KIEL INSTITUTE FOR THE WORLD ECONOMY

KIEL WORKING PAPER

Gains associated with linking the EU and Chinese ETS under different assumptions on restrictions, allowance endowments, and international trade

No. 2185 May 2021

Malte Winkler, Sonja Peterson, and Sneha Thube

Kiel Institute for the World Economy
ISSN 1862–1155

ABSTRACT

GAINS ASSOCIATED WITH LINKING THE EU AND CHINESE ETS UNDER DIFFERENT ASSUMPTIONS ON RESTRICTIONS, ALLOWANCE ENDOWMENTS, AND INTERNATIONAL TRADE

Malte Winkler, Sonja Peterson, and Sneha Thube

Linking the EU and Chinese Emission Trading Systems (ETS) increases the cost-efficiency of reaching greenhouse gas mitigation targets, but both partners will benefit – if at all – to different degrees. Using the global computable-general equilibrium (CGE) model DART Kiel, we evaluate the effects of linking ETS in combination with 1) restricted allowances trading, 2) adjusted allowance endowments to compensate China, and 3) altered Armington elasticities when Nationally Determined Contribution (NDC) targets are met. We find that generally, both partners benefit from linking their respective trading systems. Yet, while the EU prefers full linking, China favors restricted allowance trading. Transfer payments through adjusted allowance endowments cannot sufficiently compensate China so as to make full linking as attractive as restricted trading. Gains associated with linking increase with higher Armington elasticities for China, but decrease for the EU. Overall, the EU and China favor differing options of linking ETS. Moreover, heterogeneous impacts across EU countries could cause dissent among EU regions, potentially increasing the difficulty of finding a linking solution favorable for all trading partners.

Keywords: Paris Agreement, NDC, Emission Trading, Linking ETS, China, EU

JEL classification: F130; F180; Q580; Q540

Corresponding author
Malte Winkler
Kiel Institute for the World Economy
Kiellinie 66
D-24105 Kiel, Germany
Email:
malte.winkler@ifw-kiel.de
www.ifw-kiel.de

Sonja Peterson
Kiel Institute for the World Economy
Kiellinie 66
D-24105 Kiel, Germany
Email:
sonja.peterson@ifw-kiel.de
www.ifw-kiel.de

Sneha Thube
Kiel Institute for the World Economy
Kiellinie 66
D-24105 Kiel, Germany
Email:
Sneha.thube@ifw-kiel.de
www.ifw-kiel.de

„We thank two anonymous referees for valuable comments and discussions. This work is supported by the German Federal Ministry of Education and Research (BMBF) [grant number 01LA1816A and 01LA1816B]"

Gains associated with linking the EU and Chinese ETS under different assumptions on restrictions, allowance endowments, and international trade

Declarations of interest: none

Abstract

Linking the EU and Chinese Emission Trading Systems (ETS) increases the cost-efficiency of reaching greenhouse gas mitigation targets, but both partners will benefit – if at all – to different degrees. Using the global computable-general equilibrium (CGE) model DART Kiel, we evaluate the effects of linking ETS in combination with 1) restricted allowances trading, 2) adjusted allowance endowments to compensate China, and 3) altered Armington elasticities when Nationally Determined Contribution (NDC) targets are met. We find that generally, both partners benefit from linking their respective trading systems. Yet, while the EU prefers full linking, China favors restricted allowance trading. Transfer payments through adjusted allowance endowments cannot sufficiently compensate China so as to make full linking as attractive as restricted trading. Gains associated with linking increase with higher Armington elasticities for China, but decrease for the EU. Overall, the EU and China favor differing options of linking ETS. Moreover, heterogeneous impacts across EU countries could cause dissent among EU regions, potentially increasing the difficulty of finding a linking solution favorable for all trading partners.

Key Words: Paris Agreement, NDC, Emission Trading, Linking ETS, China, EU

JEL classification: F130, F180, Q580, Q540

1. Introduction

The Paris Agreement abandoned the top-down approach of the Kyoto protocol, which defined an overall emission reduction target to be distributed among individual countries. Instead, following a bottom-up approach, individual countries are called upon to submit new pledges and emission reduction targets regularly, ideally adding up to a pre-determined global target (UNFCCC, 2020). Within the context of the Paris Agreement, these pledged emission reduction targets are termed *Nationally Determined Contributions (NDCs).* Article 6 of the Paris Agreement (UNFCCC, 2015) outlines the possibility of reaching the NDCs through international cooperation, and includes the option of linking Emission Trading Systems (ETS) to do so. This is a recognized mechanism for increasing the cost-efficiency of international greenhouse gas mitigation (e.g. Alexeeva and Anger 2016, Nong and Siriwardana 2016, Fujimori et al. 2016), and the linking of national ETS is perceived as a fallback option when international top-down approaches have failed (e.g. Ostrom 2010, Tuerk et al. 2009).

However, several studies find that linking existing ETS does not automatically benefit all participating countries but can instead lead to welfare losses in the allowance selling region through terms-of-trade (ToT) effects (e.g. Flachsland et al. 2009). ToT is a country´s ratio of export prices to import prices. In this context, ToT refers to the decreased competitiveness faced by allowance sellers as they connect to an ETS characterized by a higher emission allowance price. Indeed, the allowance prices of all participating regions converge the linked ETS, leading to an increase in the domestic allowance price of selling regions. As a consequence, the export prices of energy intensive goods increase, hereby decreasing the international competitiveness of allowance selling regions and potentially causing welfare loss. In Fujimori et al. (2016), several regions, China included, face negative economic impacts through the ToT effect when engaging in a global emission trading compared to unilateral carbon pricing. Peterson and Weitzel (2016) find that transfer payments to energy exporters are necessary to counteract indirect market effects in a global ETS, with targets calibrated to a regionally equal loss of welfare. A similar situation applies to emission exporters when ToT effects prevail over the revenue gains from selling emission allowances.

The EU and China have implemented the two largest ETS in the world. The EU-ETS was established in 2005 and covers energy intensive industries and the power sector. The Chinese ETS officially started in February 2021 and applies to the power sector alone, with plans to further extend its coverage to the energy intensive industry sectors. Several studies have already analyzed the effects of linking a stylized EU and Chinese ETS. Hübler et al. (2014) find that China benefits marginally at best when a link to the EU ETS with restricted trading volume is established. In Liu and Wei (2016), both EU and China benefit from linking their ETS. Li et al. (2019) show that import quotas can avoid the negative effects of unlimited linking between the EU and Chinese ETS. In case of full linking, China's net imports of chemicals, non-ferrous metals and refined oil increase, indicating a worsening of the ToT. If the number of permits traded is limited, Chinese exports (imports) of energy intensive goods increase (decrease), implying that a smaller tradeable permit quota protects the energy intensive industries in China. Gavard et al. (2016) model scenarios with a full link between the EU and Chinese ETS as well as allowance trading with different degrees of restrictions. They find that China suffers welfare loss when the ETS are fully linked, since the revenues from selling allowances do not offset the losses associated with the higher carbon prices induced by linking. Furthermore, China experiences welfare gains when the trading of allowances between the EU and China is limited. Welfare effects depend on the permit price (which decreases with a higher degree of linking) and on the traded volume (which increases with a higher degree of linking). Consequently, revenue from allowance selling and welfare effects are not linear (Gavard et al., 2016).

