Linking the emissions trading schemes of Europe and China
- Combining climate and energy policy instruments

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Abstract

Both Europe and China have announced targets for greenhouse gas emissions reduction and renewable energy development. To achieve their emissions targets, Europe has introduced emissions trading scheme (ETS) since 2005 and China has planned to establish a national ETS in 2015. We assess the impact of a joint Europe-China ETS when both climate and energy policy instruments are simulated in a multi-regional general equilibrium model. Our results show that a joint ETS markedly increases total carbon emissions from fossil fuels even though global mitigation costs are reduced. Moreover, a joint ETS helps China achieve its renewable energy target, but for Europe, it works opposite. While the renewable energy target does not help Europe achieve additional abatement, the renewable energy target in China reduces mitigation costs and emissions, and increases renewable energy consumption and sales of carbon allowances. Financial transfer through a joint ETS remains marginal compared to China’s demand for renewable energy subsidies. We conclude that as long as an absolute emissions cap is missing in China, a joint ETS is not attractive for mitigation and China’s renewable energy target can reduce emissions.

Keywords Linking; Emissions Trading scheme; Climate Policy; Energy Policy; General Equilibrium; International Cooperation

1. Introduction

Domestic climate and energy policy instruments can mitigate Greenhouse gas (GHG) emissions. Typical examples of the policy instruments include carbon pricing through taxes or emissions trading scheme (ETS) and subsidies for renewable electricity generation. Domestic policy instruments in one country can affect emissions from other regions through international trade. Hence, the global net emissions abatement may differ from the country's abatement. This calls for coordinated action across all countries. Whereas global climate negotiations are progressing slowly, a way to coordinate actions emerges as practical bottom-up mitigation options. These options can be bilateral or multilateral cooperation, e.g., linking separately implemented ETSs across countries (Newell et al., 2014).

Most ETSs are designed as cap-and-trade systems (Ranson and Stavins, 2014). In these systems, allowances are distributed and traded on a market given a cap for total emissions. Currently, the European Union ETS is the world's largest cap-and-trade system with an absolute emissions cap. China has announced a national ETS in 2015 and implemented pilot ETSs in seven provinces (Zhang et al., 2014) to fulfill its carbon intensity target of lowering carbon dioxide (CO_2) emissions per unit of gross domestic product (GDP) by 40–45 % by 2020 compared to the 2005 level (UNFCCC, 2010). In the international climate negotiations, carbon intensity targets are proposed to encourage developing countries to participate in a climate agreement. An intensity target allows for flexibility in emissions since future economic development may differ from its expected path (Ellerman and Wing, 2003). The emissions cap determined by an intensity target moves proportionally with the actual GDP and may differ markedly from an absolute cap in a country (Newell and Pizer, 2008).

Linking China's ETS and the European Union ETS requires adjustment of domestic schemes to make them compatible (Ranson and Stavins, 2014). The adoption of absolute versus intensity targets can be one of the major barriers to a linkage (Hawkins and Jegou, 2014). A direct linkage of China’s electricity sector alone to the European Union ETS can considerably reduce carbon prices in the European Union ETS (Gavard et al., 2013). The reduction of carbon prices may prevent the European Union from such a linkage. As shown in the second trading period of the European Union ETS, the supply of carbon offset credits from developing countries is considered one of the major drivers for the allowances surplus together with economic recession. The surplus of allowances results in marked reduction of the carbon prices (European Commission, 2012), showing the potential consequences of linking the European Union ETS with China’s ETS.

Further, both Europe and China have proposed renewable energy targets to reduce domestic GHG emissions. Traditionally, these targets can also benefit energy security, industrial policy and local pollution (see Lehmann and Gawel, 2013 for an overview). Hence, renewable electricity subsidies, e.g., feed-in tariffs, have become the most widely implemented climate-relevant policy. At least 61 countries including many developing countries (REN21, 2011) have implemented such subsidies even though the main policy purposes may differ across countries.

Some studies have estimated the economic impact of the 2020 emissions and energy targets of the European Union (e.g. Bernard and Vielle, 2009; Böhringer et al., 2009; Capros et al., 2011; Tol, 2012). Most of the studies argue that as long as the emissions target is binding, the renewable energy policy cannot reduce additional emissions but may instead lower the carbon price and discourage renewable energy development. Thus, the renewable energy policy may potentially conflict with the ETS. On the other hand, China’s energy target seems more ambitious than its carbon intensity target if GDP continues its rapid growth (Zhang and Bauer, 2013). Some energy-economic modeling studies show that China can reach its carbon intensity target even without any climate policy (Calvin et al., 2012; Glomsrød et al., 2013).

The present paper aims to provide insights into the impact of a joint Europe-China ETS. A region implements an ETS to fulfill its emissions target and renewable electricity subsidies to achieve its energy target. We will assess the impact of a joint ETS covering the OECD Europe[1] (EU) and China and study the role of the renewable electricity subsidies in the joint carbon market from the perspective of key policy-relevant dimensions, i.e., mitigation and cost effectiveness, energy transition, equity and competitiveness.

2. Model and policy scenarios

2.1 The GRACE model

The model for Global Responses to Anthropogenic Change in the Environment (GRACE) is a multi-sector, multi-regional, recursively dynamic global computable general equilibrium (CGE) model (Aaheim and Rive, 2005). The model has been applied to several studies (e.g. Aaheim et al., 2012; Eskeland et al., 2012; Glomsrød et al., 2013; Rypdal et al., 2007). In this version of the GRACE model, the world is divided into 7 regions, i.e., North America, OECD Europe (EU), Japan, China, India, Russia, and the Rest of the World. The regional economy involves activities of 15 production sectors (Table 3, Glomsrød et al., 2013). The model is calibrated around the Global Trade Analysis Project (GTAP) v7 database with 2004 as base year (Badri and Walmsley, 2008), where the world is divided into 113 regions and 57 production sectors[2]. The latest GTAP database is GTAP v8 database with 2007 as base year (Badri et al., 2012). Since some climate policies are emissions targets compared with the 2005 level, it is convenient to use GTAP v7 with 2004 as base year. The database choice will not be an issue for our analysis considering the illustrative purpose of our study.

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[1] OECD refers to the Organisation for Economic Co-operation and Development and OECD Europe include Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey and United Kingdom.

[2] To aggregate the GTAP data by sector and region to the data needed by GRACE, we adopted the codes provided by Rutherford, T.F., (2005) GTAP6inGAMS: The dataset and static model. After slight modification for GTAP 7 database.

Within a region and time period the endowment of production factors (i.e., labour, capital, and natural resources) are exogenous. Labor can move among production activities, whereas capital and natural resources cannot be reallocated among activities. The model assumes full utilization of all available resources. Producers pursue profit maximization and consumers pursue utility maximization. Bilateral trade is modeled with substitution among regional contributions. Income to a region consists of fixed income shares of the remuneration to production factors and taxes collected by the regional government.

Savings as fixed shares of regional income are invested in the world economy such that the changes in rates of return to capital are equalized for all regions. Regional investments are allocated to production activities such that the rates of returns to new capital are equalized, whereas the existing capital is activity-specific. Economic growth is mainly driven by savings and investments, but is also determined by population growth, available natural resources, and technological change. A more detailed description of the standard GRACE model is available in the Appendix.

