# Potential Integration of Chinese and European Emissions Trading Market: Welfare Distribution Analysis

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**Abstract**

Central to the aims of the Paris Agreement, a multilateral coordinated action through integrated carbon markets has been a practical bottom up option for effective and efficient mitigation. This paper quantifies the welfare effects of potential integration of Emission Trading Scheme (ETS) between the European Union (EU) and China. The analysis is performed up to the year 2040, assessing the economic and welfare impacts for China and 28 EU Member States. Using the European version of the computable general equilibrium model GEMINI-E3, the analytical assessment reveals that integrating trading markets is beneficial for both regions, albeit stronger for the EU. Linking the EU-China trading market decreases welfare cost from abatement to some notable countries with high constitutes of energy-intensive industries such as Poland, Romania and the Czech Republic. A few others, such as Netherland and Ireland, face higher welfare cost from negative

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gain of trade. Limiting the trade quotas up 30 per cent, captures most of the welfare gain coming from $CO_2$ trading for the EU. Further analysis in sectoral level finds that market integration significantly minimizes the loss of competitiveness of European energy-intensive industries and reduces the international leakage. Our finding thus confirms the potential of emissions trading market as an effective instrument to facilitate multilateral coordination in global mitigation.
*Keywords:* European Union, China, Paris Agreement, Computable general equilibrium model, Emissions trading system, Linking

## 1. Introduction

Voluntarily basis of Paris Agreement (PA) brings flexibility for countries in adopting their own choices of policy measures to reduce carbon emissions. Through emerging economic, a domestic policy instrument now affects emission of others through the international trade. It further raises a political concern for the need of coordinated action across countries in term of carbon market and international cooperation. This is one of the key outcomes agreed at the recent climate conference of the United Nations, and currently holds a highest profile of casualties of climate negotiation and a priority to be resolved.

Integrating the current Emission Trading Schemes (ETS) is arguably one way to initiate this coordinated action and creating international cooperation through bilateral or multilateral agreement. Linking and re-sharpening ETS is practical bottom up option for mitigating global emissions (Newell et al., 2014), where countries could meet their emission target in a fair and sustainable way based on their economic capacities. ETS linkage initiates a global free restriction market where countries' National Determined Contributions (NDCs) efficiently achieved, and solves the stagnation of the current global climate negotiations.

Currently, there are more than 15 trading schemes operating around the world that covers various geographic scales. Among those, prior to mention is the European Union (EU) ETS. It is the first carbon trading market and the world's largest cap-and-trade system. More than 75 per cent of international carbon trading takes place in this region (European Commission, 2017) which covers all 28 Member States (MSs) along with European Economic Area members of Norway, Liechtenstein and Iceland. The EU ETS has become a key instrument to achieve its climate policy targets, and the forefront of international actions of global mitigation and climate negotiations (Delbeke and Vis, 2016).[1]

The EU initiates a number of regional level initiatives to counter climate effects, including full adoption of Climate Act in 2009 and the climate and energy framework of 2030 towards low carbon economy by 2050. Under the EU ETS, a cap or upper limit can be placed on the total amount of Green House Gases (GHG)[2] emitted by power or manufacturing plants, classified under the system. Around 11,000 plants in Europe are involved, and the cap could be reduced overtime for lower supply of allowances and greater incentives for abatements. Firms can receive free allowances via primary auctions and buy additional credits or sell the unused in the ETS market. Heavy fines will be imposed for negative imbalance of emission allowances at the end of the year. The open trading mechanism under ETS has supported the development of low carbon technology in production in

[1]EU28 was responsible for 7.87 per cent of global GHG emission, after China on 23.67 per cent and the United States of America on 12.88 per cent – including land-use change and forestry (World Resources Institute, 2017).

[2]Carbon Dioxide ($CO_2$), Methane ($CH_4$), Nitrous Oxide ($N_2O$) and Perfluorocarbons (PFCs).

the EU.

In line with the EU, China has also announced a national ETS in 2015 and implemented the pilot in seven provinces (Zhang et al., 2014). As the world greatest emitter, China focuses on its climate policies and actions to specific sectors from the energy and transportation to the agriculture and forestry. Those aim to fulfill the carbon intensity target of lowering $CO_2$ emissions per unit of Gross Domestic Product (GDP) by 60–65 per cent by 2030 from the 2005 level, and reaching peak at same year (UNFCCC, 2010). China's trading scheme involves two big cities of Beijing and Shanghai, two industrial municipalities of Tianjin and Chongqing, two provinces of Guangdong and Hubei, and the special economic area of Shenzhen.[3] During the first stage, China's carbon market covers the emission-intensive enterprises in the eight major industrial sectors, including petrochemical, energy intensive sectors, electricity and aviation. In 2016, the accumulated trading volume in all the pilot markets accounted for 68.6 $MtCO_2$, with a total value of CNY 1.1 billion or EUR 153 million (Welfens et al., 2017). Shenzens held the highest market values of CNY 298 million, while the largest share of trading volume was recorded in Guangdong for 23.4 $MtCO_2$. This potential growth in China market could support the introduction of a nationwide ETS system in China that once completed will be the largest carbon emissions trading market in the world.

As a major economic and political actor in the world economy, China's progress with ETS is critical. With the increasing tension for more significant abatement at the global scale, coordinated action between China and the EU's ETS could be a prominent solution for more effective global mitigation. Both roles in

[3] Fujian province became the eighth pilot market in 2016.

leading climate action are substantial after the US withdrawal from the PA, and zero chance that it will come on board with its national ETS system. ETS allows flexibility, thus an integrated market in both regions could also encourage developing countries to participate in a climate agreement. The emissions cap is determined by an intensity target that moves proportionally with the actual GDP and may differ markedly from an absolute cap in a country (Newell and Pizer, 2008). This scheme eases the negotiation process that leads to more participation in climate agreement.

On the other hand, integrating the EU and China trading market also raises question on the economic outcomes, conditioning to the current defined climate target for both countries, and on the sufficient impacts in stabilization of the global mitigation. These policy questions that this paper aims to address. The analysis will also cover the comparative analysis to decompose the welfare cost of the integrated market, and the optimal level of trading limit. The approximate decomposition includes the welfare gain from trade on both commodities and emission quota and the excess burden from the emission reduction. In the complement to the previous study, the analysis is directed towards the economic impacts for each 28 EU MSs, and how it differs amongst them. This point becomes the novelty of this paper. The analysis is performed up to the year 2040 by taking into account each regions last decision regarding the climate target, using an adaptation of a recursive dynamic general computable equilibrium model of GEMINI-E3.

Integration between the EU and China ETS gives positive implications in both regions, yet more robust for Europe. Welfare cost of the abatement falls in the majority of MSs, especially for countries with high energy intensive industries. Despite a few states experiencing negative gain from trade, limiting the trade quota to certain threshold will ensure the optimum welfare gained for each MSs, thus minimize the political doubtless of this potential policy.

The remainder of this paper is structured as follows. Section 2 presents the existing literatures on the current development of ETS. It focuses on the energy and economic impacts for implementation for single trading market implementation and some potential integrated cases for the EU and China. The current climate changes policies in the EU and China are elaborated in Section 3, ensuring the current updates and policy measures are included the analysis. Section 4 provides the explanation of the GEMINI-E3 model that being used to perform the welfare evaluation and decomposition. The scenario results are presented in Section 5, while Section 6 concludes the findings.

## 2. Current Studies and Development of the EU and Chinese ETS

For China and countries in the EU, most literature reveals ETS gives a relatively small impact on the overall economy.[4] Analytical studies of Wu et al. (2016), Meng et al. (2018) and Cao et al. (2019) find that ETS can help to reduce emissions effectively and with no significant distortion on overall China's economy. The impact on GDP at national level is positive, admitted the different implication among the sectors. The largest impact will be on the employment on China's coal industry (Huang et al., 2019), while another study of Mu et al. (2018) confirms that positive growth for industrial remains possible under ETS for its short-term flexibility. The number of industries involved in the market is clearly matters as the more will lead to a higher GDP and a lower carbon price Lin and Jia (2019b).

[4]Literature measured the impact and effectiveness of a single ETS implementation, mostly focus in a specific country.

Industry coverage could be adjusted to ensure the critical sectors are included.

For the EU, ETS has been instrumental for effective mitigation strategies (Muûls et al., 2016). In the first two years implementation, approximately 100 to 200 $MtCO_2$ were abated across all ETS sectors.[5] During the second phase, emission intensity was significantly reduced by 3.35 per cent. By the end of 2016, or the final year or the second phase, the EU emission is 43 per cent less than the 2005 level.

In line with this, there has been no detrimental effect on the economic performance since the first phase of implementation of the EU ETS (Hu et al., 2015; Bel and Joseph, 2015). The power and manufacturing industries pass on the additional cost to consumer with relatively insignificant escalation in output price. The sectoral level analysis, however shows that during the first implementation, there was a small negative effect on return of capital. But there was no effect on employment, productivity and investment thus rule out the concern of the adverse economic effects in losing competitiveness.

To name a few of the European cases, the sectoral impacts from the EU trading market is generally positive. Focusing on German electricity sector, Schaefer (2019) evaluates the EU ETS's impact on $CO_2$ emission reduction, and finds that intensity-based emission is more effective than the absolute cap. Löschel et al. (2019) investigates the impact of German manufacturing firms and also concludes that the EU ETS has a positive effect as it may encourage investment in a more efficient capital stock, that will allow companies to produce more products with fewer inputs.