In this study, we use the computable-general equilibrium (CGE)-model DART Kiel to evaluate the drivers behind these partly contradicting results. We implement the EU ETS along with a disaggregated representation of the electricity sector. The model horizon for all scenarios is 2030, which is the target year of most currently submitted NDCs (UNFCCC, 2021). We establish a full link between the EU and Chinese ETS (aligned with its stylized current design plans) and develop a set of scenarios to analyze under which circumstances linking is most beneficial to the EU and/or China. These scenarios include 1) limits to traded allowance volume; 2) altering emission reduction targets in both regions so that EU has to abate more and China less, simulating transfer payments from EU to China; and 3) altering

Armington trade elasticities[1]. Thus, we address three main topics which are referred to in the literature: restricted trading, the opportunity for transfer payments through adjusted allowance endowments, and ToT effects.

Our study is part of a broader cross-model comparison study of the Energy Modelling Forum which is denoted "EMF36 - Carbon Pricing after Paris" and summarized in Böhringer et al. (this issue). We add to the existing literature by systematically addressing the problem of unequal gains from ETS linking between allowance buyer and allowance seller. This topic has been addressed by a number of papers, albeit with diverse results. To the best of our knowledge, this study is the first to conduct a systematic analysis of how different measures affect these inequalities. We also at some points discuss inner-European heterogeneity stemming from different linking options and equalizing schemes.

This paper proceeds as follows. In section 2, we describe the model and our scenarios. In section 3 we present and discuss the modelling results, focusing on the gains from linking ETS in the EU and China. In section 4 we discuss our findings against the literature. Section 5 concludes.

2. Model description and scenario runs

The analysis in this paper is undertaken with the multi-regional, multi-sectoral, recursive-dynamic CGE model DART of the Kiel Institute for the World Economy (DART Kiel), which is designed to analyze climate and energy policies and calibrated to the GTAP9 power database (Aguiar et al. 2016). A short non-technical description of the model can be found in the Appendix. The regional disaggregation of the model is displayed in Table 1. The sectoral aggregation is in line with the EMF36 core scenarios (see Böhringer et al., this issue), but we further disaggregate the electricity sector into eight different technologies (coal, oil, gas, wind, solar, nuclear, and hydro based electricity and electricity based on other inputs) based on the GTAP9 Power database (Peters 2016). With the remaining four energy sectors (crude oil, refined oil products, coal, gas) and five production sectors (energy-intensive trade-exposed goods, transport, agriculture, other manufacturing, services) we model a total of 17 sectors.

Table 1 List of regions modelled in DART Kiel. Grey shading indicates EU ETS regions.

Region code	Countries / regions
CHN	China
FRA	France
GER	Germany
GBR	United Kingdom, Ireland
BLX	Belgium, Netherlands, Luxembourg
SEU	Italy, Spain, Portugal, Greece, Austria, Cyprus, Malta
SCA	Denmark, Finland, Sweden, Norway
EEU	Poland, Czech Republic, Slovakia, Slovenia, Hungary, Baltic States, Croatia, Romania, Bulgaria
REU	Rest of Europe (non-ETS): Switzerland, Albania, Belarus, Ukraine, Serbia, Rest of EFTA

---

[1] Armington trade elasticities describe the substitutability between a domestically produced good and an imported good. With higher Armington elasticities, domestic goods can be substituted by imported goods more easily; thus, higher Armington elasticities can be interpreted as more trade openness.

The remaining 12 regions are in line with the EMF36 harmonization (Böhringer et al., this issue): USA, Canada, Russia, Japan, India, South Korea, Brazil, Australia + New Zealand, Other Americas, Other Asia, Middle East, Africa.

For the **Baseline** scenario, we calibrate DART Kiel to meet the GDP and CO_2-emissions projections of the World Energy Outlook 2018 (WEO; IEA 2018) in the year 2030. In this process we adjust constant annual regional total factor productivity growth rates and increase the GTAP Armington elasticities by a factor of 1.5 allowing for a maximal value of 12 in order to achieve the given GDP growth rates[2]. The DART Kiel model is a multi-region, multi-sector, recursive dynamic CGE model. The version used in this study is based on the GTAP 9 data base for 2011 (Aguiar et al. 2016) and the related GTAP-9 Power data base (Peters 2016) and contains the following sectors and regions.

Table A 1 DART Kiel regions

Europe	
GBR	United Kingdom, Ireland
SCA	Denmark, Finland, Sweden, Norway
DEU	Germany
FRA	France
BLX	Benelux
SEU	Southern Europe: Austria, Italy, Spain, Portugal, Malta, Greece, Cyprus
EEU	Czech Republic, Slovakia, Slovenia, Hungary, Estonia, Latvia, Lithuania, Bulgaria, Romania, Croatia, Poland
REU	Rest EU incl. Iceland, Liechtenstein, Switzerland, Albania, Belarus, Ukraine,
Americas	
CAN	Canada
USA	USA
BRA	Brazil
OAM	Other Amercias
Russia & Asia & Pacific	
RUS	Russia
IND	India
ANZ	Australia, New Zealand
JPN	Japan
CPA	China, Kong-Kong
KOR	Korea
OAS	Other Asia
Africa & middle East	
MEA	Middle East, North Africa
AFR	Sub Saharan Africa

Table A 2 DART Kiel sectors

Energy & Electricity		Other	
Col	Coal	EIT	Energy Intensive Sectors
Cru	Crude oil	TRN	Transport Aggregate
Gas	Natural gas	AGR	Agriculture & Food

---

[2] This is necessary to achieve the given GPD growth in China, which turns out to be only possible in DART if there is enough flexibility for increased exports.

Oil	Refined oil products	MFR	Other manufactured goods
ENuclear,	Electricity from Nuclear	SER	Services
ECoal	Electricity from Coal	CGD	Savings good / Aggregate Investment
EGas	Electricity from Gas		
EWind	Electricity from Wind		
EHydro	Electricity from Hydro		
EOil	Electricity from Oil		
ESolar	Electricity from Solar,		
EOther	Electricity from Other		

The economic structure for each region covers production, consumption, investment and governmental activity. Markets are perfectly competitive. Prices are fully flexible. For each region, the model incorporates three types of agents: the producers, distinguished by production sectors, the representative private household and the government.

Producer Behavior

All industry sectors are assumed to operate at constant returns to scale. Output of each production sector is produced by the combination of energy, non-energy intermediate inputs, and the primary factors labor and capital (land in the agricultural sector). Figures A1 and A2 show the nested production structure for non-energy goods and fossil energy.

