existing sectoral policies and an expanded carbon market.

First, we find that some regions are consistently importers of emission permits across all scenarios, while others' status depends on the coverage of the linked market. Reduction targets in each region result in different quantities of CO_2 reduction and, if markets are not linked, meeting these targets within territorial boundaries is very expensive for some regions. For example, ANZ must reduce a quantity that is large relative to territorial emissions (29%) but small relative to total emissions in a linked market setting, especially when the USA or China or both are included. This high territorial reduction burden translates into high marginal costs (and a carbon price of $132/ton in the unlinked scenario), and consistently makes ANZ an importer of emissions permits when included in a linked market. By contrast, the status of the EU as an importer or exporter of permits depends on which countries are included. If the EU, ANZ, and China are linked, China absorbs a significant portion of the territorial reduction burden of the EU and ANZ, which are importers of permits. However, if the USA is added, the EU actually becomes a very modest exporter of permits, and ANZ and the USA pay China and the EU to undertake some reductions on their behalf. Under the assumptions made here, the EU gains from joining a trading system that includes China but not the US, but it is worth noting that gains or losses from participating in a linked system (relative to establishing an isolated ETS) are relatively modest for all regions except for ANZ. This region faces the highest marginal abatement costs but accounts for only small percentage of the total reductions required, and so always outsources a large share of its reduction burden given the opportunity.

Second, our results suggest that the interaction between existing region-specific sectoral or command-and-control policies and the internationally-linked emissions market is important. Any such policies that target reductions in CO_2 emissions act independently of the carbon price (i.e. they are pursued regardless of the availability of more cost-effective opportunities), raising the average cost of reductions and the welfare cost of climate policies (Morris, Reilly, and Paltsev, 2010). From the perspective of a linked international ETS, sectoral policies restrict the quantity of extra-territorial emissions that can be used to meet the cap. The EU has multiple sectoral policies that result in the EU undertaking some emissions reductions (e.g., by deploying renewables and energy efficiency) regardless of the international CO_2 price. The fact that these reductions are predetermined is probably one reason why the EU is an exporter for reductions in 2020 when the four regions are linked.

Third, we acknowledge several issues that affect our results. Some of the trading systems we model cover all GHGs (e.g., the EU ETS and the proposed system in US legislation), while China's climate policy has so far targeted only CO_2. Including the full range of GHGs may alter the costs of emissions abatement. We also assume all sectors are covered within the markets comprising a linked ETS, but there are many potential designs that involve partial sectoral coverage or offset arrangements that may increase the acceptability to policymakers of linking markets.

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