[5] It represents 2.4 to 4.7 per cent of total emission reduction.

Integrating both EU and China trading market has been a centre of analysis of current research (Heindl and Voigt, 2012; Fragkos et al., 2018). Admittedly, the focal points only covers the macro perspective in both regions. The detail analysis on the national level, particularly for each EU MSs is out of scope. A multilateral or bilateral integration on existing ETS is becoming the policy directions on climate negotiation to strengthen the international cooperation in climate change mitigation and adaptation. Integration of the EU and China market is potential as China's lower abatement cost, in particular, attracts the EU to consider it as potential market to offset their permits. In addition to this, the electricity generation industry has been the largest source of $CO_2$ emission in both regions (Zeng, 2017).

A potential integration for the EU ETS market focusing on the economic impacts for the MSs, has been addressed by the study of Alexeeva and Anger (2016). Yet the study measures the macro economic welfare impacts and trade competitiveness for the EU and non-EU in Europe. Using both a stylised partial market and general equilibrium analysis, the study confirms that the economic efficiency losses are diminished by integration. The EU MSs improves their term of trade by the emerged market, while the non-EU face the opposite trade effect with competitiveness losses. This conclusion underlines the importance of the welfare analysis for the integrated ETS market, complementing the effort for common agreement in future climate negotiation.

The analytical study of potential linking between the EU and China started with Gavard et al. (2013) which analyzes the impact of trading in carbon permits between the EU ETS and Chinese electricity sector using the EPPA CGE model. Their analysis reveals that the European carbon price would decrease by more that

76 per cent under condition of unlimited sector trading. As the general equilibrium effect dominates the revenue effect, the EU is generally better off but the impact is contradictory for China. This finding is then confirmed by their latest study of Gavard et al. (2016). Extending the analysis by adding the US in the integrated market, again the EU and now the US have welfare improvements. China is still worse off.

Other notable studies focusing on thee sectoral analysis, however, reveals different cases. Using the Global Responses to Anthropogenic Change in the Environment (GRACE) model, Liu and Wei (2016) find that the integrated market can help China achieve its renewable energy target accompanied by $CO_2$ emissions and abatement cost reduction. But integration will do the opposite for the EU's renewable. The recent study of Li et al. (2019) also confirms that unlimited linking of EU and China ETSs can benefit the development of clean energy in China, but hinder to meet the EU's renewable energy target.

Limited linking is more feasible in the middle term, since the EU and China are able to achieve 5 per cent more $CO_2$ emission reduction without additional welfare losses. However, this limited linking creates at best a small benefit for China (Hübler et al., 2014), giving the transfer volume to one third of the EU's reduction effort. Zhang et al. (2017) points out the integration will result in the redistribution of clean energy and effect the international competition in participating countries. The integration could optimize the allocation of emissions permit and bring economic welfare for permits importing countries. This effect is stronger for China, yet weak for the EU renewable industry.

In the perspective of carbon leakage, the potential integration ETS market between two markets has a positive implication as well. At first, Marschinski et al.

(2012) contends that linking the carbon trading market will be effective in reducing emissions for it includes a country with certain abatement target. Taking the electricity sector under China and the EU's ETS, Zeng et al. (2018) suggests that potential leakage from China to the EU is significantly reduced by integrating both markets, and it should be a main consideration in the future climate negotiations.

In the complementary of these literature, this paper aims to re-assess and to evaluate the potential integration between China and the EU ETS. It focuses on the welfare effects on each EU MSs and finding the optimal level of limited trading by incorporating the existing climate targets. A recursive dynamic general equilibrium model of a GEMINI-E3 is used to simulate the impact of with/without integrating the ETSs on welfare under these two scenarios up to 2040.

## 3. Climate change policies

### *3.1. European climate policy*

The EU climate actions have been directed through implementing a sustainable climate and energy policy (Tol, 2012). In 2018, the European Commission (EC) presented the strategic long-term vision for a climate-neutral Europe (European Commission, 2018), aiming to achieve net-zero greenhouse gas emissions by 2050. The key climate and energy targets are set in the "2030 climate & energy framework" that includes at least 40 per cent cuts in cuts in greenhouse gas emissions from 1990 levels, 32 per cent share for renewable energy and 32.5 per cent improvement in energy efficiency.

To achieve the 40 per cent reduction in GHG emissions, the EU has divided the European economy into two parts following an adoption of the 2008 "Energy–Climate" directive (Delreux, 2019). The first part covers sectors subject to the

European ETS that were chosen from those most energy-intensive. These are primarily electricity generation which have to cut emissions by 43 per cent with respect to 2005 levels. The second part covers all other sectors (non-ETS), including the fossil energy consumption of households. These sectors will need to reduce GHG emissions by 30 per cent compared to their 2005 emissions.

The target for 2040 is not officially defined, but it is expected to be at least a 60 per cent reduction of GHG emissions from 1990 levels. Following the same incremental trend between 2020 to 2030, it is predicted that non-ETS sectors will increase by 20 percentage points from 2030 to 2040, while the ETS target is defined using the residual emissions. Table 1 resumes these targets for 2020, 2030 and 2040 on both the ETS and the non-ETS sectors.

Table 1: European GHG emissions targets

| | 2020 | 2030 | 2040† |
|---|---|---|---|
| ETS target in % of 2005 level | -21% | -43% | -68% |
| Non-ETS target in % of 2005 level | -10% | -30% | -50% |
| Total in % of 1990 level | -20% | -40% | -60% |

† own computation.

The ETS constitutes an exchange-tradable permits market for firms, characterized by one $CO_2$ price (Venmans, 2012). The allocation of allowances is primarily based on free allowances with some auctioning. The Commission estimates that 57 per cent of the total amount of allowances will be auctioned during 2013-2020, while the remaining allowances are available for free allocation.[6] It is predicted that auctioning will become the default method in future allocation

[6] https://ec.europa.eu/clima/policies/ets/auctioning_en

(Hepburn et al., 2006).

For the non-ETS market, $CO_2$ abatement objectives are based on the so-called "Effort Sharing Decision". The Effort Sharing Regulation (ESR) sets GHG emission targets for MSs according to their economic capacity based on the relative wealth measured by GDP per capita. Two rounds of burden-sharing were already defined, for the year 2020[7] and for the year 2030 (European Commission, 2016b).The target by country of 2040 is allocated using the same estimated coefficient GDP per capita in 2007. Table 2 shows these the defined burden sharing for 2020 and 2030 and the proposed level for 2040.

### *3.2. Chinese climate policy*

As the largest $CO_2$ emitter and the second largest economy over the world China targets to lower $CO_2$ emissions per unit of GDP by 40 per cent to 45 per cent from the 2005 level by 2020. In addition to this, the share of non-fossil fuels in primary energy consumption is expected to increase approximately 15 per cent, and the forested area increased by 40 million hectares.[8] For the commitment beyond 2020, China strives to peak the $CO_2$ emissions in year 2030 or sooner, and to reduce $CO_2$ emissions per unit of GDP by 60 per cent to 65 per cent compared to the 2005 level. China also aims to increase the share of non-fossil energy in primary energy consumption for approximately 20 per cent and the volume of forest stock by around 4.5 billion cubic meters from the 2005 level.

The annual emission intensity is targeted to fall at a minimum rate of 3.3 per cent during 2005-2020 and 3.1 per cent during 2020-2030. Following this trend,

[7] Adopted in 2007.

[8] Or by 1.3 billion cubic meters in the forest stock volume compared to the 2005 levels.

Table 2: Effort Sharing Decision (source: European Commission (2016b))

| | GDP per capita in € 2013 | ESD target 2020 | ESR target 2030 in % of 2005 levels | Target 2040† |
|---|---|---|---|---|
| Bulgaria (BGR) | 5'800 | 20% | 0% | -19% |
| Romania (ROU) | 7'200 | 19% | -2% | -21% |
| Croatia (HRV) | 10'200 | 11% | -7% | -26% |
| Hungary (HUN) | 10'200 | 10% | -7% | -26% |
| Poland (POL) | 10'200 | 14% | -7% | -26% |
| Latvia (LAT) | 11'300 | 17% | -6% | -27% |
| Lithuania (LIT) | 11'800 | 15% | -9% | -28% |
| Slovakia (SVK) | 13'600 | 13% | -12% | -31% |
| Estonia (EST) | 14'400 | 11% | -13% | -32% |
| Czech Republic (CZE) | 14'900 | 9% | -14% | -33% |
| Portugal (POR) | 16'300 | 1% | -17% | -35% |
| Greece (GRE) | 16'500 | -4% | -16% | -36% |
| Slovenia (SVN) | 17'400 | 4% | -15% | -37% |
| Malta (MLT) | 18'100 | 5% | -19% | -38% |
| Cyprus (CYP) | 21'000 | -5% | -24% | -43% |
| Spain (SPN) | 22'100 | -10% | -26% | -44% |
| Italy (ITA) | 26'500 | -13% | -33% | -50% |
| United Kingdom (GBR) | 31'900 | -16% | -36% | -55% |
| France (FRA) | 32'100 | -14% | -36% | -55% |
| Germany (DEU) | 35'000 | -14% | -37% | -57% |
| Belgium (BEL) | 35'400 | -15% | -38% | -57% |
| Finland (FIN) | 37'400 | -16% | -39% | -58% |
| Austria (AUT) | 38'100 | -16% | -39% | -59% |
| Netherlands (NLD) | 38'700 | -16% | -39% | -59% |
| Ireland (IRL) | 39'000 | -20% | -39% | -59% |
| Sweden (SWE) | 45'400 | -17% | -40% | -59% |
| Denmark (DNK) | 45'500 | -20% | -40% | -59% |
| Luxembourg (LUX) | 85'600 | -20% | -40% | -59% |

These commitments refer to targets in the non-ETS part of the economy.