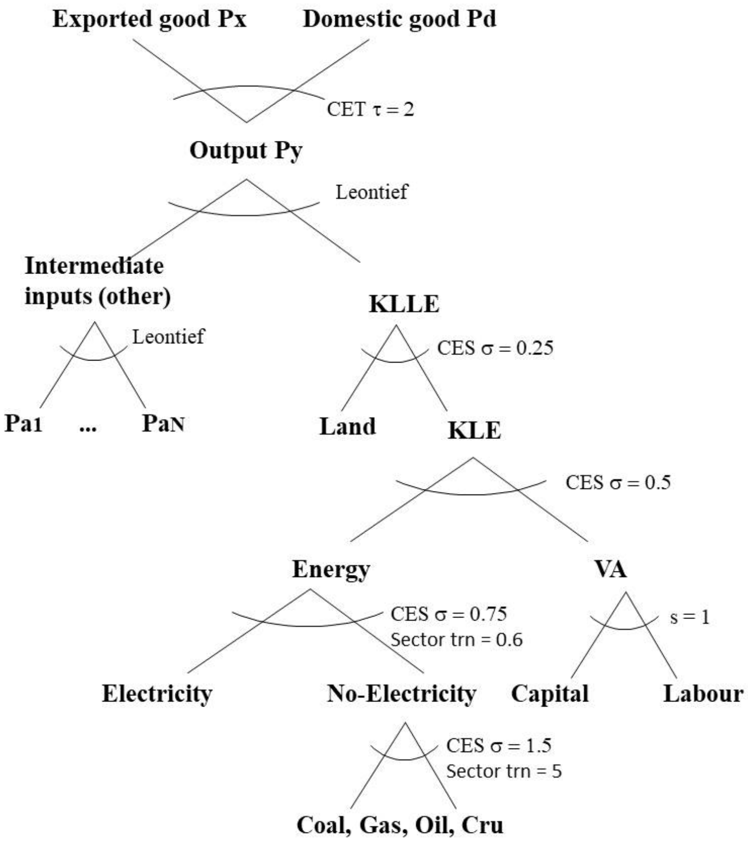


Figure A 1: Nesting of non-energy production

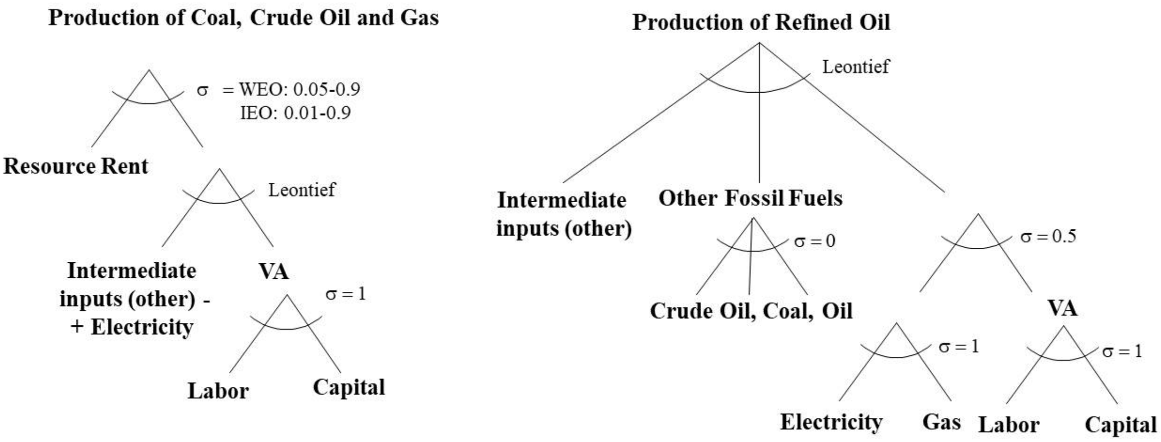


Figure A 2: Nesting of fossil fuel production

Electricity production is differentiated between coal, gas, oil, hydro, nuclear, wind and solar based electricity plus other electricity. The elasticity of substitution between the different types of electricity is 12. Note that we do not use the baseload-peak load disaggregation proposed in Peters (2016), but aggregate e.g. GasBL and GasP to EGas.The nesting structure is depicted in Figure 2:

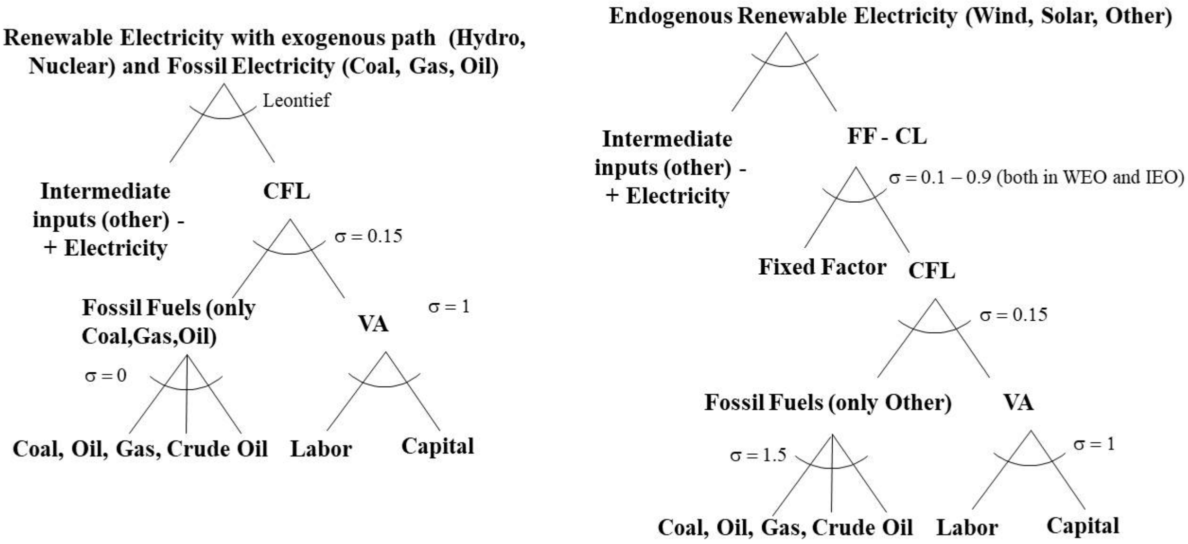


Figure A 3: Nesting of electricity production

Composite investment is a Leontief aggregation of Armington inputs by each industry sector. Investment does not require direct primary factor inputs. Producer goods are directly demanded by regional households, governments, the investment sector, other industries, and the export sector.

Consumption and Government Expenditure

The representative household receives all income generated by providing primary factors to the production process. Disposable income is used for maximizing utility by purchasing goods after taxes and savings are deducted. Private consumption is calibrated to a LES, which divides demand into subsistence and supernumerary consumption based on a Stone-Geary utility function. Households first spend a fixed part of their income on a subsistence quantity for each commodity and allocate their supernumerary income to different commodities according to fixed marginal budget shares which are the product of average budget shares and income elasticities of demand. This division of total consumption into fixed subsistence and flexible supernumerary quantities allows for a calibration to non-unitary income elasticities and non-homothetic preferences. To avoid that, the LES will eventually converge to a Cobb-Douglas system and approach homothetic preferences when income grows, the subsistence quantities are updated with population growth in each period following Schünemann and Delzeit 2019, which also includes further information on the LES calibration.

The third agent, the government, provides a public good which is produced with commodities purchased at market prices. Public goods are produced with the same two-level nesting structure as the household "production" function (see also Figure A4). The public good is financed by tax revenues.