To study the implications of renewable energy policies, we split the only electricity generation sector into five sub-sectors, i.e., coal-fueled power, gas-fueled power, oil-fueled power, nuclear power, and renewables including hydropower, solar power, wind power, and bioenergy power. All sub-sectors have the same nested constant elasticity substitution (CES) production structure as the initial aggregated electricity sector except for two adjustments. One is that the key fuels used by sub-sectors are demanded proportional to its electricity generation. The other is the introduction of a capacity constraint for the sub-sectors. The electricity generations by sub-sectors are controlled by their capacity constraints such that the sub-sectors may earn net profits in the form of returns to the capacity constraint. A virtual distributor buys all the electricity and supplies users at a uniform price such that the distributor earns zero profit[3].

2.2 Policy scenarios

A business as usual (BAU) scenario reproduces regional GDP growth and associated primary energy consumption as depicted in the New Policies scenario of World Energy Outlook 2010 (IEA, 2010) with one exception that GDP growth rates of China are lowered to be annually 7 percent from 2010 to 2015 and 6 percent onward. Besides the BAU scenario, we design four policy scenarios, each of which introduces regional ETSs from 2011 and yearly emissions abatements in a region are equal from 2011 to 2020.

The first policy scenario, Independent ETS (SN1), introduces independently regional ETS to achieve their mitigation objectives pledged in the Copenhagen Accord (UNFCCC, 2010). In other words, this scenario assumes that EU, Japan, and Russia reduce total emissions to 30 percent, 25 percent, and 15 percent below the 1990 level, respectively. China and India reduce CO_2 emissions intensity by 40 percent and 20 percent in 2020 relative to the 2005 level, respectively. North America reduces total emissions to 17 percent below the 2005 level and the rest of the world keeps emissions at the BAU level.

The second policy scenario, Joint ETS (SN2), differs from the first one (SN1) by assuming that China's ETS is interlinked with the EU ETS to allow trade of carbon allowances between the two regions. The same as in SN1, EU's mitigation target is an absolute cap while China's is a relative cap determined by its carbon intensity target. The joint ETS allows EU to purchase carbon allowances from China until China's relative cap is binding in the sense that carbon

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[3] A detailed description of the electricity generation module can be found in the Appendix 1 of Glomsrød, S., Wei, T., Mideksa, T., Samset, B. (2014) Energy market impacts of nuclear power phase-out policies. Mitigation and Adaptation Strategies for Global Change, 1-17..

allowances purchased by EU are taken into account as part of its carbon emissions. Comparing these policy scenarios can provide insights on the importance of regional mitigation policies for the linkage.

The other two scenarios add policy to achieve the renewable energy target of both renewable electricity and bioenergy accounting for 20 percent of primary energy consumption for EU and both renewable and nuclear electricity accounting for 15 percent of primary energy consumption for China. We have to choose one accounting method for nuclear and renewable electricity. One Exajoule (EJ) of nuclear and renewables can be treated equivalent to three EJ (Option 1) or one EJ (Option 2) of fossil energy (Calvin et al., 2012). We choose Option 1 since it is consistent with the method generally adopted by the Chinese government.

In GRACE, bioenergy is not included as a separate energy type. Renewables not used for electricity generation are assumed to keep a constant share in primary energy consumption for EU. The renewable target for EU is thus achieved by the increasing share of renewables in electricity generation. Both EU and China introduce subsidies for renewable electricity generation to achieve their renewable energy targets in the scenarios. The subsidies are income to the renewable electricity producers additional to what they can obtain from the electricity market. The subsidies make the renewable electricity production competitive towards conventional electricity[4]. The counterpart scenario of SN1 with renewable electricity subsidies is Independent ETS with renewable subsidy (SN3) and the counterpart of SN2 is Joint ETS with renewable subsidy (SN4). These two scenarios aim to investigate the impact of renewable electricity subsidies in the context of a joint EU-China ETS. Table 1 summarizes the differences across scenarios.

(Insert Table 1 about here)

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[4] The efficiency implications related to the different subsidy forms, such as the feed-in tariff or tradable green certificates, is beyond the scope of this study.

3. Results and discussion

3.1 Emissions and CO_2 prices

In both scenarios with separate trading areas, total abatement is higher in both EU and China than in the joint ETS scenarios (Fig. 1). The renewable energy subsidies markedly contribute to additional total abatement in both regions in the case of independent ETS areas, but contribute slightly less to total abatement in the case of interlinked ETS market.

(Insert Fig. 1 about here)

Without the joint EU-China ETS (SN1 and SN3), EU's absolute emissions target is binding, and its emissions are reduced by 18 percent (i.e., 880 million tons CO_2) compared to the BAU level in 2020. On the other hand, in the independent ETS scenario (SN1) China's emissions are even slightly higher than the BAU level. The independently implemented ETSs in all regions increase the cost to use fossil fuels and reduce demand for fossil fuels, leading to lower fossil fuel prices in the world market. Hence, China consumes more fossil fuels since its carbon intensity target does not provide an upper bound for emissions. Meanwhile, motivated by relatively low energy costs in China, emissions-intensive industries in other regions such as EU may also relocate certain production activities to China (see Section 3.5). The emissions in China increase by 3 percent of EU's abatement (i.e., 28 million tons CO_2)[5]. The additional renewable electricity subsidies (SN3), however, encourage renewable electricity production and turn the emissions increase to a marked reduction of 218 million tons (Mt) CO_2 in China, equivalent to 25 percent of EU's abatement. Hence, China's energy target can markedly reduce emissions in the independent ETS case.

With a joint ETS covering EU and China, EU purchases emissions allowances from China where the abatement cost is low. The emissions trade results in EU's emissions above the capped

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[5] Note that India also sets a carbon intensity target and emits more in all four scenarios than the BAU level due to lower prices of fossil fuels.

level in the interlinked ETS scenarios (Fig. 1). EU purchases emissions allowances of around 860 Mt CO_2 in both scenarios, equivalent to almost all EU's domestic abatement when the joint ETS is not in place. In other words, EU achieves almost all its abatement abroad in China. The joint ETS relaxes the absolute cap in EU by allowing EU to purchase excess carbon allowances from China, leading to lower emissions in China. The joint ETS also increases the emissions cost and discourage domestic demand for emissions allowances in China. Both effects result in China's emissions reduced by 410 (SN2) and 434 (SN4) Mt CO_2 in the joint ETS cases compared to the BAU level. Consequently, total abatement in both regions decreases markedly in the joint ETS cases to be around one-half of that in the independent ETS cases, due to the low abatement cost in China with a relative emissions cap determined by its carbon intensity target.

In the joint ETS cases, EU purchases carbon allowances until the relative cap of the joint ETS is binding. Renewable electricity subsidies in China make the abatement cost even lower and encourage more emissions allowances purchased by EU. Further, the subsidies help China achieve its renewable energy target and discourage domestic fossil fuel use, leading to more abatement. Consequently, the renewable energy subsidies reduce additional 24 Mt CO_2 emissions in China. However, EU tends to emit more due to lower carbon cost associated with renewable energy subsidies in both regions. Hence, total abatement in both regions (SN4) is reduced slightly compared to the case without the energy subsidies (SN2). It seems that in the joint ETS case, the renewable energy targets in both regions may not contribute to total abatement in the joint ETS case even though they may modestly contribute to additional domestic abatement in China.