† own computation.

we assume that the emission intensity will fall at a minimum annual rate of 2.9 per cent during 2030-2040 and reduce at least by 75 to 80 per cent from the 2005 level (Table 3). For further development scenario analysis, the paper uses this assumption to consider China's emission range target. China low commitment level of mitigation will result in 75 per cent of reduction in its emissions intensity, while the 80 per cent represents the high commitment level.

Table 3: China's emission intensity targets

| | 2020 | 2030 | 2040† |
|---|---|---|---|
| Emission intensity targets in % of 2005 level | -40% to -45% | -60% to -65% | -75% to -80% |

† own assumption.

In China's current emissions trading market, the government controls the total amount of carbon emissions in one or more sectors following the "Cap-and-Trade" system where a company needs one unit of carbon credits for every ton of greenhouse gas emission. The government also manage the emission quota that could be given for free or by auction and trade with others. Since June 2013, China has launched pilot projects for carbon emission trading in Beijing, Shanghai, Shenzhen, Chongqing, Tianjin, Guangdong and Hubei provinces (or cities) (Weng and Xu, 2018). Table 4 shows the comparison of seven pilot ETS.

The China's national ETS was officially launched in 2017 by the issue of the "National Carbon Emissions Trading Market Construction Plan (Power Generation Industry)".[9] Under this plan, the government manages the market construction goals, path and the preliminary work of China ETS(Lin and Jia, 2019a;

[9]https://www.ndrc.gov.cn/xxgk/zcfb/ghxwj/201712/t20171220_960930.html

Table 4: Comparison of seven pilot ETS

| ETS | Sectors and enterprise | Threshold | Quota covered |
|---|---|---|---|
| Beijing | Electricity, heat, cement, petrochemical and other industrial enterprises, service industries and public transport | Regulated unit with 5 thousand (inclusive) tons of $CO_2$ emissions (2009-2012) | 40% |
| Shanghai | Electricity, steel, , petrochemical, chemical, airports, ports, shopping malls, hotels, etc. | Industrial sectors with more than 20 thousand tons of $CO_2$ emissions and non-industrial sectors with more than 10 thousand tons of $CO_2$ emissions (2010-2011) | 40% |
| Guangdong | Electricity, cement, steel, petrochemical, aviation | Regulated unit with 20 thousand (inclusive) tons of $CO_2$ emissions (2011-2012) | 56% |
| Chongqing | Electricity, electrolytic aluminum, ferroalloy, calcium carbide, caustic soda, cement, steel | Regulated unit with 20 thousand (inclusive) tons of $CO_2$ emissions (2008-2012) | 40% |
| Tianjin | Electricity, heat, steel, chemical, petrochemical, oil and gas exploration | Regulated unit with 20 thousand (inclusive) tons of $CO_2$ emissions (2009-2012) | 50%-60% |
| Shenzhen | Electricity, water, manufacturing, and large public buildings | Industrial sectors with more than 3 thousand tons of $CO_2$ emissions, and the public buildings with more than 10 thousand square meters | 38% |
| Hubei | Electricity, steel, chemicals, cement, automobile manufacturing, non-ferrous metals, glass, paper, etc | Annual energy consumption of more than 60 thousand tons tce (2010-2011) | 44% |

Source: Authors collect the information from Tang et al. (2020) and seven pilot trading platforms.

Tang et al., 2020). At present, the market only covers the power industry sectors for its significant $CO_2$ emissions.[10] Achieving low-cost and low-carbon development of the industry is the main objective for this exclusivity in order to provide a price signal of $CO_2$ emissions costs for mature electricity market and to force the power industry to accelerate the energy transition.

This paper follows the previous study of Tang et al. (2018) and focuses only two $CO_2$ emissions projections on China's power industry.[11] The first is the Business as Usual (BAU). It represents the emissions under the existing policies with no change on the share of renewable in electricity generation. Under this projection, the $CO_2$ emission from power generation will increase 1.4 per cent per year, from 4451 $MtCO_2$ in 2015 to 6274 $MtCO_2$ in 2040 (see Figure 1). Second, the Advanced Technology and Renewable Energy Development (AT & RED) represents China commitment to peak its emissions before 2030. It incorporates policies to improve the energy efficiency, to promote advanced technologies and to increase the share of renewable electricity generation. Under AT & RED, the $CO_2$ emissions will peak at 4842 $MtCO_2$ in 2023. It decreases to 4755 $MtCO_2$and 4203 $MtCO_2$ in 2030 and 2040 respectively. With higher commitment of renewable used in generation, AT & RED predicts more significant emission reduction, achieving the level under 3000 $MtCO_2$ in 2040.

The AT & RED represents China's low commitment for electricity generation in this paper. While in defining China's high commitment, we assume that $CO_2$

[10]Annual $CO_2$ emissions reach 26 thousand tons, or annual energy consumption reaches 10 thousand tce.

[11]China's strategy of its green power industry is currently regulated under the 13$^{\text{th}}$ Five-Year Plan.

marginal abatement cost in electricity generation is lower than the one in the rest of this economy. If additional $CO_2$ emissions reductions are required, the electricity would have to do more abatement. We use a correcting factor equals to 1.5 and assume that if a percentage point additional abatement is required in the overall economy, electricity sector would have to decrease emissions by 1.5 percentage point. With this assumption, the electricity sector has to decrease emissions by 54.9 per cent with respect to the baseline emissions for its high commitment. Following this, the non-ETS emissions has to decrease by 29.2 per cent and the overall Chinese emissions by 42.8 per cent.[12]

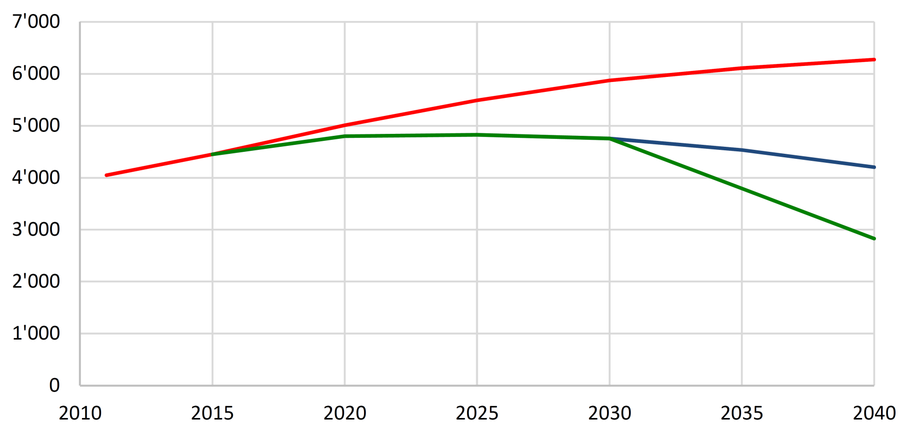


Figure 1: Chinese emissions from electricity generation in Mt $CO_2$ - Reference and climate policy scenarios

[12]Refer to Table 6.

## 4. The GEMINI-E3 model

### *4.1. Overview*

GEMINI-E3 is a multi-country, a multi-sector and a recursive computable general equilibrium model (Bernard and Vielle, 2008).[13] The standard model is based on the assumption of total flexibility in all markets, i.e. both macroeconomic markets, such as capital and international trade markets (with associated prices being the real rate of interest and the real exchange rate, which are then endogenous), and microeconomic or sector markets (goods, factors of production, etc.).

### *4.2. Key features of the model*

The current version is built on the GTAP 9 data base (Aguiar et al., 2016), with 2011 as the reference year. The spatial decomposition of this version of GEMINI-E3 describes each of the 28 EU MSs as individual regions, plus China and the rest of the world. The number of sectors described by GEMINI-E3 is aggregated to 11 in order to have a tractable model and acceptable computation time. The classification is built in order to distinguish sectors participating in the ETS market from the others. The EU ETS sectors include the petroleum products, the electricity generation, and energy-intensive industry. Later industry comprises the iron and steel, the chemical, the non-ferrous metals, the non-metallic minerals products, and the paper and paper products. Three other energy goods are described by the

[13]Comparatively to other models of this class such as EPPA, OECD-Env-Linkage, etc., or models built and implemented by other modeling teams and institution. It shares the same long experience in the design of this class of economic models.

model consist of coal, crude oil, and natural gas. The remaining sectors are aggregated into agriculture, land transport, sea transport, air transport, and other goods and services.

For each sector, the model computes the demand of its production on the basis of household consumption, government consumption, exports, investment and intermediate uses. Total demand is then divided between domestic production and imports using the Armington assumption (Armington, 1969), which assumes that domestic and imported goods are not perfectly homogenous. Production technologies are described by a nested Constant Elasticity of Substitution (CES) functions as shown in Appendix.

Household's behavior consists of three interdependent decisions for labor supply, savings, and consumption of the various goods and services. Both labor supply and saving rates are exogenous in the model. Demand in the different commodities has prices of consumption and income (more precisely "spent" income, income after savings), and is derived from a nested CES utility function as described in Appendix.

The government collects taxes and distributes the revenues to households and firms through transfers and subsidies. Wage is chosen as a numeraire in each region. The model is recursive dynamic, with backward looking (adaptive) expectations.