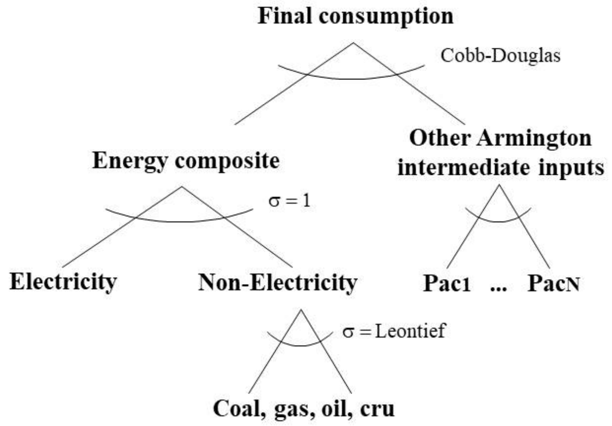


Figure A 4: Nesting structure of final consumption

Foreign trade

The world is divided into economic regions, which are linked by bilateral trade flows. All goods are traded among regions, except for the investment good. Following the proposition of Armington (1969), domestic and foreign goods are imperfect substitutes, and distinguished by country of origin. Transport costs, distinguished by commodity and bilateral flow, apply to international trade but not to domestic sales.

On the export side, the Armington assumption applies to final output of the industry sectors destined for domestic and international markets. Here, produced commodities for the domestic and for the international market are no perfect substitutes. Exports are not differentiated by country of destination.

Factor markets

Factor markets are perfectly competitive and full employment of all factors is assumed. Labor is assumed to be a homogenous goods, mobile across industries within regions but internationally immobile. The capital stock is given at the beginning of each time period and results from the capital accumulation equation. Capital is also region specific and a putty-lay vintage capital approach is chosen, so that only new investment is mobile across sectors. In every time period the regional capital stock earns a correspondent amount of income measured as physical units in terms of capital services. The primary factor land is only used in agricultural sectors and exogenously given.

Coverage of GHG emissions

DART covers CO_2-emissions from the burning of fossil fuels taken from the GTAP 9 data base.

Dynamics and Calibration

The DART Kiel model is recursive-dynamic, meaning that it solves for a sequence of static one-period equilibria for future time periods connected through capital accumulation. The major driving exogenous factors of the model dynamics are change in the labor force, the savings rate, the depreciation rate and the gross rate of return on capital, and thus the endogenous rate of capital accumulation. Finally, the rate of total factor productivity (TFP) growth is used to calibrate DART Kiel to a given GDP-path. For the EMF-36 GDP baseline it was in addition necessary to reduce the growth of the labor force for a few regions since already a TFP of zero led to too high growth rates. If this was still not enough also depreciation was increased.

Finally, it turned out that the given Chinese GDP value for 2030 could not be reached with higher TFP in China alone but required import let growth in DART. For this reason, the usual Armington elasticities we increased by 1.5 worldwide. Table A3 below shows the base data and these adjustments.

The savings behavior of regional households is characterized by a constant savings rate over time. This rate is allowed to adjust to income changes in regions with extraordinary high benchmark savings rates, namely China, India, AFR, OAS and KOR. Labor supply considers population growth and the development of the share of the working force in the population.

The supply of the sector-specific factor land is held fixed to its benchmark level over time. Current period's investment augments the capital stock in the next period. The allocation of new capital among sectors follows from the intra-period optimization of the firms.

Furthermore, the baseline path of renewable electricity plus nuclear is calibrated to match the projections of the IEA. The development of electricity from hydro and nuclear is fixed at an exogenous growth path through an endogenous subsidy. For solar- and wind-power as well as other-electricity, we adjust the growth of the fixed factor and the elasticity of substitution between the fixed factor and the other inputs to calibrate to the given path that then also reacts to policy shocks.

Emissions are traditionally calibrated only on global level for CO_2-emissions from gas, coal and oil by adjusting the supply elasticity of these fossil fuels. To achieve a given regional emission level at 2030 for the EMf-36 scenarios we used regional supply elasticities of fossil fuels and in addition adjusted the autonomous energy efficiency improvement (AEEI) which is typically 1% p.a. to achieve the required emission intensity of GDP. In India even very high rates were not sufficient to bring down emission intensity sufficiently so we increased the KLE elasticity as well. Finally, the WEO baseline used in this study is based on carbon prices for the EITE sector and the power sector in Europe (27$/tCO2) China (20$/tCO_2), Canada (36.5$/t$CO_2$) and Korea (28$/tCO_2). We also implemented carbon prices for WEO in EITE sectors starting in 2015 and linearly rising to the given level in 2030. To match the given CO_2 level in 2030 and for the EU the communicated targets for the EU emissions trading scheme, the prices were slightly adjusted to 21$/t$CO_2$ in Europe, 18 $/t$CO_2$ in Canada, 15 $/t$CO_2$ in China and 14 $/t$CO_2$ in Korea.

Relevant elasticities and parameter are summarized in Tables A3 and A4. We use the same method as Böhringer et al. (this issue) to calibrate the emissions from ETS and non-ETS sectors in the EU for our Baseline. As a result, in our Baseline the total CO_2 emissions in EU ETS sectors increase by 20.6%, while in the non-ETS sectors they reduce by 0.6%, which results in an overall increase of 4.4% in emissions, all relative to Baseline.

Table A 3 Core elasticities and adjustments for EMF calibration

Elasticity	Explanation	Value	Adjustment for EMF WEO Baseline
ESUB_ES(*,r)	Elasticity fixed resource in coal, gas, cru production	Default: Coal 0.3, GAS 0.2, CRU 0.2	0-0.8 to calibrate regional emission path
ESUB_ELE(I)	ele vs Non-electricity energy	0.75	
	For Transport	6	
ESUB_NE(I)	Non-electricity energy	1.5	
	For Transport	5	
ESUB_LD(r)	land vs KLE	0.25	
esub_kle(r,i)	Energy vs Capital /Labor	0.5	IND: 0. 75; BRA: 0.85
S	Elas. KLE vs material	0	
esub_ele	Diff. ele types	12	
Va	Elas capital / labor	1	
Esub_res(*,r)	Elasticity of fixed resource EWind, ESolar, EOther	Default: 0.1	0-0.8 to calibrate path
preleexp(*,r)	exponent for increase of fixed factor EWind, ESolar, EOther		0-0.9 to calibrate path
ARMEL(i,r)	Imports from diff. regions		Min(12,1.5*armel(i,r));
	All electricity types	2.8	4.2
	COL	3.05	4.6
	CRU, GAS	12.849	12.0
	OIL	2.1	3.2
	EIT	3.239	4.9
	TRN	1.9	2.9
	AGR	2.761	4.1
	MFR	3.529	5.3
	SER	1.917	2.9
ARM_REG(I)	imports vs domestic	Min(14, 2*ARMEL)	=Min(14,1.5*arm_reg(i);