The joint ETS in both regions can result in very low CO_2 price, consistent with the findings of a recent study on making China's electricity sector a carbon trading partner to the European Union ETS (Gavard et al., 2013). In our independent ETS scenario (SN1), the CO_2 prices in 2020 are United States Dollars (USD) 13.6 per ton for EU and zero for China (Fig. 1). The CO_2 price of China is zero because China has already fulfilled its emissions pledge in the BAU scenario where China's carbon intensity declines as economic growth is surpassed by energy efficiency improvement. With a joint EU-China ETS (SN2), the CO_2 price in both regions settles at USD 0.7 per ton, 95 percent below the EU price in the independent ETS case (SN1). China's emissions are around double of EU's emissions in 2020 and China can reduce emissions substantially at very low prices of allowances. The same trade-off is made for the joint ETS when renewable electricity subsidies are considered. However, the renewable electricity subsidies reduce demand for the emissions allowances, resulting in lower CO_2 price in both scenarios with and with the linked ETS.

3.2 Renewable shares and energy import share

The emissions targets alone may not provide sufficient incentives to invest more in renewable energy in the regions to meet their respective renewable energy targets. In the independent ETS scenario (SN1), China's share of renewable energy (including nuclear power) in primary energy consumption is even reduced slightly compared to the BAU level (Fig. 2). Mitigation policy in other regions reduces fossil fuel prices and encourages fossil fuel consumption in regions without an absolute emissions cap. Since China's carbon intensity target is not binding in any of these scenarios, it is feasible for China to increase fossil fuel consumption. On the contrary, the independent EU ETS encourages domestic renewable energy consumption. Compared to BAU, the renewable electricity consumption increases by 37 million tons of oil equivalent (Mtoe), whereas total primary energy consumption falls by 156 Mtoe. Consequently, EU's share of renewable energy in primary energy consumption increases from 14.3 percent in BAU to 17.6 percent in SN1 (Fig. 2). This is still below EU's renewable target of 18.6 percent (corresponding to 20 percent including bioenergy other than bioelectricity). On the other hand, a joint ETS makes China's emissions target binding and encourages renewable energy use, leading to a slight increase in China's renewable energy share. However, the joint ETS leads to very low CO_2 price, meaning renewable energy production is much less profitable in EU than in the independent ETS case. Hence, EU's renewable energy share only increases slightly in SN2 compared to BAU, and ends up at a much lower level than in SN1. The renewable electricity shares in total electricity generation follow almost the same trends as shown in Fig. 2.

(Insert Fig. 2 about here)

If renewable energy targets are binding for both regions, then renewable energy shares in total energy consumption are the same for both ETS cases (SN3 and SN4). However, in the joint ETS case, the renewable electricity share in total electricity generation is slightly lower for China and markedly higher for EU than in the independent ETS case. For China, the joint ETS reduces fossil fuels consumption due to positive CO_2 price and less renewable electricity consumption is required to meet its renewable energy target. For EU, the joint ETS allows EU to consume more fossil fuels by compensating emissions allowances from China. However, to achieve its renewable energy target, EU has to increase renewable electricity consumption, leading to larger renewable electricity share than in the independent ETS case.

Interestingly, the share of energy import in GDP is always smaller than BAU for both EU and China. China tends to import more oil in all policy scenarios but the effect is marginal. The share of energy import in GDP is always markedly lower for EU in the independent ETS when EU faces a limit to emissions that cannot be softened by emissions allowances. If the energy import share is taken as an indicator of energy security, the results demonstrate that the energy security benefits associated with the renewable energy targets are negligible for China where the electricity is generated primarily from domestic resources. In EU, the benefits are observable since coal and natural gas is imported for electricity generation.

3.3 GDP losses

The joint ETS reduces mitigation costs (represented by GDP losses) since the high-cost abatement in EU is substituted by the low-cost abatement in China. GDP losses are smaller for both EU and China in the two joint ETS scenarios than their counterparts (Fig. 3). However, the renewable electricity subsidies have different impacts on the mitigation costs between EU and China. In the independent ETS scenarios (SN1 and SN3), the renewable electricity subsidies (SN3) slightly reduce the mitigation cost in China, but increase the cost in EU. The same impacts are observed in the two joint ETS scenarios. Renewable electricity subsidies reduce the electricity prices, resulting in two opposite effects, i.e., reducing income of the electricity sector and increasing income of the other sectors due to lower cost of electricity inputs. Thus, whether or not the mitigation cost represented by GDP losses is increasing depends on which effect is stronger. In China, the renewable electricity subsidies lower the cost of energy use and encourage activities of the industry and services. The income from these activities outweighs the losses in the electricity sector. In EU, the gains from non-electricity sectors do not offset the losses in the electricity sector.

In absolute terms, total GDP losses in EU and China are the least in the joint ETS without renewable subsidy scenario (SN2) and the highest in the independent ETS with renewable subsidy scenario (SN3). However, if we consider the GDP losses per ton CO_2 abatement, it seems that the joint ETS with renewable subsidy scenario (SN4) are the most expensive (Fig. 3), whereas the joint ETS scenario (SN2) holds the position as the least costly for both regions as a whole.

(Insert Fig. 3 about here)

However, the estimates focusing on the two trading areas only are problematic since the climate and energy policies in both regions affect mitigation costs of other regions through international trade. Particularly, the joint ETS can make other regions better off since the global economy avoids high abatement cost in EU. Hence, the plausible mitigation cost should be calculated as the global GDP losses in both absolute and relative terms. In terms of the global GDP losses, the joint ETS scenario (SN2) is still the least costly, followed by the scenario of joint ETS with renewable subsidy (SN4). Interestingly, the global GDP losses in the independent ETS with renewable subsidy scenario (SN3) are higher than in the independent ETS scenario (SN1), while the global GDP losses per ton CO_2 abatement in SN3 are smaller than in SN1. On the one hand, the renewable energy subsidies are costly for the economy at the aggregate level. On the other hand, because of the relatively high marginal abatement cost in the independent ETS case, the renewable energy subsidies can result in more renewable energy use and reduce the need for other emissions abatement and associated GDP losses. Hence, the global GDP losses per ton CO_2 abatement are reduced with the implementation of the renewable energy subsidies. In the joint ETS cases, the global abatement cost is already very low and the renewable energy subsidies can no longer reduce the GDP losses per ton CO_2 abatement at a greater extent than the aggregate GDP losses.

3.4 Electricity prices, renewable subsidies and financial transfers

Electricity prices

The mitigation cost passes through to the final consumers via energy prices. For example, in the independent ETS scenario (SN1), the CO_2 price is USD 13.6 per ton and the electricity price increases by nearly 3 percent of the BAU level in EU. When the CO_2 price becomes USD 0.7 per ton in the joint ETS scenario (SN2), the increase in the electricity price is lower than one-half percent of the BAU level (Fig. 4).

Renewable electricity subsidies encourage renewable electricity production by reducing production costs. The increasing supply of renewable electricity further reduces the overall electricity price as shown in the renewable subsidy scenarios (SN3 and SN4). It is noteworthy that a renewable energy subsidy together with carbon pricing may also lead to higher electricity price (e.g. Böhringer and Rosendahl, 2010; Fischer, 2010; Traber and Kemfert, 2009). If the subsidy is financed by a tax on electricity consumption, Traber and Kemfert (2009) present two countervailing effects. The electricity price paid by consumers tends to increase because the electricity consumers pay additional taxes to finance the support to renewable electricity generation. On the other hand, more renewables supply reduces the demand for fossil fuels and associated carbon allowances, resulting in lower carbon price and the consumer price of electricity. In their case, consumer prices of electricity decrease slightly in the EU countries apart from in Germany. In our exercise, the renewable subsidies in EU and China come from the government tax revenue. In other words, the renewable subsidies are implicitly paid not only by the electricity consumers, but also by other consumers who pay taxes to the government. Hence, the upward pressure from the tax on electricity prices is contained considerably, resulting in much lower electricity prices in the renewable subsidies scenarios.