### *4.3. GHG emissions covered*

The analysis only considers $CO_2$ emissions from energy combustion, while the non $CO_2$ of methane, nitrous oxide, and fluorinated gases are not covered. The representation of these gases requires a detailed modeling tool and representation of bottom up options, such as offered by the GAINS model (Amann et al., 2011) with its detail and diverse emissions sources. These non-$CO_2$ gases represent 19 per cent of EU28 GHG emissions in 2016 (United Nations Framework Convention on Climate Change, 2018) and the agriculture sector contributes the most (52 per cent), followed by the waste and waste-water sector (18 per cent) and the energy sector (15 per cent) (Höglund-Isaksson et al., 2012).

Non-$CO_2$ GHG emissions included in the EU-ETS are nitrous oxide emissions from adipic and nitric acid production, and perfluorocarbons emissions from the aluminium industry. Incorporating these requires to integrate GEMINI-E3 with a bottom-up model as it done in the EU 2016 reference scenario (European Commission, 2016b) or in (Weitzel et al., 2019). Weitzel et al. (2019) indicates that excluding non-$CO_2$ abatement could lead to abatement cost in the EU that are 30-40 per cent higher than including non-$CO_2$ abatement options. We consider this as the limitation of our paper, and it is certain matter to be accommodated in the future research.

### *4.4. Assessing welfare cost*

Like other computable general equilibrium models, GEMINI-E3 assesses the welfare cost of policies through compensating variation of income. This measure is preferable to change in GDP or change in households' final consumption since both are measured at constant prices that follows the methods of national accounting. Both fails capturing the change in the structure of prices which is a main effect of climate change policies. In addition, it is essential to split the welfare cost between its two components, the domestic component or deadweight loss of taxation (DWL) and the imported component or gains from terms of trade (GTT). The GTT represents spill-over effects due to changes in international prices which come mainly from the drop in fossil energy prices resulted from the decrease of world energy demand.

Decomposition of the welfare cost into components is certainly a complex issue.[14] This paper aims to approximate decomposition between domestic and imported cost, in order to obtain a general idea of their relative importance. This approach is justified by the fact that the change in price, particularly the price of foreign trade, is fairly small. In practice, compensative variation income is first calculated from the results of the model, and the specification and coefficients of the demand function. The GTT are then calculated based on the results of the involved scenario using the following equation:

$$GTT = \sum_i \Delta Pexp_i \cdot Export_i - \sum_i \Delta Pimp_i \cdot Import_i \tag{1}$$

where $\Delta Pexp_i$ and $\Delta Pimp_i$ represent changes in the exports and imports prices (for product $i$), with respect to the reference scenario; and $Export_i$ and $Import_i$ represent the levels of exports and imports, respectively, in the reference scenario. Finally, the DWL is the difference between the compensative variation income and the GTT.

## 5. Numerical analysis

### *5.1. Reference scenario*

The GEMINI-E3 reference scenario is built on the period of 2011-2040 with yearly time steps with all prices given in €$_{2017}$.[15]

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[14]Refer to study of Böhringer and Rutherford (2002) in the case of climate change policy and Harrison et al. (2000) in a more general framework.

[15]The model is calibrated on the GTAP 9 data base, and therefore the economic variables are measured in US\$$_{2011}$. We compute figures in €$_{2017}$ by using the exchange rate between € and US$

Based on historical population and international energy prices of 2011 to 2015, we compute the technical progresses associated with labor and energy consumption to reproduce historical GDP, energy consumption, and related $CO_2$ emissions. Our reference scenario thus considers implicitly all previous policies implemented since 2015, emphasizing on those related to energy and climate fields. Assumptions about population, GDP, and international energy prices post 2016 are based on the EU reference scenario 2016 (European Commission, 2016a). It is projected that European GDP will grow by 1.5 per cent annually between 2015-2040 while GDP growth rates for MSs follow the projection of DG ECFIN (European Commission, 2015b).

For energy consumption and $CO_2$ emissions after 2015, our reference scenario differs from the one computed in the EU reference scenario 2016. Our analysis do not integrate additional climate abatements in the EU-ETS and new climate and energy policies. China GDP growth assumptions follows the World Energy Outlook (International Energy Agency, 2019) where the annual GDP growth will decrease slightly to 3.7 per cent at the end of the simulation (Table 5).

In 2040, our baseline simulation predicts China's emission will reach 11.9 Gt $CO_2$. It represents one quarter of the 45.5 Gt World $CO_2$ emissions. Chinese emissions from electricity generation and heat production follows the same path as the one computed in Tang et al. (2018) in their business as usual scenario. These emissions increase by 1.4 per cent yearly from 2015 to 2040. On the same period, total Chinese $CO_2$ emissions increase by 30 per cent, representing one per cent annual growth rate (see Figure 3). The EU carbon emissions are stable along the

for the year 2011, and the European GDP deflator between 2011 and 2017 provided by Eurostat.

Table 5: Key indicators on the reference scenario

| | 2015-2020 | 2020-2030 | 2030-2040 |
|---|---|---|---|
| GDP growth per year in % | | | |
| EU28 | 1.5% | 1.4% | 1.5% |
| China | 6.1% | 4.8% | 3.7% |
| World | 3.1% | 3.6% | 3.4% |
| | 2020 | 2030 | 2040 |
| Total $CO_2$ emissions in Mt $CO_2$ | | | |
| EU28 | 3’382 | 3’399 | 3’429 |
| China | 9’790 | 11’078 | 11’871 |
| World | 33’182 | 39’359 | 45’562 |
| ETS $CO_2$ emissions in Mt $CO_2$ | | | |
| EU28 | 1’629 | 1’648 | 1’670 |
| China | 5’010 | 5’872 | 6’274 |

forecast, reaching 3.4 Gt $CO_2$ in 2040 (see Figure 2).

### *5.2. Non integrated market scenario*

In these scenarios we assume that the EU and China implement their climate policies without integrating their ETS markets with no emissions constraint in the rest of the World (ROW). The EU ETS sectors participate in a $CO_2$ tradable market with full auctioned emission allowances. The EC collects and redistributes to the allowances to MSs based on their emissions shares.

Following this assumption, the non-ETS sectors implement a domestic $CO_2$ tax, based on the ESR targets presented in Table 2.[16] Firm contributions are inclu-

[16]We do not consider numerous type of measurement that have been or will be implemented in the EU non-ETS sectors such as fuel efficiency target for passenger cars, appliance subsidies,

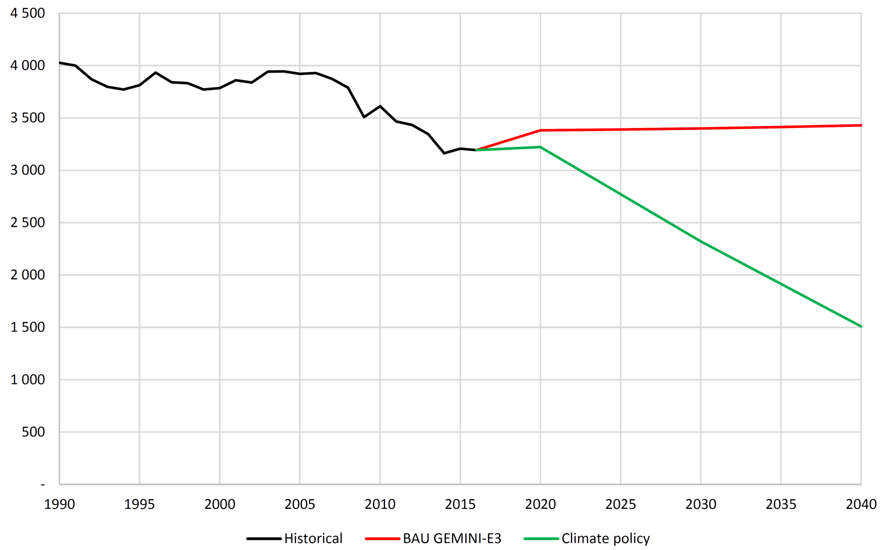


Figure 2: European Union emissions in Mt $CO_2$ - Reference and climate policy scenarios

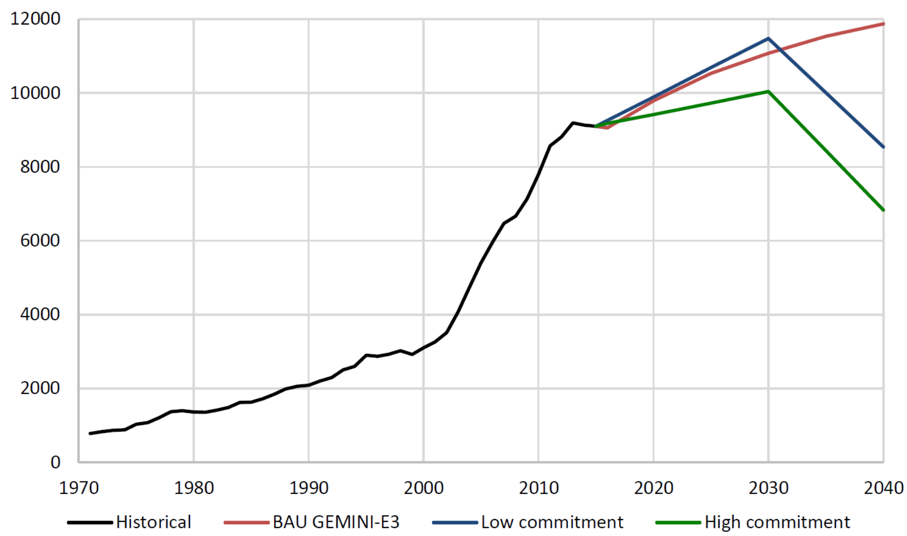


Figure 3: Chinese emissions in Mt $CO_2$ - Reference and climate policy scenarios

carbon taxes and others. Representing all of these is difficult and is out the scope of our model.

ded in the ESR emissions, and households pay a domestic $CO_2$ tax on their fossil energy consumption. The $CO_2$ tax revenue is redistributed to household through a lump-sum transfer. Other redistributive rules could be envisaged but they do not constitute the scope of this study. The number of $CO_2$ prices in EU is then one plus the number of MSs (i.e., 29=1 ETS price + 28 domestic carbon taxes).