Table A 4 Further core parameters

Elasticity	Explanation	Value	Adjustment WEO
AEEI	Autonomous Energy Efficiency Improvement p.a.	1% p.a. in all regions	AFR 1%; BLX 2.5%; BRA 0%; CAN 0.5%; CHN 2.4%; EEU 1.3%; FRA 2.5%; GBR 1.5%; GER 0.7%; IND 2.8%; MEA 2.4%; OAM 1.5%; REU 2%; RUS 0.3%; SCA 2.3%; SEU 0.4%; USA 2.1%; OAS 1.8%; JPN 1.7%; KOR 0.6%; ANZ 0.8%
Dep	Depreciation	0.04	OAM: 0.045; MEA: 0.045
ffshare(i,r)	Fixed factor share in ESolar and EWind	0.1	
sub	Elasticity energy composite and other inputs for final demand	1	
wrkad	Adjustment factor in growth of labor force	1	MEA: 0.8; OAM: 0.8; CHN: 0

in the Appendix displays key model parameters including Armington elasticities. To calibrate 2030 CO_2-emissions we adjust the autonomous energy efficiency (AEEI) improvements as well as the elasticity of substitution between fossil fuels and a fixed resource. The Baseline scenario also includes EU emission trading in the energy intensive industry sectors and the power sector subsequently referred to as the ETS-sectors (opposed to the remaining non-ETS sectors). Note that Rest of Europe (REU) does not participate in the EU ETS. Throughout this paper, we use the term "EU" as a synonym for "regions participating in the EU ETS"; hence, REU is excluded. By imposing a carbon price, the CO_2-emissions of the EU ETS sectors are calibrated to the emission targets proposed by the EU rather than the path outlined in IEA (2018)[3].

Next, we implement a policy scenario **NoLink**, in which China and the EU (and all other model regions) unilaterally reach their 2030 NDC emission reduction targets. DART Kiel only includes CO_2-emissions from the combustion of fossil fuels and we use the NDCs as quantified in Böhringer et al. (this issue). They disaggregate the NDCs from Kitous et al. (2016) (weighted by 2030 emissions) to the GTAP9 regional disaggregation to make them available for any desired aggregation. In our case, we aggregate the targets to the EU-regions in DART Kiel, which logically sum up to a joint EU target as shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**. The Chinese NDC is in reality formulated as an emission intensity target (emissions per unit of GDP) however similar to Gavard et al. (2016), Böhringer et al. (this issue) translate this into an absolute target. Intensity targets are sensitive to the calibrated CO_2 and GDP path. Based on the calculations of Böhringer et al. (this issue) in the case of China, this leads to zero emission reduction against the Baseline. However, given the current Chinese emission reduction efforts, this seems unrealistic. Thus, Böhringer et al. assume a 5% reduction against the Baseline, acknowledging that China has installed or will install at least moderate policies leading to effective carbon pricing. Though this approach ignores that changes in the GDP growth of China resulting from a linking of ETSs can affect the reduction efforts, any linking would probably include measures to ensure that it does not lead to extra emissions in China. Thus, our approach can be justified.

Table 2 CO_2-emission targets for EU regions and China relative to CO_2-emissions in the Baseline scenario in 2030

Region	NDC
CHN	-5%
FRA	-18%
GER	-27%
GBR	-19%
BLX	-21%
SEU	-22%
SCA	-21%
EEU	-30%
EU	-23%

We then run the model so that all NDC targets are reached by a uniform national carbon price covering all sectors. For China and the EU, we use the resulting emissions in the ETS sectors and non-ETS sectors as targets for the following scenarios. For the EU we use these targets also in the final NoLink scenario to model a joint EU ETS price and seven differing national prices to reach the non-ETS targets. This

---

[3] The EU proposes the following targets: 21% reduction (against 2005 emissions) in 2020, 43% reduction in 2030; see https://ec.europa.eu/clima/policies/effort_en. This adjusted target for CO_2-emissions in ETS sectors is the only difference between our baseline and the harmonized EMF36 Baseline_WEO from Böhringer et al. (this issue), as in the latter, the EU is not disaggregated into individual regions.

stylized approach makes our results comparable to other EMF36 results[4] but implies that we do not implement actual regional EU ETS allowance allocation.

We define three sets of scenarios to address our research questions. With the first set of scenarios (labeled "**restricted trading**"), we analyze the impacts of establishing a joint EU - Chinese emissions trading scheme for the ETS sectors with and without limiting the traded allowance volume between the EU and Chinese ETS. The first scenario of this set is the NoLink scenario described above. In the scenario with unlimited allowance trading between the EU and Chinese ETS (labeled **FullLink**), 709 $MtCO_2$ are traded in 2030 between the EU and China. In nine additional scenarios, only a certain share of the emissions traded in FullLink can be traded between the two ETS. In particular, trading is restricted to 10%, 20%, …, 90% of 709 $MtCO_2$. The impact of this restriction on individual EU regions is determined endogenously in the model through the EU ETS. The total of eleven scenarios (NoLink, FullLink, and nine restricted trading scenarios) in the "restricted trading" set allows us to create a gradient of the of traded allowance volumes.

In the second set of scenarios (labeled "**adjusted allowance endowments**"), we change the reduction targets to simulate transfer payments from the EU towards China, which could be used to equalize negative effects resulting from the linking of the two ETS. We run scenarios in which the respective EU emission target for the ETS sectors is increased by 10%, 20%,…, 50%[5], and the respective Chinese target for the ETS sectors is decreased by the same amount of emissions so that joint reduction efforts remain constant. The adapted reduction targets are defined for each EU region, which adds up to EU-wide reductions due to inner-European emission trading. The adapted targets are applied to FullLink and half linking (restricted to 50% of the volume traded in FullLink; subsequently labelled as **HalfLink**). We do not model scenarios including adjusted allowance endowments without linking of ETS because the transfers are implemented to equalize effects from linking. Thus, there would be no transfer payments without linking of ETS. Running FullLink and HalfLink scenarios for the five compensation scenarios altogether leads to 10 scenarios, which again allows for the creation of a gradient of the strictness of the EU emission reduction target.

Previous studies have shown that results relating to climate policy analysis with CGE models are highly sensitive to the chosen trade elasticities (see e.g. Paltsev 2001). Therefore, with the third set of scenarios (labeled "**Armington elasticities**"), we analyze the impacts of different Armington elasticities since international trade is the main channel for international feedback effects influencing the gains from linking carbon markets of the EU and China. This allows for an in-depth analysis of ToT effects, which play a crucial role in the costs and benefits of emission trading regions. We run scenarios in which Armington elasticities are doubled and halved relative to the elasticities used in the Baseline scenario. This is applied either to all sectors or only to ETS sectors and for three linking situations: NoLink, FullLink, and HalfLink. Since altering Armington elasticities is not a policy scenario, but changes the model settings and thus the Baseline, the four alternative Armington assumptions (halved in all sectors; halved in ETS sectors; doubled in ETS sectors; doubled in all sectors) are also run for the Baseline.

---

[4] Except for the EU-ETS, the scenario NoLink is equivalent to the REF scenario in Böhringer et al. (this issue), and the scenario FullLink is equivalent to the EURCHN scenario.