(Insert Fig. 4 about here)

Renewable subsidies

To reach their renewable energy targets, EU's and China's renewable subsidy rates depend on carbon prices. Higher carbon prices lower subsidies demand. In 2020, China's renewable subsidy rate reaches 120 percent of the electricity price in the independent ETS case (SN3) and only 24 percent in the joint ETS case (SN4). In EU, the subsidy rate is 85 percent in SN3 and 93 percent in SN4. Hence, in the joint ETS case, the subsidy level is much lower in China and slightly higher in EU than in the independent ETS case.

Financial transfers

The financial transfers from EU to China in the joint ETS with renewable subsidies case (SN4) amount to only USD 0.2 billion[6], which remains marginal compared to the renewable subsidy required in both regions, amounting to USD 102 billion in EU and USD 23 billion in China. The small financial transfers are primarily associated with a very low level of the common carbon price in the integrated carbon market.

3.5 Competitiveness of steel and cement sectors

Mitigation policies have particularly marked impacts on energy-intensive industries, leading to the risk of production and income losses. This raises concern about the competitiveness of those industries in the independent ETS cases. Mitigation policy in a region may reduce domestic fossil fuel use and result in lower energy prices in the world market. The reduction in energy cost encourages energy-intensive industries in countries without absolute binding emissions constraints. We take the steel and cement sectors as an example. In the independent ETS cases (SN1 and SN3), the emissions of both sectors are higher than the BAU level in China, while the emissions are markedly reduced for both sectors in EU (Fig. 5). If the production per unit emissions was constant, then production of the two sectors would be constrained considerably in EU and encouraged modestly in China. However, the production per unit emissions in EU increases since renewables substitute fossil fuels. Consequently, the production of steel and cement varies only one percent around the BAU level.

(Insert Fig. 5 about here)

The mitigation and energy policies have marginal effect on the international trade in the steel and cement sectors. As shown in Fig. 6, relative to the BAU production in 2020, the net export of cement reduces in EU but increases in China in the independent ETS cases (SN1 and SN3). The

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[6] The transfer is USD 0.6 billion in the case without the renewable subsidy (*SN2*).

picture for steel is mixed mainly because steel is more exposed to international trade than cement. The net export of steel from EU reduces in SN1 but increases in SN3, while it increases in both independent scenarios for China. The renewable subsidy policy can dampen, to some extent, the increase in the electricity price caused by the emissions control policy and thus weaken the competitiveness challenge. In addition, an integrated carbon market with very low CO_2 price can almost eliminate the problem by synchronizing the trends on emissions and net export of the steel and cement in the two regions, as shown by SN2 and SN4 (Fig. 6). In the joint ETS with renewable subsidy scenario (SN4), the increase in the net export of steel in EU even markedly outweighs that in China.

(Insert Fig. 6 about here)

4. Conclusions

We have assessed the impact of a joint EU-China emissions trading scheme (ETS) in a global computable general equilibrium model (GRACE). The key results of our analysis are summarized in Table 2. We cannot find the best scenario in terms of all the key policy-relevant dimensions, i.e., mitigation and cost effectiveness, energy transition, equity and competitiveness. Hence, the preferred policy mix is a trade-off between these key policy-relevant dimensions.

(Insert Table 2 about here)

From the perspective of mitigation effectiveness, a joint ETS can reduce CO_2 abatement by roughly one-half compared to the independent ETS case. Since China's carbon intensity target does not determine an absolute emissions cap, renewable energy subsidies can lead to additional abatement in China. On the contrary, the renewable energy subsidies in EU can only lower carbon prices and have no effect on the abatement as long as the absolute emissions cap is binding.

From the cost effectiveness point of view, the joint EU-China ETS is the most preferred in terms of global GDP losses, but may be less preferred in terms of GDP losses per ton CO2 abatement for both regions as a whole. The renewable electricity subsidy policy has different effects on mitigation costs of EU and China. The energy policy in China reduces the mitigation cost in terms of GDP losses even though the carbon intensity target is not binding. By contrast, facing an absolute emissions cap, EU faces a trade-off between renewable energy objective and carbon price incentive.

Depending on the energy policy implementation, a joint EU-China ETS can generate opposite energy-transition incentives. Without the renewable energy targets, China increases its renewable share in primary energy consumption in the joint ETS case. However, the joint ETS lowers the share of renewable electricity in total electricity generation when renewable energy targets are realized through subsidies. In both situations, EU experiences the opposite trends.

While the joint ETS can alleviate the concern on competitiveness faced by EU's emissions-intensive industries, the equity issue remains unsolved because EU always prefers a scenario that China does not prefer. Further, renewable energy subsidies required in China still largely outweighs the financial transfer through the carbon market from EU to China.

Our study shows that China's carbon intensity target allows for more emissions in a joint EU-China ETS where the carbon price is too low to be accepted by EU. Additionally, in a joint EU-China ETS, the renewable energy targets do not induce more abatement in the common trading area even though the energy target does induce more abatement within China. Generally, if developing countries insist on emissions intensity targets due to political feasibilities, sectoral policies towards renewable energy targets can reduce mitigation costs and achieve higher abatement even though their energy-security benefits might be modest. On the other hand, international transfers have been expected to buy-in developing countries into a coalition of mitigating countries. In a joint ETS, however, unlimited access to low-cost abatement may markedly decrease the carbon price and affect the effectiveness of the joint ETS. Hence, compatible climate and energy policies are necessary for establishment of any joint ETS.

Appendix A. Description of the GRACE model

As a recursively dynamic model, GRACE finds a static general equilibrium solution for a period given exogenous settings, which can be updated from one period to another. For example, total returns to capital of all regions are allocated to regions proportional to shares of regional savings at the beginning of a period. After receiving its share of returns to capital and other income, a region allocate a fixed share of its income for investment in the global economy such that the changes in expected rates of return to capital are equalized for all regions. The investment forms new capital stock available for the next period. In a region, productivity of labor and natural resources increases at the same rates as GDP growth while productivity of capital keeps constant over time. The effective supply of labor and capital is updated such that economic growth approximately follows a plausible projection.

Interregional commodity flows may include international trade and transboundary flows of capital, labor, natural resources, and greenhouse gas emissions. This version of GRACE does not allow transboundary flows of labor and natural resources. Capital existing already at the beginning of the previous period is immobile even between production activities even though its depreciation together with investments forms new capital at the end of the previous period. The new capital is fully mobile across production activities and regions to equalize expected changes in the rates of returns to capital.

International trade is modeled through a nested constant elasticity of substitution (CES) function (Fig. A1). The parameters starting with small letter ‘e’ indicate the elasticities of substitution at the level where they stay. An Armington good combines domestic production and an aggregate of imports from all other regions. Exceptions of the elasticities are made for the following sectors: (a) refined oil (eARM = 6), (b) electricity (eARM = 0.5; eIMP = 0.3), and (c) gas and coal (eIMP =4). With the trade of a good, the importing country pays a fixed unit cost to the international transport sector. The international transport is provided by a Cobb-Douglas composite of regional transport services.