On the other hand, China ETS market only includes the electricity generation while others are subject to a Chinese $CO_2$ tax. The revenue gained from ETS allowances and $CO_2$ tax follow the same rules used for European countries. There are two additional assumptions for China's commitments on total $CO_2$ emissions, a low and a high commitment as described in section 3.2 and represented in Figure 3.

Table 6 shows the main results of non integrated market scenario of the EU and China. Regardless China's emissions commitment, the non integrated EU market results in a 52 per cent effective abatement in 2040. The carbon price in the EU ETS reaches 45 € in 2030 and 277 € in 2040. Non-ETS carbon prices are much higher with large differences across Member States.[17] The averaged ESR price[18] is equal to 209 € in 2030 and 834 € in 2040. The European welfare cost reaches around 2 per cent of households consumption in 2040.

For China, its low commitment results in a 28 per cent abatement in effective emissions in 2040, and a 43 per cent reduction when its commitment turning high. The carbon price in the ETS market is approximately 11 € in 2040, indicating the significant carbon abatement opportunities in Chinese electricity generation is

[17] The aim of this paper is not to analyse the EU burden sharing, such analysis has been already performed and published in Vielle (2020).

[18] The average $CO_2$ price is weighted with the emissions of the scenario.

mainly contributed by coal power plants. It increases quite significantly and reaches 28 € in 2040 once the commitment is high. China's carbon tax, in contrast, shows insignificant changes when the commitment altered to high. This indicates further the stringency of this scenario for ETS emissions as shown in Figure 4. China's $CO_2$ prices are relatively low, compared to the EU with the welfare costs reach 1.47 per cent and 2.44 per cent of household consumption for the low and high commitment scenarios respectively.

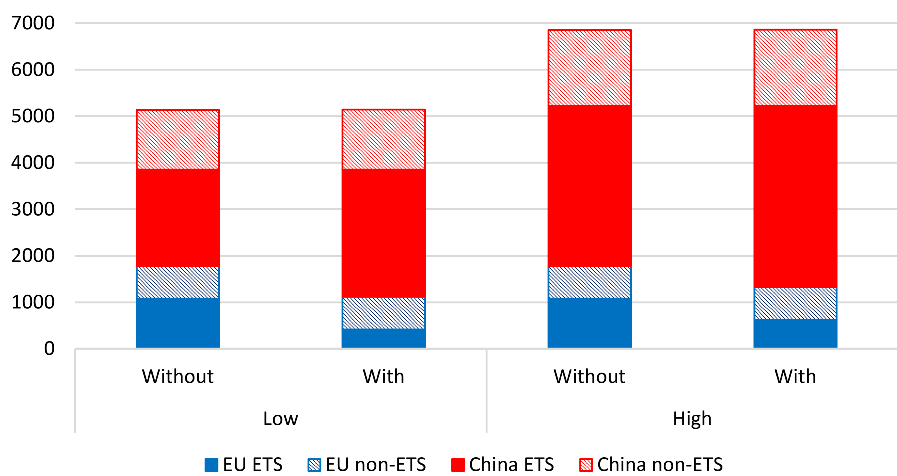


Figure 4: Abatement in Mt $CO_2$ - Year 2040

### *5.3. Integrated market scenario*

Integrating ETS markets requires to define the allocation of allowance for each European country from the non integrated scenario in previous section. These allowances reflect an efficient allocation within the EU that equalizes the marginal abatement cost within firms and countries to the European ETS price. In this scenario, the integrated ETS market gives positive impacts for both regions, despite stronger gain of trading to the EU. Table 7 lists the results.

Table 6: Scenario results without ETS coupling

| | Low commitment | | High commitment | |
|---|---|---|---|---|
| | 2030 | 2040 | 2030 | 2040 |
| *Total emissions change** | | | | |
| EU28 | -25.8% | -51.9% | -25.8% | -51.9% |
| China | -9.2% | -28.3% | -9.4% | -42.8% |
| *ETS emissions change** | | | | |
| EU28 | -35.4% | -64.6% | -35.4% | -64.6% |
| China | -19.0% | -33.0% | -19.0% | -54.9% |
| *Non-ETS emissions change** | | | | |
| EU28 | -16.8% | -39.9% | -16.8% | -39.9% |
| China | 1.8% | -23.0% | 1.4% | -29.2% |
| *ETS price in €* | | | | |
| EU28 | 45 | 277 | 45 | 277 |
| China | 5 | 11 | 5 | 28 |
| *Non-ETS price €* | | | | |
| EU28 | 209 | 834 | 209 | 834 |
| China | 0 | 11 | 0 | 15 |
| *Welfare change* † | | | | |
| EU28 | -0.15% | -2.09% | -0.15% | -2.10% |
| China | -0.46% | -1.47% | -0.45% | -2.13% |

* percentage change with respect to baseline emissions

† in percentage of household consumption

First, when China's commitment is low, the common ETS price reaches 17 € in 2040. European welfare improves as the cost decreases from 2.09 to 1.56 per cent. Chinese welfare cost is reduced to 1.35 per cent, compared to 1.47 per cent with no integration (Table 8). When the ETS market are merged, the EU has to do less abatement, from 64.6 to 24.8 per cent in 2040. It reduces the DWL from 4.72 per cent of household consumption to 3.85 per cent. The EU MSs have to buy Chinese quotas which represents 0.11 per cent of their household consumption. The gain of trading is estimated to 0.53 per cent of household consumption (2.09 - 1.56 per cent). China is of course faced to an opposite situation. A more abatement is required in electricity generation, but selling of quotas represents additional 0.24 per cent of the household consumption. The net gain of trading is equal to 0.12 per cent of household consumption in 2040 (i.e. 1.47 -1.35 per cent). When China abatement commitment is high, our simulation reveals same trends yet different magnitude. The net gain equals 0.36 and 0.2 per cent of household consumption for the EU and China respectively.

*5.4. Impacts per Member States, energy intensive industries and leakage*

Figure 5 shows the welfare changes for the year 2040 in each MSs when ETS markets are integrated. Poland, Romania, Croatia and the Czech Republic (Czechia) gain positive impacts as their welfare are improved by more than 1.5 per cent in term of the households consumptions. For these new member states, ETS sectors constitute a larger part of the economy (Brink et al., 2016), thus the reduction of the ETS price is highly beneficial. Some European countries are worse off, however, as their losses in term of trade overcompensate the decrease in the

Table 7: Scenario results with ETS coupling

| | Low commitment | | High commitment | |
|---|---|---|---|---|
| | 2030 | 2040 | 2030 | 2040 |
| *Total emissions change** | | | | |
| EU28 | -14.3% | -32.5% | -14.3% | -38.7% |
| China | -12.5% | -33.9% | -13.0% | -46.6% |
| *ETS emissions change** | | | | |
| EU28 | -11.6% | -24.8% | -11.6% | -37.5% |
| China | -25.7% | -43.6% | -25.7% | -62.1% |
| *Non-ETS emissions change** | | | | |
| EU28 | -16.8% | -39.8% | -16.8% | -39.8% |
| China | 2.3% | -23.1% | 1.3% | -29.3% |
| *ETS price in €* | | | | |
| EU28 | 8 | 17 | 8 | 40 |
| China | 8 | 17 | 8 | 40 |
| *Non-ETS price €* | | | | |
| EU28 | 216 | 908 | 216 | 897 |
| China | 0 | 6 | 0 | 8 |
| *Welfare change* † | | | | |
| EU28 | -0.13% | -1.56% | -0.13% | -1.74% |
| China | -0.41% | -1.35% | -0.41% | -1.93% |

* percentage change with respect to baseline emissions

† in percentage of household consumption

Table 8: Welfare decomposition in % of household consumption - Year 2040

| | Low | | High | |
|---|---|---|---|---|
| | Without | With | Without | With |
| *EU28* | | | | |
| Welfare | -2.09% | -1.56% | -2.10% | -1.74% |
| GTT | 2.63% | 2.39% | 2.62% | 2.37% |
| Trade of quotas | – | -0.11% | – | -0.17% |
| DWL | -4.72% | -3.85% | -4.72% | -3.94% |
| *China* | | | | |
| Welfare | -1.47% | -1.35% | -2.13% | -1.93% |
| GTT | -0.90% | -0.82% | -0.81% | -0.67% |
| Trade of quotas | – | 0.24% | – | 0.38% |
| DWL | -0.57% | -0.77% | -1.32% | -1.64% |

DWL.[19] Lithuania, Ireland, Estonia and the Netherland are predicted to have up to one per cent welfare loss (higher welfare cost) of their households consumptions.