[5] Note that an increase of emission reduction targets means that the amount of allowed emissions decreases: Hence, in this scenario allowed emissions in the EU decrease and those in China increase.

In conclusion, we obtain a total of 38 scenarios to include in our analysis, which are also listed in Table 3.

Table 3 Summary of scenario names and assumptions on traded allowance volume, Armington elasticities and emission reduction target.

No. of scen.	Scenario names	traded allowance volume	Armington assumption	emission reduction target
1	Baseline	0%	Standard	EU-ETS targ
1	NoLink	0%	Standard	NDC
1	FullLink	100%	Standard	NDC
9	Link_X; X= 10, 20,…, 90)	X%	Standard	NDC
5	Link_full_comp_X; X= 10, 20, …50	100%	Standard	NDC ± X%
5	Link_50_comp_X; X= 10, 20, …50	50%	Standard	NDC ± X%
2	BAU_ / NoLink_Arm_halveETS	0%	standard /2 in ETS	-
2	BAU_ / NoLink Arm_doubleETS	0%	standard *2 in ETS	-
2	BAU_ / NoLink Arm_halveAllSec	0%	standard /2 in all sectors	-
2	BAU_ / NoLink Arm_halveAllSec	0%	standard *2 in all sectors	-
2	Link_full_ / Link_50_Arm_halveETS	50%	standard / 2 in EITE	NDC
2	Link_full_ /Link_50_Arm_doubleETS	50%	standard *2 in EITE	NDC
2	Link_full_/ Link_50_Arm_halveAllSec	50%	standard / 2 in all sectors	NDC
2	Link_full_/ Link_50_Arm_doubleAllSec	50%	standard *2 in all sectors	NDC

3. Description of results from scenario runs

In this section we sequentially discuss the key results of our three sets of scenarios, focusing on the implied efficiency gains from trading for both partners (EU and China) and the resulting burden-sharing for reaching the joint target. We also briefly discuss the implications for different EU countries/regions. Throughout the paper, the term “efficiency” refers to cost-efficiency, meaning that the climate policy is termed more efficient when the same emission reduction is reached with lower costs. As common in CGE literature, we use welfare measured in terms of Hicks Equivalent Variation (HEV)[6] as a measure for economy-wide costs. Note that DART Kiel does not include welfare effects resulting from (decreased) environmental damages through climate policy[7]. All results displayed refer to the year 2030.

3.1 Core-linking scenario

When we implement the described emission targets, on the one hand, we see all EU regions lose in terms of welfare relative to the Baseline scenario, with the loss being larger without linking the EU ETS with the Chinese ETS (scenarios NoLink; Figure 1). China, on the other hand, receives welfare gains when NDCs are implemented globally. There are two reasons for this occurrence. First and foremost, as described by Peterson and Weitzel (2016), the demand for fossil fuels decreases as a consequence

---

[6] HEV is a better measure of national welfare than GDP since it takes price changes into account. It is defined as the change in income at current prices that would have the same effect on welfare as would the change in prices, with income unchanged.

[7] For all climate policy scenarios though, the global emission level is fixed, so that there is no difference in climate damages among these scenarios.

of global climate policy, bringing net prices of fossil fuels down. This is beneficial to energy importing regions such as China. Second, reduction targets in China are relatively low compared to the EU (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). Thus, China is relatively less affected by the introduction of the NDCs and consequently becomes more competitive compared to the EU and other regions with stricter targets.

When both regions link their ETS, the EU buys allowances covering a total of 709 $MtCO_2$ from China. While EU emissions in 2030 increase by 30.3% relative to NoLink, Chinese emissions decrease by 8.4%. This linking is beneficial for both the EU and China. Figure 1 reveals that not just the EU at large, but every EU region benefit from fully linking to the Chinese ETS, since the welfare costs relative to the baseline are lower in FullLink than it is in NoLink. Yet, Figure 1 also illustrates that the gains from linked emissions trading systems are significantly larger for most individual EU countries and certainly for the EU as a whole than they are for China. For instance, when moving from NoLink to FullLink, welfare improves by 0.08% in China, against 0.55% in the EU. Throughout the rest of this study, we analyze how our different assumptions affect these regionally unequal gains. In order to do so, we now turn towards the three sets of scenarios introduced in section 2.

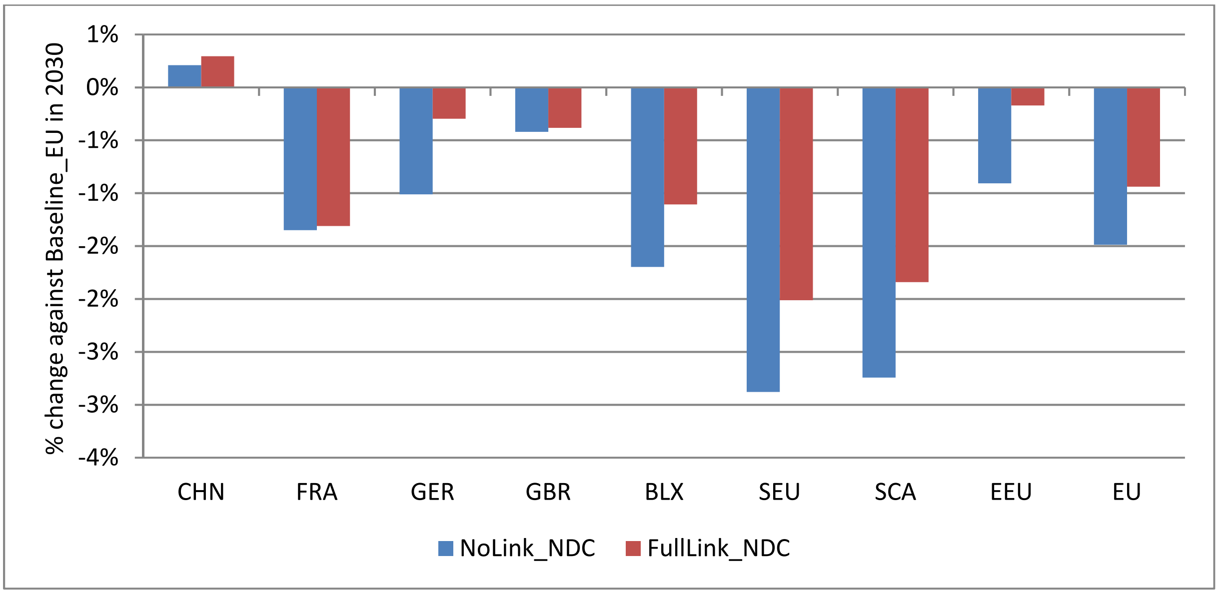


Figure 1: Welfare changes in NoLink and FullLink scenarios in 2030 relative to Baseline.