(Insert Fig. A1 about here)

Fig. A2 illustrates the economic activities of a region. Together with intermediate inputs of goods and services, available productive resources – capital (CAP), labor (LAB), and natural resources (RES) – are utilized to produce goods and services, which can export to other regions and meet final demand for domestic private and public consumption and investments together with imported substitutes. Investments form new capital for the next period. As by-products, greenhouse gas emissions accompany with these economic activities. CO_2 emissions from fossil fuels (Lee, 2008) are linked to fossil fuels used by producers and households by fixed emission factors.

(Insert Fig. A2 about here)

Sectoral production is simulated by two types of nested CES functions. One type is illustrated in Fig. A3 for production of primary energy, i.e., crude oil, coal, and gas. To highlight the dependence on natural resources, the top level is a combination of the natural resource and an aggregate of remaining inputs. At the middle level, the remaining inputs are a Leontief composite of intermediate goods and value added, where the value added combines capital and labor.

(Insert Fig. A3 about here)

The other type of production functions (Fig. A4) is for goods and services other than the primary energy. The top level is a Leontief composite of intermediate non-energy inputs and an aggregate of value-added and energy inputs (VA-Energy). The next level is a combination of value-added and energy inputs. The value added is further a combination of capital and labor. The energy inputs are a combination of electricity (ELC) and other energy inputs as a Cobb-Douglas aggregate of crude oil (CRU), coal (COL), refined oil (REF), and gas (GAS).

(Insert Fig. A4 about here)

Fig. A5 illustrates the demand structures of consumers and investors. At the top level, substitution can be made between energy and non-energy goods. At the bottom level, the energy combines five energy goods and the non-energy combines all the other goods.

(Insert Fig. A5 about here)

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References

Aaheim, A., Amundsen, H., Dokken, T., Wei, T. (2012) Impacts and adaptation to climate change in European economies. Global Environmental Change-Human and Policy Dimensions 22, 959-968.

Aaheim, A., Rive, N., (2005) A Model for Global Responses to Anthropogenic Changes in the Environment (GRACE), Report. CICERO, Oslo, Norway.

Badri, N., Aguiar, A., McDougall, R., (2012) Global Trade, Assistance, and Production: The GTAP 8 Data Base. Center for Global Trade Analysis, Purdue University, http://www.gtap.agecon.purdue.edu/databases/v8/v8_doco.asp.

Badri, N.G., Walmsley, T.L., (2008) Global Trade, Assistance, and Production: The GTAP 7 Data Base. Center for Global Trade Analysis, Purdue University, https://www.gtap.agecon.purdue.edu/databases/v7/v7_doco.asp.

Bernard, A., Vielle, M. (2009) Assessment of European Union transition scenarios with a special focus on the issue of carbon leakage. Energy Economics 31, Supplement 2, S274-S284.

Böhringer, C., Löschel, A., Moslener, U., Rutherford, T.F. (2009) EU climate policy up to 2020: An economic impact assessment. Energy Economics 31, Supplement 2, S295-S305.

Böhringer, C., Rosendahl, K. (2010) Green promotes the dirtiest: on the interaction between black and green quotas in energy markets. Journal of Regulatory Economics 37, 316-325.

Calvin, K., Clarke, L., Krey, V., Blanford, G., Jiang, K., Kainuma, M., Kriegler, E., Luderer, G., Shukla, P.R. (2012) The role of Asia in mitigating climate change: Results from the Asia modeling exercise. Energy Economics 34, Supplement 3, S251-S260.

Capros, P., Mantzos, L., Parousos, L., Tasios, N., Klaassen, G., Van Ierland, T. (2011) Analysis of the EU policy package on climate change and renewables. Energy Policy 39, 1476-1485.

Ellerman, A.D., Wing, I.S. (2003) Absolute versus intensity-based emission caps. Climate Policy 3, Supplement 2, S7-S20.

Eskeland, G.S., Rive, N.A., Mideksa, T.K. (2012) Europe's climate goals and the electricity sector. Energy Policy 41, 200-211.

European Commission, (2012) The state of the European carbon market in 2012, Report from the Commission to the European Parliament and the Council.

Fischer, C. (2010) Renewable Portfolio Standards: When Do They Lower Energy Prices? The Energy Journal 31.

Gavard, C., Winchester, N., Paltsev, S., (2013) Limited Sectoral Trading between the EU ETS and China, Joint Program Report Series.

Glomsrød, S., Wei, T., Alfsen, K. (2013) Pledges for climate mitigation: the effects of the Copenhagen accord on CO2 emissions and mitigation costs. Mitigation and Adaptation Strategies for Global Change 18, 619-636.

Glomsrød, S., Wei, T., Mideksa, T., Samset, B. (2014) Energy market impacts of nuclear power phase-out policies. Mitigation and Adaptation Strategies for Global Change, 1-17.

Hawkins, S., Jegou, I., (2014) Linking Emissions Trading Schemes: Considerations and Recommendations for a Joint EU-Korean Carbon Market. International Centre for Trade and Sustainable Development, Geneva, Switzerland, www.ictsd.org.

IEA (2010) World Energy Outlook 2010, International Energy Agency.

Lee, H.-L., (2008) The combustion-based CO_2 emissions data for GTAP version 7 data base. GTAP.

Lehmann, P., Gawel, E. (2013) Why should support schemes for renewable electricity complement the EU emissions trading scheme? Energy Policy 52, 597-607.

Newell, R.G., Pizer, W.A. (2008) Indexed regulation. Journal of Environmental Economics and Management 56, 221-233.

Newell, R.G., Pizer, W.A., Raimi, D. (2014) Carbon Market Lessons and Global Policy Outlook. Science 343, 1316-1317.

Ranson, M., Stavins, R., (2014) Linkage of greenhouse gas emissions trading systems: Learning from experience. National Bureau of Economic Research, Cambridge, MA, Working Paper 19824.

REN21, (2011) Renewables 2011 Global Status Report, Paris, Renewabl Energy Policy Network for the 21st Century (REN21) Secretariat.

Rutherford, T.F., (2005) GTAP6inGAMS: The dataset and static model.

Rypdal, K., Rive, N., Åström, S., Karvosenoja, N., Aunan, K., Bak, J.L., Kupiainen, K., Kukkonen, J. (2007) Nordic air quality co-benefits from European post-2012 climate policies. Energy Policy 35, 6309-6322.

Tol, R.S.J. (2012) A cost–benefit analysis of the EU 20/20/2020 package. Energy Policy 49, 288-295.

Traber, T., Kemfert, C. (2009) Impacts of the German Support for Renewable Energy on Electricity Prices, Emissions, and Firms. The Energy Journal 30.

UNFCCC, (2010) Information provided by Parties to the Convention relating to the Copenhagen Accord, in: Change, U.N.F.C.o.C. (Ed.).

Zhang, D., Karplus, V.J., Cassisa, C., Zhang, X. (2014) Emissions trading in China: Progress and prospects. Energy Policy.

Zhang, S., Bauer, N. (2013) Utilization of the non-fossil fuel target and its implications in China. Climate Policy 13, 328-344.

Table 1. Differences between the BAU and policy scenarios

	Region	**BAU**	**Independent ETS (SN1)**	**Joint ETS (SN2)**	**Independent ETS with renewable subsidy (SN3)**	**Joint ETS with renewable subsidy (SN4)**
2020 emissions reduction targets	EU	No	30 percent from 1990	30 percent from 1990	30 percent from 1990	30 percent from 1990
	China	No	Carbon intensity reduced by 40 percent from 2005	Carbon intensity reduced by 40 percent from 2005	Carbon intensity reduced by 40 percent from 2005	Carbon intensity reduced by 40 percent from 2005
2020 renewable targets	EU	No	No	No	20 percent	20 percent
	China	No	No	No	15 percent[*]	15 percent[*]
Interlinked ETS	EU & China	No	No	Yes	No	Yes

[*] The non-fossil fuel (including nuclear power) share in total primary energy consumption.