Tables 9 and 10 list the exchange of quotas in Mt $CO_2$. It is estimated 664 Mt of $CO_2$ sold from China to the EU in 2040. The high commitment, conversely give more pressure to China as only 452 Mt $CO_2$ quota sold. The EU main buyers are big countries of Germany, United Kingdom, Italy and Spain, or the countries that consume a lot of fossil energy in ETS sectors such as Poland. France that has already decarbonized its electricity generation, is less interested in the ETS coupling.

Figure 6 shows the impacts of the integrated markets on the competitiveness of energy intensive industries in both regions, measured as the percentage change

[19] It confirms the previous finding of Babiker et al. (2004).

Table 9: ETS Abatement, allowances and trading of quotas per Member State - Low commitment scenario

| | Abatement in % | | Allowances | Trade | Trade in |
|---|---|---|---|---|---|
| | Without | With | in Mt $CO_2$ | in Mt $CO_2$ | % of allowances |
| Austria | -53% | -19% | 10 | -7 | 75% |
| Belgium | -54% | -18% | 16 | -12 | 79% |
| Cyprus | -39% | -4% | 2 | -1 | 57% |
| Czechia | -74% | -30% | 19 | -31 | 167% |
| Denmark | -72% | -33% | 6 | -8 | 142% |
| Estonia | -43% | -4% | 6 | -4 | 67% |
| Finland | -61% | -23% | 12 | -12 | 99% |
| France | -50% | -19% | 47 | -29 | 63% |
| Germany | -70% | -25% | 114 | -166 | 146% |
| Greece | -59% | -16% | 14 | -14 | 104% |
| Hungary | -55% | -20% | 9 | -7 | 76% |
| Ireland | -63% | -26% | 6 | -6 | 99% |
| Italy | -56% | -21% | 71 | -55 | 78% |
| Latvia | -48% | -10% | 1 | -1 | 74% |
| Lithuania | -41% | -14% | 3 | -1 | 47% |
| Luxembourg | -53% | -12% | 1 | -1 | 87% |
| Malta | -41% | -6% | 1 | -1 | 58% |
| Netherlands | -54% | -23% | 30 | -20 | 68% |
| Poland | -76% | -30% | 49 | -96 | 195% |
| Portugal | -62% | -25% | 8 | -8 | 95% |
| Slovakia | -55% | -19% | 8 | -6 | 78% |
| Slovenia | -67% | -19% | 2 | -3 | 142% |
| Spain | -59% | -24% | 52 | -44 | 85% |
| Sweden | -46% | -19% | 9 | -5 | 50% |
| United Kingdom | -70% | -31% | 62 | -79 | 127% |
| Bulgaria | -70% | -23% | 12 | -19 | 160% |
| Romania | -65% | -23% | 19 | -23 | 122% |
| Croatia | -58% | -23% | 3 | -3 | 82% |
| EU28 | -65% | -24% | 591 | -664 | 112% |
| China | -33% | -44% | 4’203 | 664 | 16% |
| China+EU28 | -40% | -40% | 4’794 | – | – |

Table 10: ETS Abatement, allowances and trading of quotas per Member State - High commitment scenario

| | Abatement in % | | Allowances | Trade | Trade in |
|---|---|---|---|---|---|
| | Without | With | in Mt $CO_2$ | in Mt $CO_2$ | % of allowances |
| Austria | -53% | -27% | 10 | -6 | 56% |
| Belgium | -54% | -26% | 16 | -10 | 61% |
| Cyprus | -39% | -10% | 2 | -1 | 47% |
| Czechia | -74% | -46% | 19 | -19 | 104% |
| Denmark | -72% | -48% | 6 | -5 | 90% |
| Estonia | -43% | -11% | 6 | -3 | 55% |
| Finland | -61% | -34% | 12 | -8 | 69% |
| France | -50% | -27% | 47 | -22 | 46% |
| Germany | -70% | -39% | 114 | -113 | 99% |
| Greece | -59% | -29% | 14 | -10 | 73% |
| Hungary | -55% | -30% | 9 | -5 | 53% |
| Ireland | -63% | -37% | 6 | -4 | 68% |
| Italy | -56% | -31% | 71 | -40 | 56% |
| Latvia | -48% | -18% | 1 | -1 | 58% |
| Lithuania | -41% | -20% | 3 | -1 | 37% |
| Luxembourg | -53% | -21% | 1 | -1 | 68% |
| Malta | -41% | -12% | 1 | -1 | 49% |
| Netherlands | -54% | -32% | 30 | -15 | 49% |
| Poland | -76% | -48% | 49 | -60 | 122% |
| Portugal | -62% | -37% | 8 | -5 | 64% |
| Slovakia | -55% | -30% | 8 | -4 | 55% |
| Slovenia | -67% | -33% | 2 | -2 | 101% |
| Spain | -59% | -34% | 52 | -31 | 59% |
| Sweden | -46% | -27% | 9 | -3 | 35% |
| United Kingdom | -69% | -43% | 62 | -53 | 86% |
| Bulgaria | -70% | -39% | 12 | -13 | 108% |
| Romania | -65% | -37% | 19 | -15 | 81% |
| Croatia | -58% | -34% | 3 | -2 | 56% |
| EU28 | -65% | -37% | 591 | -452 | 76% |
| China | -55% | -62% | 2’829 | 452 | 16% |
| China+EU28 | -57% | -57% | 3’421 | – | – |

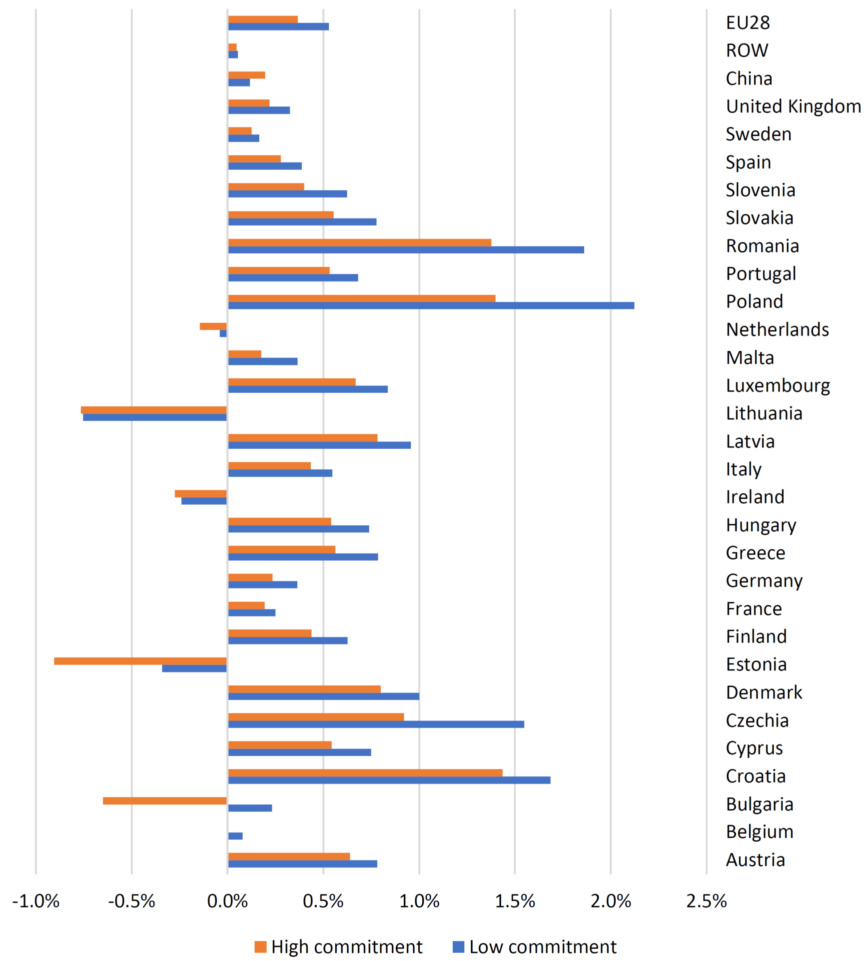


Figure 5: Welfare change in % of household consumption - Year 2040

of the production in China's high commitment scenario for the year 2040. The results clearly demonstrate that integrated EU and Chinese ETS market significantly reduce the loss of competitiveness of European energy intensive industries.