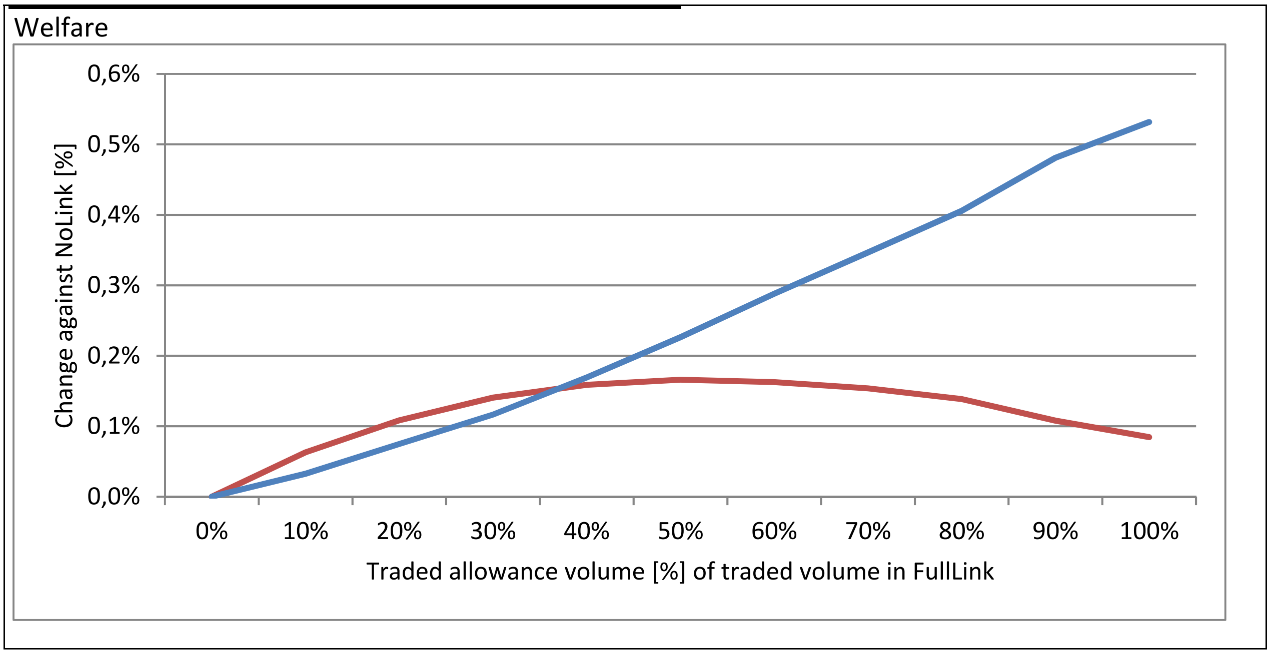
3.2 Restricted trading scenarios

Core results for the “restricted trading” scenarios are shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**. The more trading is allowed, the lower the allowance price in the EU becomes, and the more CO_2 the EU emits. We see that the EU as whole benefits in terms of welfare not only from fully linking to the Chinese ETS, but also in all other “restricted trading” scenarios. The results for individual EU regions, which are not displayed here, reveal that the main sellers of allowances in the NoLink scenario do not benefit under the highly restricted linking of EU and Chinese ETS. This arises from the fact that under linked ETS these regions lose part of their market to cheaper CO_2 allowances provided by China. Only for linked shares beyond 60% do all EU regions experience welfare gains, due to the benefits from lower carbon prices.

Different effects are observable in China. While we do not find a negative effect in welfare as a result of the linking of ETS, there is an optimum point where the trading of allowances is restricted to around 50% of the traded volume in scenarios with fully linked ETS[8]. China´s welfare thus forms an inverted U-shape when depicted as a function of the volume of allowance traded between China and the EU (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). This inverted U-shape is driven by the same factors as in Gavard et al. (2016): Revenue that China gains from selling allowances is a function of the allowance price (which decreases with more linking) and the traded volume (which increases with more linking). The carbon prices converge in EU and China as the traded volume increases. Thus, carbon revenues generated with higher linking no longer compensate for the losses associated with sharing a stricter emission constraint with the EU. The relative changes in welfare against NoLink reach a maximum of 0.17% in China and 0.53% in the EU. As expected, the allowance price and CO_2 emissions in China develop contrary to that in the EU i.e. the allowance price increases with higher trading volume and the emissions decrease.

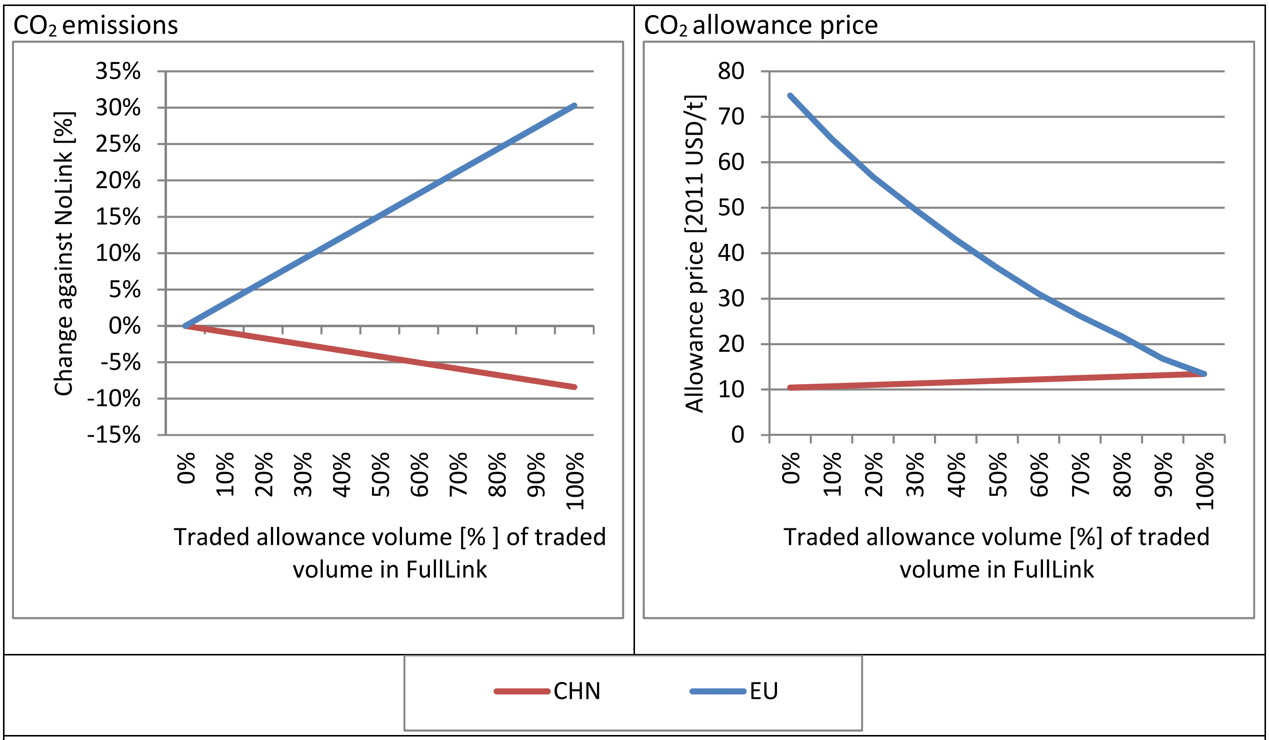
Table 4 Change between NoLink and FullLink in "restricted trading" scenarios . The absolute allowance price marks differences between NoLink and FullLink; e.g. the allowance price in the EU is 61.23 $/tCO$_2$ lower in FullLink than it is in NoLink.