Table 2. Overview on the simulation results of policy scenarios

	Indicator	**Region**	**SN1**	**SN2**	**SN3**	**SN4**
Mitigation effectiveness	Total abatement		+++	++	++++	+
Cost effectiveness	GDP losses	EU	+++	++++	+	++
		China	+	+++	++	++++
	Global GDP losses per ton CO$_2$	Global	+	++++	++	+++
Energy transition	Renewable share in the primary energy	EU	+++	++	++++	++++
		China	++	+++	++++	++++
	Renewable electricity share	EU	++	+	+++	++++
		China	+	++	++++	+++
Equity	Electricity price	EU	+	++	+++	++++
		China	++	+	++++	+++
	Renewable subsidy	EU	NA	NA	++	+
		China	NA	NA	+	++
	Financial transfer		NA	++	NA	+
Competitiveness	Net exports of steel	EU	+	++	+++	++++
		China	++++	++	+++	+
	Net exports of cement	EU	+	+++	++	++++
		China	+++	+	++++	++

Note: “++++” denotes the most preferred case. The less “+”means the less preferred. Only one “+” denotes the least preferred case. “NA” means inapplicable.

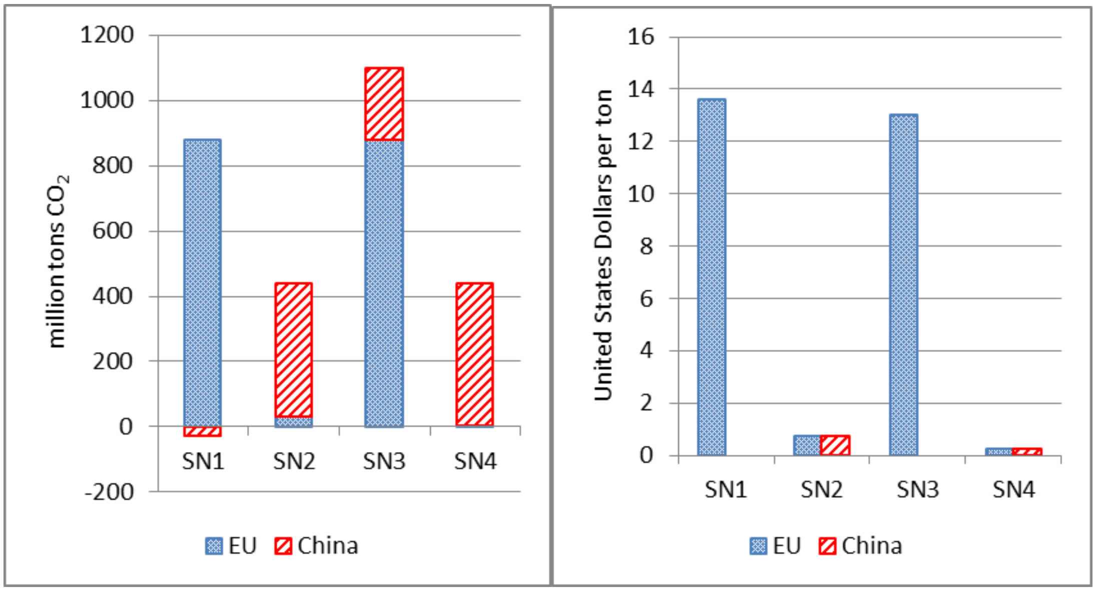

Fig. 1 Abatements in 2020 compared to BAU (left) and CO_2 prices in 2020 (right)

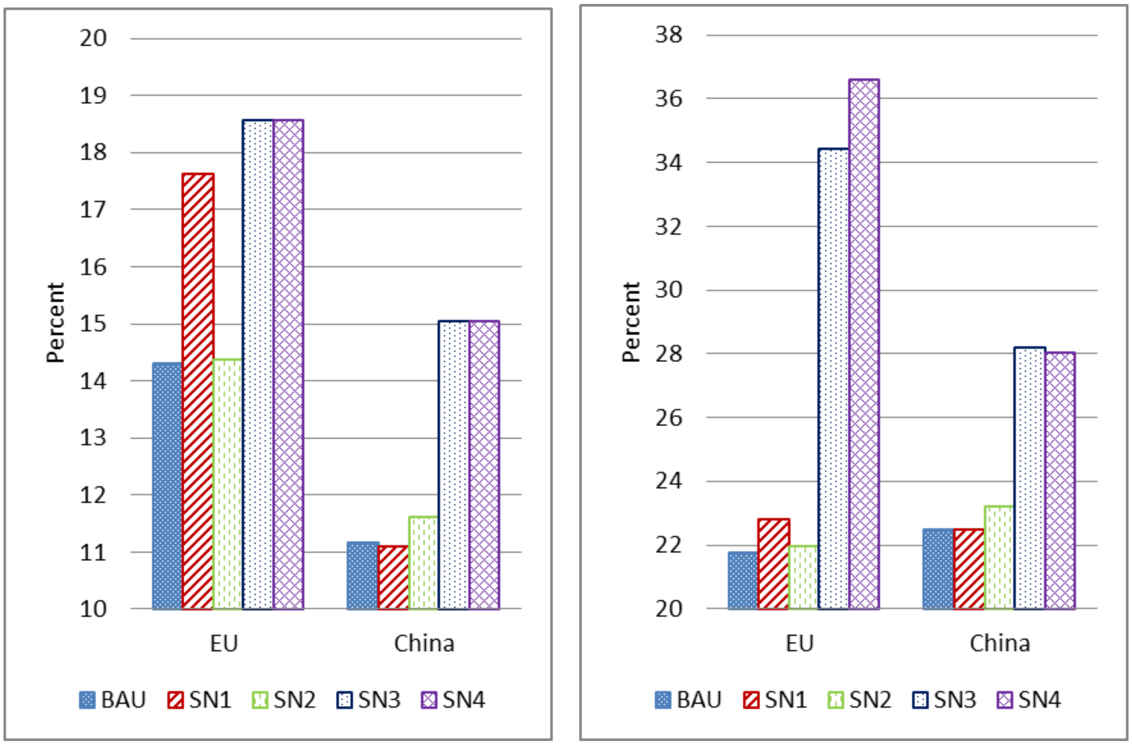

Fig. 2 Renewable energy shares in primary energy consumption (left) and renewable electricity shares in total electricity generation (right) in 2020. In both cases, nuclear power is included in the renewable energy for China and excluded for EU.