Finally, for the evaluation on the leakage, Figure 7 shows the incremental percentage change of international leakage i.e. the $CO_2$ emissions increase in the

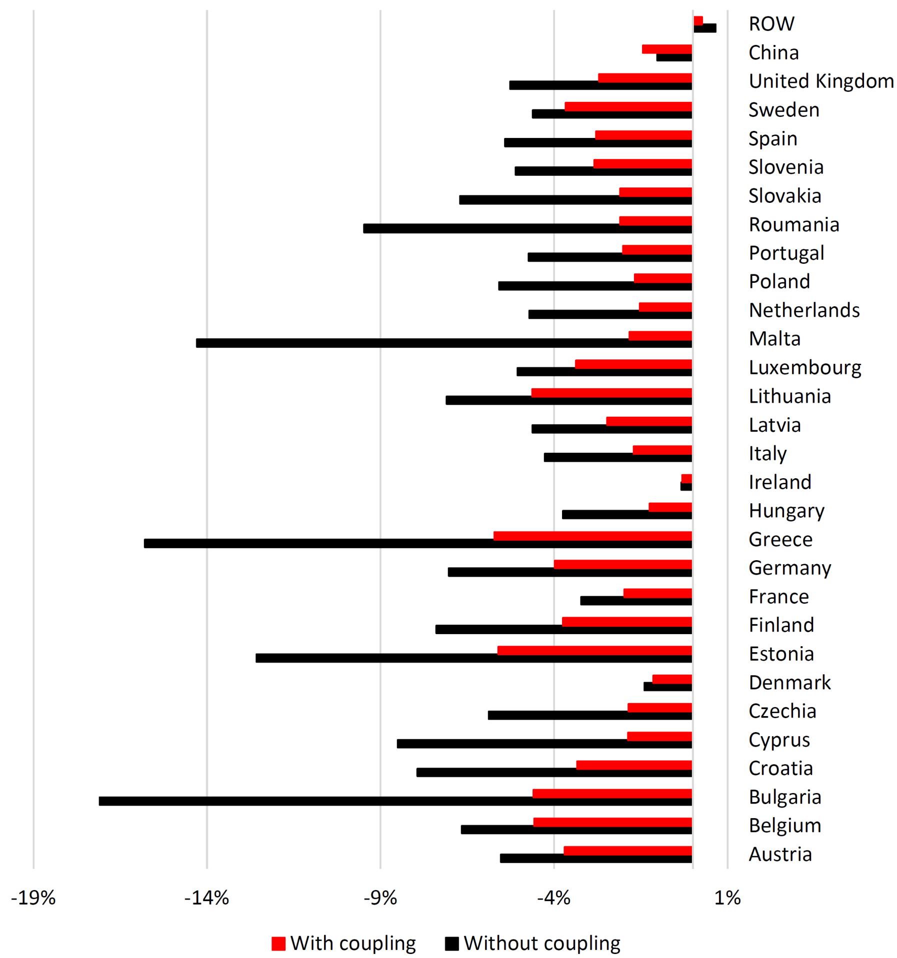


Figure 6: Percentage change in production of energy intensive industries - Year 2040 & high commitment scenario

ROW divided by the decrease in European and Chinese $CO_2$ emissions. We asses that the international leakage driven by two factors which include the fall of international fossil energy prices followed by the decrease of energy consumption in EU and China,[20] and the loss of competitiveness of European and Chinese industries that increases the demand of good produced by the ROW with correlative $CO_2$ emissions. The leakage is rather small, less than 12 per cent. Albeit integrating ETS markets limits the leakage effect by around one quarter, as the competitiveness loss of European energy intensive industries is reduced when the ETS markets are joined.

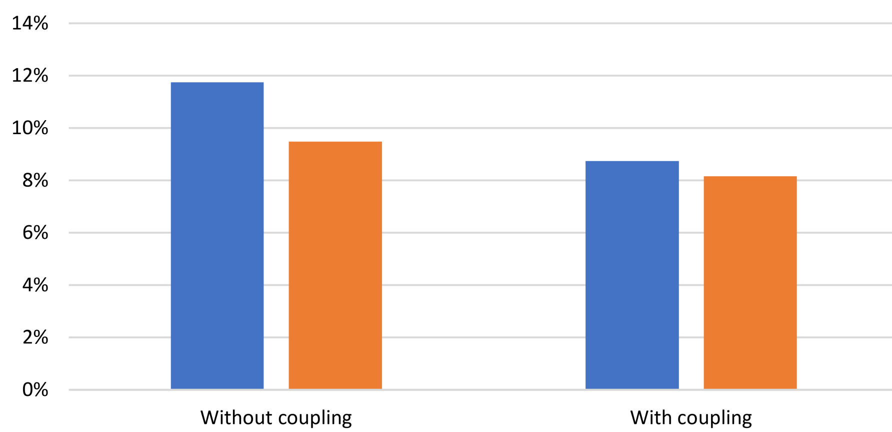


Figure 7: $CO_2$ leakage in % - Year 2040

### *5.5. Limit on trading*

In integrated market, the share of $CO_2$ allowances bought by European countries from China with respect to the initial commitment is quite large. Under the condition of China low commitment, Czechia, Poland and Bulgaria buy more than 150 per cent of their allocation, higher than the overall EU purchasing level of 112 per cent. When China is putting more commitment to abatement, the MSs share

[20]Therefore ROW without any emission constraint increases fossil energy consumption and the $CO_2$ emissions.

in buying the allowance is still above 75 per cent. Only a few EU countries such as France, the Netherland and Sweden, have a share of quotas bought below 50 per cent.

Full participation in the integrated market with unlimited trading might be politically unacceptable. It should be noted, the EU ETS legislation already allows the use of international credits, namely clean development mechanism and joint implementation instruments with some limits. In 2013 to 2020, installations which already fell into the scope of the EU ETS in the period of 2008 to 2012 may use these credits of the year 2008 to 2020, up to a limit of 11 per cent of their allocation for 2008 to 2012 (European Commission, 2015a).

Several literature have already addressed the trading limit for China (Gavard et al., 2013, 2016; Li et al., 2019). Here, we apply a same constraint but for the EU MSs level. Assuming that China put its high commitment to abate, we vary scenarios where the trading is limited from 10 to 90 per cent. Figure 8 illustrates two ETS prices for the EU and China. The China ETS price decreases slightly with linear trend when trading limit becomes more and more binding (i.e when trading limit decreases in percentage). In contrast, the EU ETS price increases when trading is more binding with a quadratic trend.

The critical point is on the 50 per cent trade limit, as most of the MSs are faced to a binding constraint (see Table 12). Above this threshold, the EU welfare is unchanged as the gain from trade is relatively small as the difference between ETS prices are reduced (see Table 11). From an European perspective, limiting the trade of quotas to 30 per cent captures most of the welfare gain coming from $CO_2$ trading. This would probably be politically acceptable in 2040. Conversely, China's welfare is linearly correlated to the trade limit, thus full trade is more preferable. Limiting the trade to 30 per cent will not make the difference relative to a non-trade.

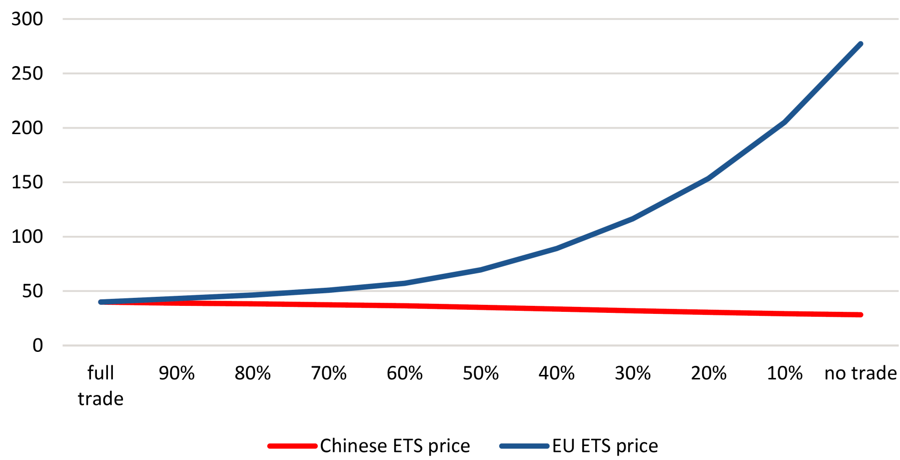


Figure 8: ETS prices in € with respect to trading limit - Year 2040 & high commitment scenario

## 6. Conclusion

In this paper, we asses the economic impacts of joining European and Chinese ETS markets. We perform a comparative analysis of individual and integrated ETS market in the EU and China, assuming that the NDCs decided at COP21 in the Paris Agreement are implemented. The scenarios are simulated up to 2040, taking into consideration the latest climate commitments. The analysis leads to three significant points of conclusion.

First, our results show that the integration of the Chinese and European trading markets is beneficial for both the EU and China. Under the condition of no trading limit amongst participants, the integrated market creates a competitive carbon price that lower welfare costs for both regions. With this price level, the

Table 11: Welfare decomposition with respect to trade limits - Year 2040 & high commitment scenario

| | EU | | | | China | | | |
|---|---|---|---|---|---|---|---|---|
| | Welfare | GTT | Trade of Quota | DWL | Welfare | GTT | Trade of Quota | DWL |
| full trade | -1.74% | 2.37% | -0.17% | -3.94% | -1.93% | -0.67% | 0.38% | -1.64% |
| 90% | -1.73% | 2.38% | -0.16% | -3.95% | -1.96% | -0.69% | 0.35% | -1.62% |
| 80% | -1.72% | 2.39% | -0.14% | -3.97% | -1.97% | -0.70% | 0.32% | -1.60% |
| 70% | -1.72% | 2.40% | -0.13% | -3.98% | -1.99% | -0.71% | 0.30% | -1.58% |
| 60% | -1.72% | 2.41% | -0.12% | -4.01% | -2.01% | -0.72% | 0.26% | -1.56% |
| 50% | -1.72% | 2.43% | -0.10% | -4.05% | -2.04% | -0.74% | 0.22% | -1.52% |
| 40% | -1.73% | 2.46% | -0.07% | -4.11% | -2.07% | -0.76% | 0.17% | -1.48% |
| 30% | -1.76% | 2.49% | -0.05% | -4.20% | -2.09% | -0.77% | 0.12% | -1.44% |
| 20% | -1.83% | 2.53% | -0.03% | -4.32% | -2.11% | -0.79% | 0.08% | -1.40% |
| 10% | -1.94% | 2.57% | -0.02% | -4.49% | -2.12% | -0.80% | 0.04% | -1.36% |
| no trade | -2.10% | 2.62% | 0.00% | -4.72% | -2.13% | -0.81% | 0.00% | -1.32% |

in % of household consumption

Table 12: Impact of trading limits on quotas trade, EU EEI production and domestic $CO_2$ abatement- Year 2040 & high commitment scenario

| | Quota selling by China | % of quota bought by EU | EU EEI Production change in % | EU CO2 abatement in % | China CO2 abatement in % |
|---|---|---|---|---|---|
| full trade | 452 | 76.5% | -2.6% | -38.7% | -46.6% |
| 90% | 424 | 71.8% | -2.6% | -39.5% | -46.4% |
| 80% | 401 | 67.8% | -2.7% | -40.2% | -46.2% |
| 70% | 374 | 63.2% | -2.8% | -41.0% | -46.0% |
| 60% | 342 | 57.8% | -2.9% | -41.9% | -45.7% |
| 50% | 294 | 49.7% | -3.0% | -43.3% | -45.3% |
| 40% | 236 | 40.0% | -3.3% | -45.0% | -44.8% |
| 30% | 177 | 30.0% | -3.6% | -46.7% | -44.3% |
| 20% | 118 | 20.0% | -4.0% | -48.4% | -43.8% |
| 10% | 59 | 10.0% | -4.5% | -50.2% | -43.3% |
| no trade | 0 | 0.0% | -5.2% | -51.9% | -42.8% |

EU could lower its emission reduction target by purchasing more quota, thus lowering the welfare cost by minimizing deadweight loss from emission abatement. The EU attains lower gain from terms of trade and experiences some trade loss by purchasing more emission quota, but these values are overcompensated by minimum amount of the allocative inefficiency by trading with China. In line with this, China's gains from the term of trade and the emission quota are exceeding a higher deadweight loss for more emission abatement under the integrated market scenario.

Second, the decomposition analysis reveals that most countries face lower welfare costs compared to the non-integrated market scenario. In complement to previous studies of Gavard et al. (2013, 2016); Liu and Wei (2016); Zeng et al. (2018); Li et al. (2019), we measure the economic impacts of linking ETS markets for each 28 European countries. Welfare cost from abatement decrease to some notable countries in which ETS constitutes a large part of their economies such as Poland, Romania, the Czech Republic, and Croatia. For a few others such as the Netherland, Lithuania, Ireland, and Estonia face an unavoidable higher welfare cost because of the dominance effect of loss from trade. Spatial sectoral analysis, however, finds that the linkage significantly minimizes the loss of competitiveness of the EU energy-intensive industries. International leakage under the coordinated market is also rather small by market integration, which further confirms the potential of ETS as an effective instrument to facilitate multilateral coordination in global mitigation.

Finally, limiting trade to 30 per cent is likely to be a politically acceptable policy if both markets be integrated. Limiting the trade of quotas to this threshold captures most of the welfare gain coming from $CO_2$ trading for the EU. The critical point is 50 per cent limit for the EU, as no significant change in the EU welfare and the gain from trade above this level. China's welfare, in contrast, is linearly correlated to the trade limit, thus full trade is more preferable.

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## Appendix

### *Nested CES production function*

Domestic production technologies are described through nested CES functions which differ according to the sector. Figure 9 shows the nested CES production structure of the non-fossil energy sector. Production is done with four aggregates:

Capital, labor, material and energy. In a second step (nest), material and energy are decomposed in individual goods using again CES functions.

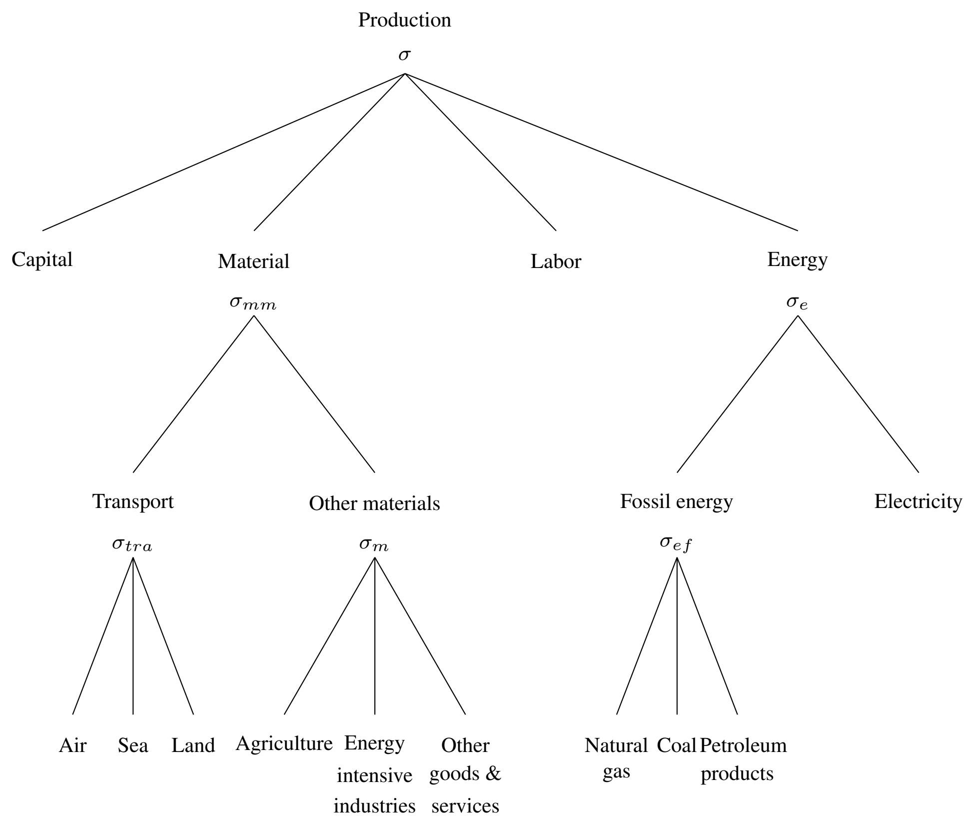


Figure 9: Nested CES production structure of non-fossil energy sector

Coal, crude oil and natural gas sectors include a fix factor that represents the non-renewable resource associated with each fossil fuel energy. For these sectors I suppose that the domestic production is realized with this fix factor and the other standard inputs (i.e. capital, labor, material and energy) through again a nested CES function. Finally, Refined petroleum products are produced from the basic input, that is crude oil. The model considers this specificity with a CES function between crude oil and other standards inputs at the top level of the nested CES structure.

*Nested CES household function*

Figure 10 shows the nested CES structure of the household consumption. At the first level of the consumption function, households choose between three aggregates: housing, transport and other consumptions. Energy consumption is divided between transportation and housing purposes. In each nest, energy can be substituted by spending more on capital goods, cars in the first case and shelter in the second one, in other words, by purchasing more energy-efficient but also more expensive cars and housing units.

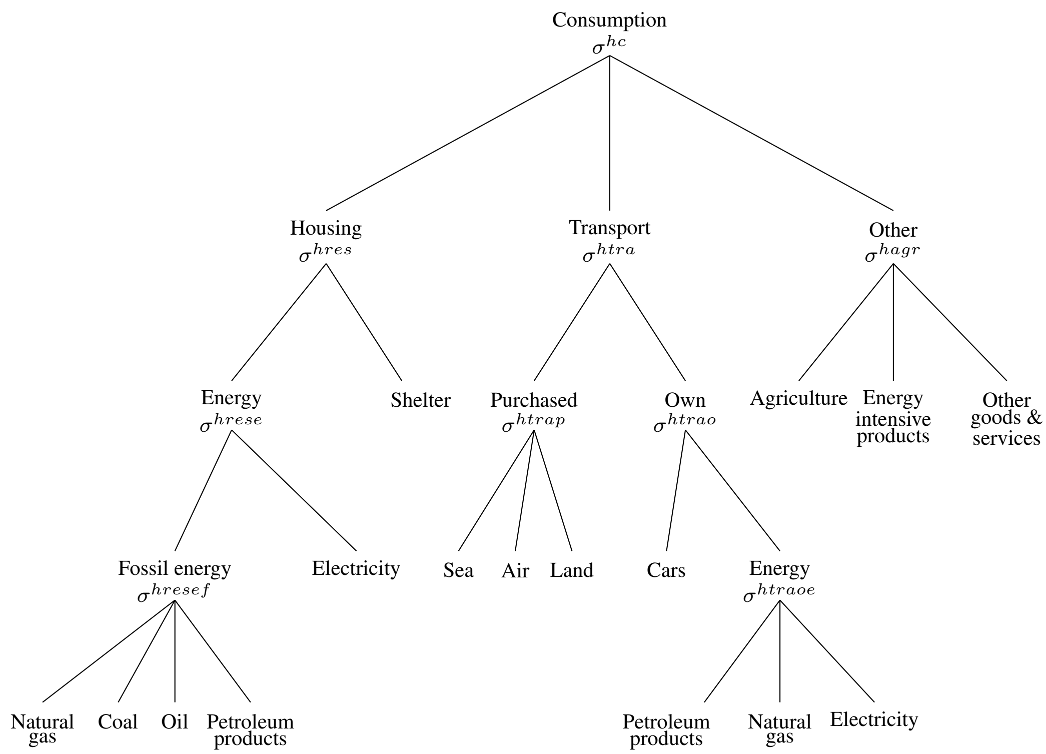


Figure 10: Nested CES structure of household consumption