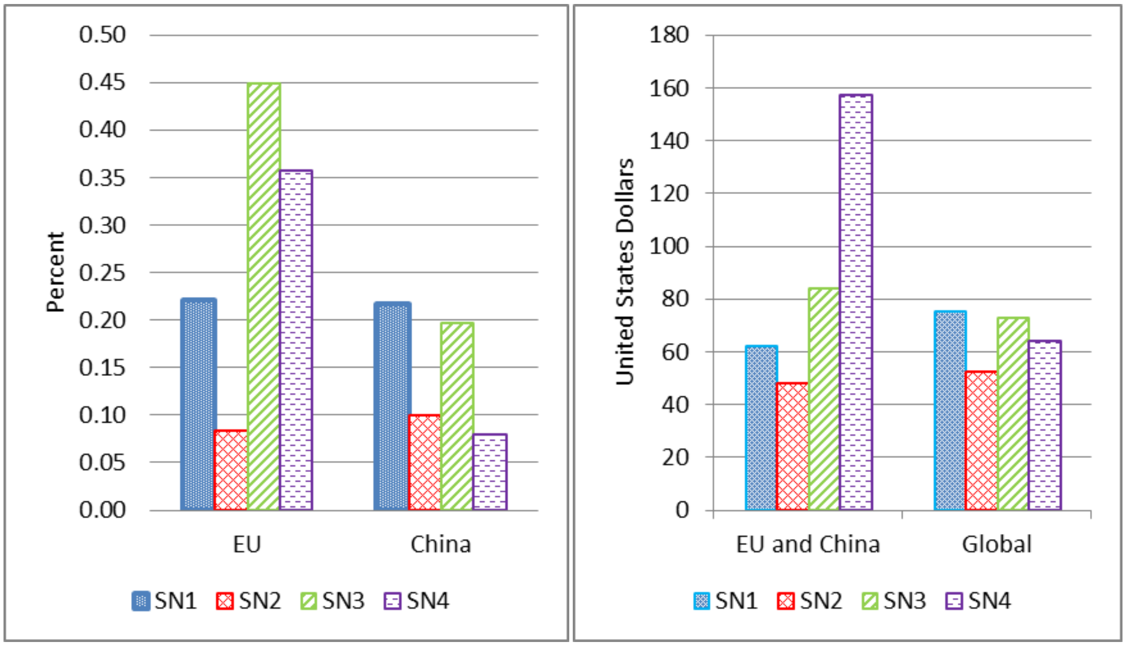

Fig. 3 GDP losses as shares of the GDP level in BAU 2020 (left) and GDP losses per ton CO_2 abatement (right)

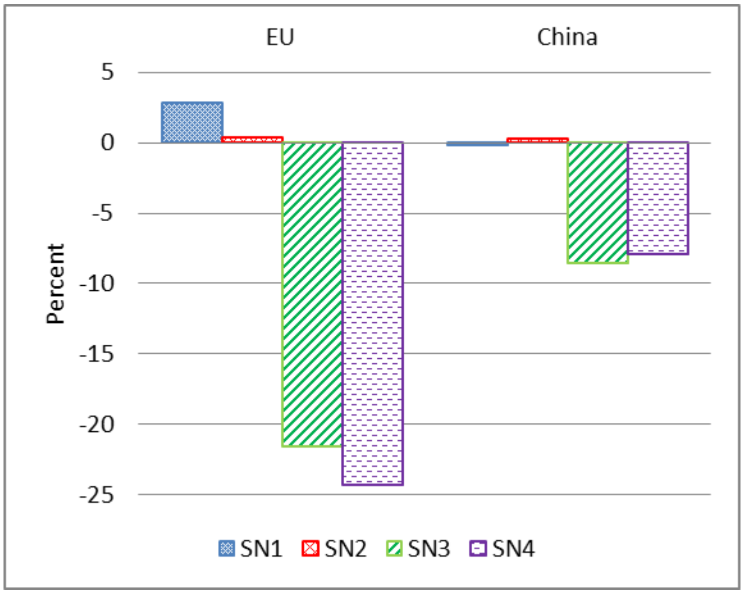

Fig. 4 Deviations of electricity prices from BAU 2020.

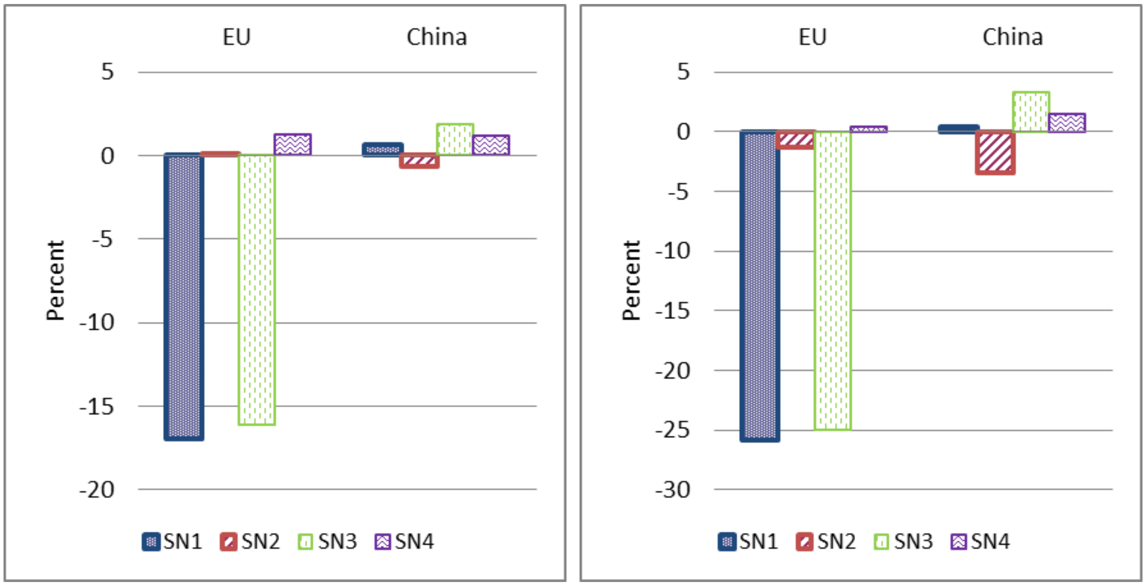

Fig. 5 Deviations of emissions from BAU in the steel sector (left) and the cement sector (right).

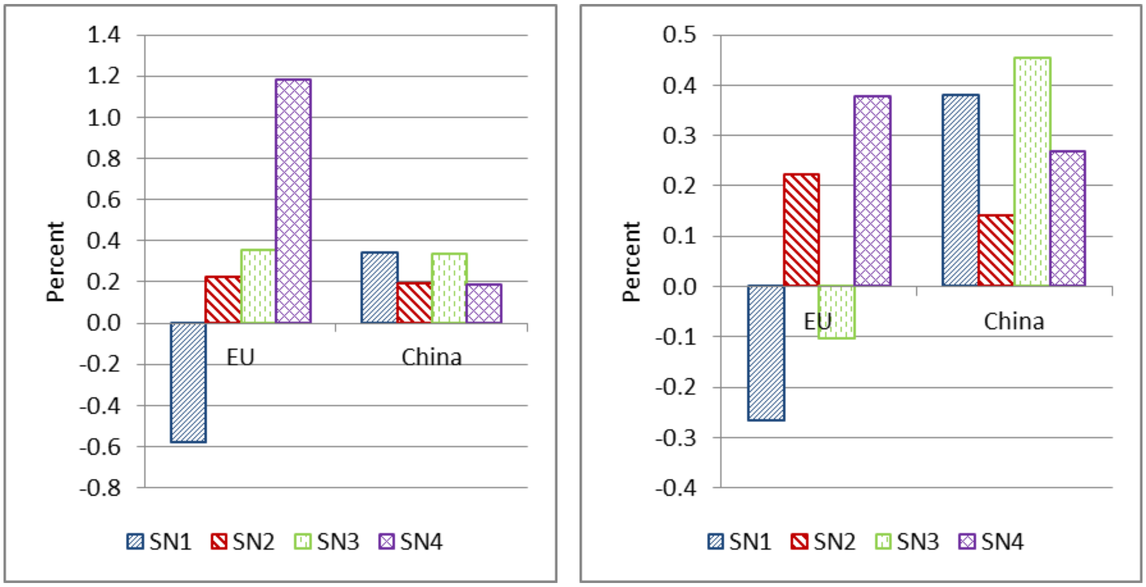

Fig. 6 Deviations of net exports from BAU as shares of domestic production in BAU in the steel sector (left) and the cement sector (right).

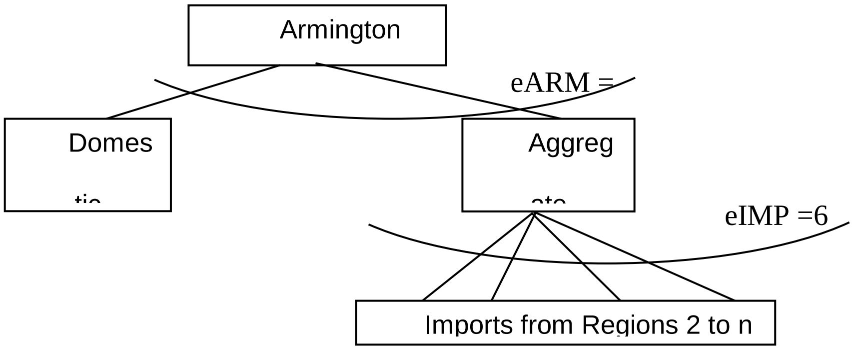

Fig. A1: Bilateral imports and the Armington aggregate. The parameters starting with small letter "e" indicate the elasticities of substitution at the level where they stay.

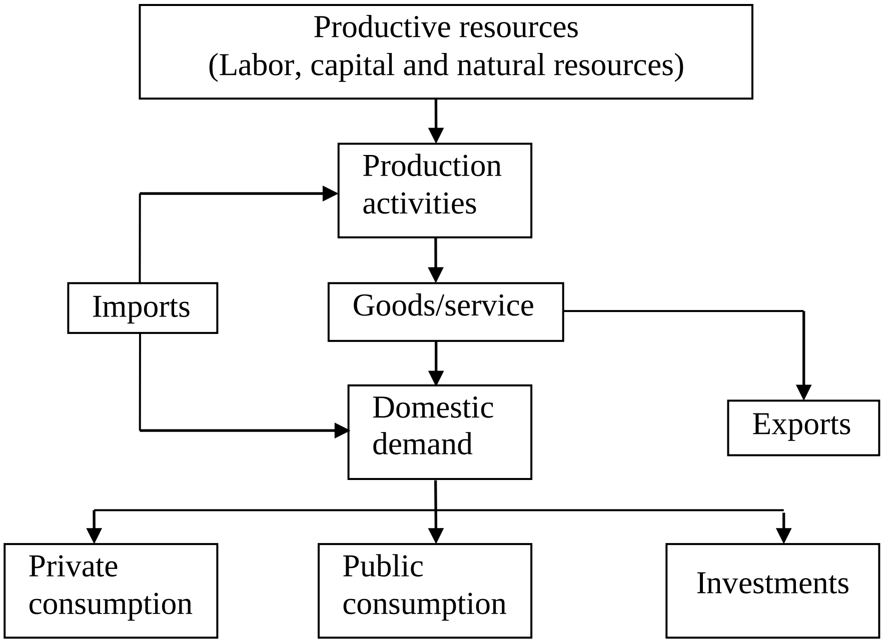

Fig. A2. Economic activities of a region

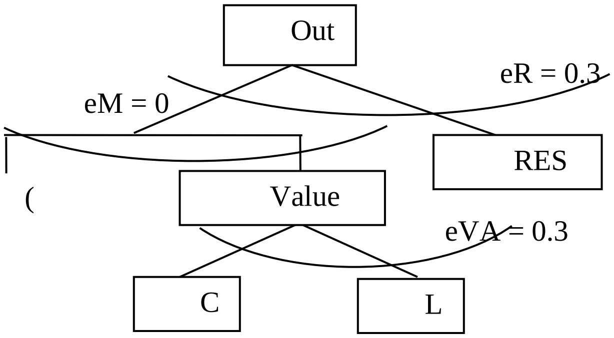

Fig. A3: Production structure of primary energy goods. The parameters starting with small letter "e" indicate the elasticities of substitution at the level where they stay.

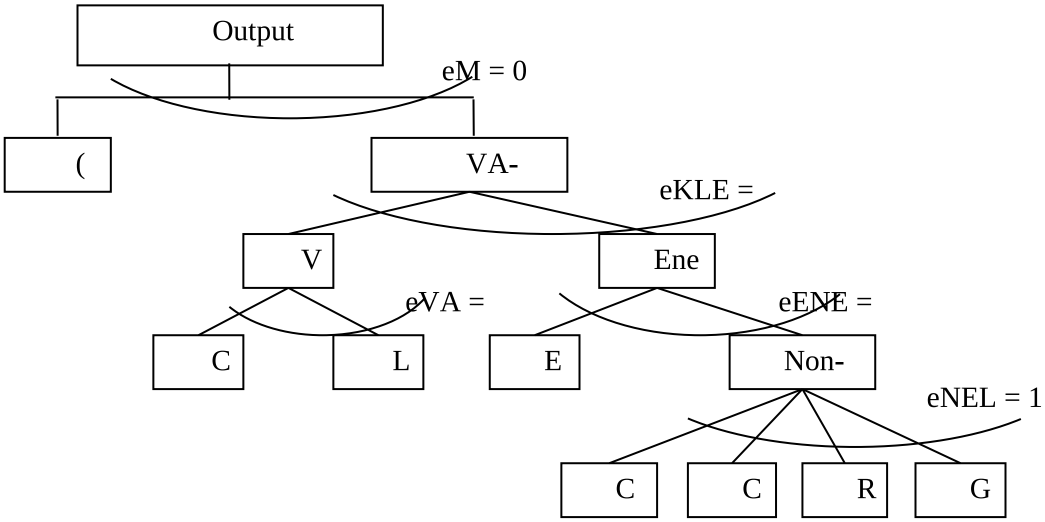

Fig. A4: Production structure of goods/services other than primary energy. The parameters starting with small letter "e" indicate the elasticities of substitution at the level where they stay.

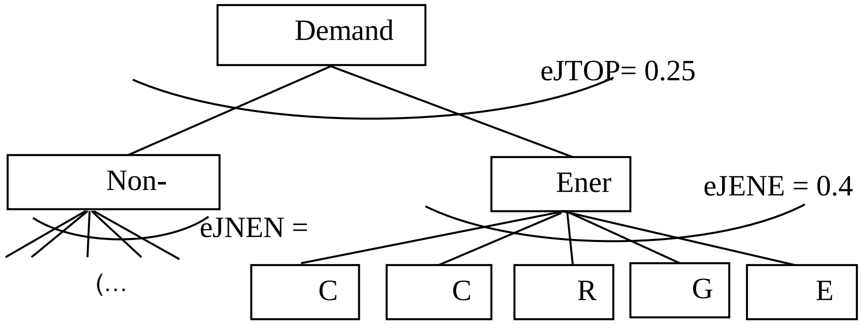

Fig. A5: Final demand structure in GRACE-EL. The parameters starting with small letter "e" indicate the elasticities of substitution at the level where they stay.