Parameter	Region	NDC
Welfare	China	0.08%
	EU	0.53%
CO_2 emissions	China	-8%
	EU	30%
allowance price relative	China	29%
	EU	-82%
allowance price absolute	China	3 \$/tCO_2
	EU	-61.2 \$/tCO_2



---

[8] This optimum at 50% is also the reason we introduce the „HalfLink" scenarios for the two following sets of scenarios.

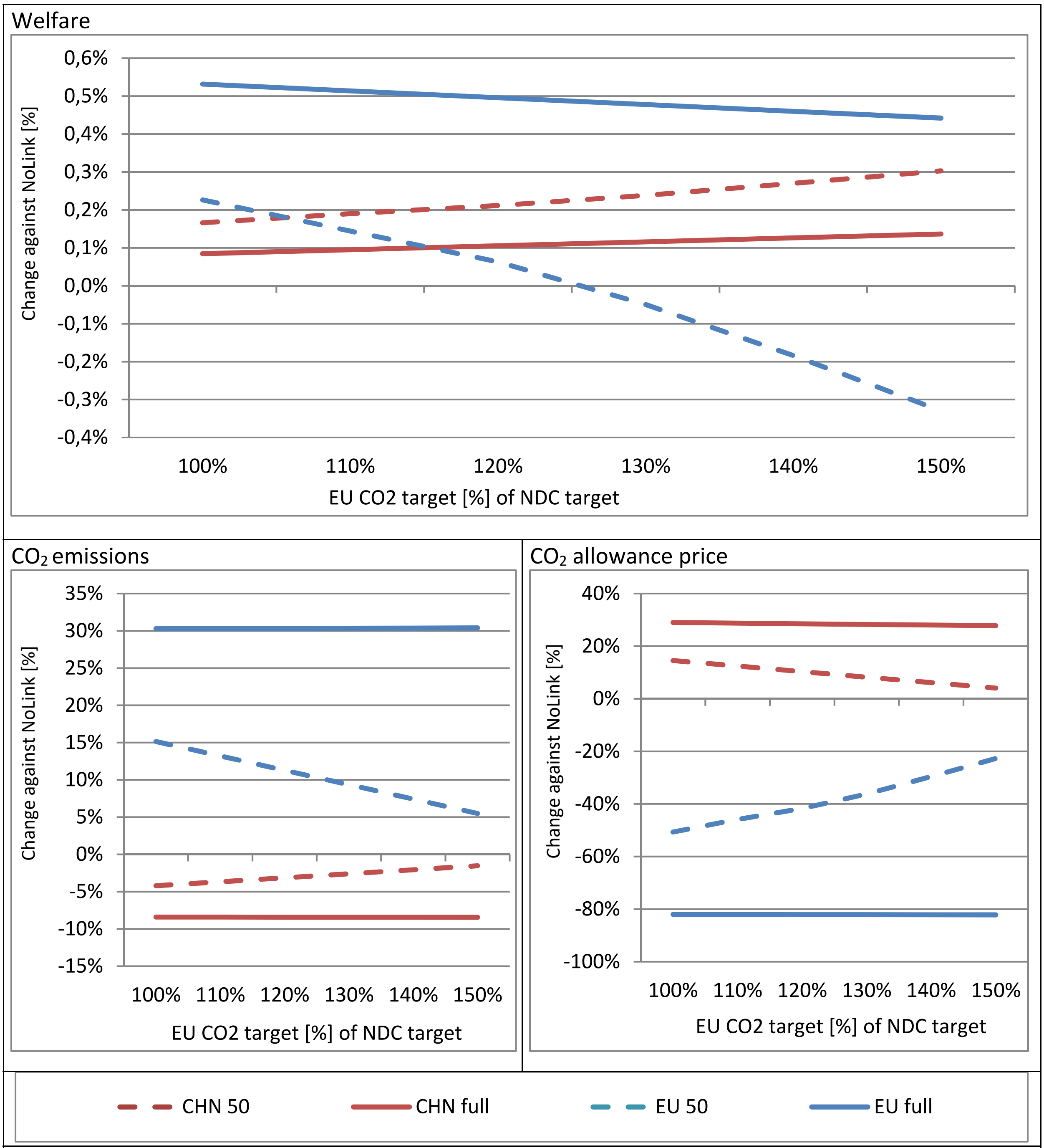

CO_2 emissions

CO_2 allowance price

Figure 2: Main results of the “restricted trading” scenarios relative to NoLink in 2030.

3.3 Adjusted endowments scenarios

For the “adjusted allowance endowment” scenarios, we compare the FullLink and HalfLink scenarios (the latter being optimal for China) to the NoLink scenario to analyze gains from allowance trading. Remember, that we model adjusted allowance endowments to the EU and Chinese ETS sectors to generate transfer payments, keeping the sum of ETS emissions of both regions constant overall compensation scenarios. For example, the scenario called “130%” assumes that the EU ETS CO_2 emission reduction target is tightened by 30% relative to the regular NDC i.e. instead of 452 $MtCO_2$ (regular NDC), the target is now 316 $MtCO_2$ (130%). Simultaneously, emission targets for the Chinese ETS sectors increase by the same amount, such that joint EU-Chinese ETS emissions remain constant. The main results of this comparison are displayed in **Fehler! Verweisquelle konnte nicht gefunden werden.**.


Welfare

CO$_2$ emissions

CO$_2$ allowance price

Figure 3: Main results of the “adjusted endowments” scenarios relative to NoLink in 2030.

Both China´s and the EU´s total CO$_2$ emissions remain almost unchanged for all compensation scenarios relative to the NoLink scenario when ETS are fully linked, and the same holds for all the regions in the EU. Also, the allowance price in a fully linked ETS is almost independent of the level of compensation. Both emissions and allowance prices are unaffected, since the EU target becomes stricter by an amount equal to the weakening of the Chinese target, so that the EU simply buys the extra demand for allowances from China in all scenarios and the income effects are negligible. This is also the reason why such a scenario is a good approximation of general transfer payments.

When allowance trading is limited to 50%, emissions in the EU decrease and emissions in China increase with higher compensation (relative to the NoLink scenario), since allowance trading cannot fully compensate for the differing allowance allocation. Thus, in this case, there are not only income effects from the transfers but also ToT effects. The CO_2 price in the EU is considerably higher and reaches 58\$/tCO_2 if emission trading is restricted compared to the price of 13\$/tCO_2 under FullLink trading. The allowance price in China decreases only slightly. Also, Chinese emissions are higher under HalfLink trading compared to FullLink. As a result, for both the EU and China, the ToT effects follow the same direction as the effects of adjusted endowments – China benefits from larger endowments not only through higher allowance revenues from a relaxation of its NDC targets but also from improved ToT. In turn, welfare in the EU decreases. As expected, effects are larger with higher compensations. In line with the ToT effects, the increase for China is higher if emission trading is restricted to 50% compared to unrestricted emission trading. The magnitude of this increase is comparable to the gains from “restricted trading” scenarios.

Even for the EU transfers as high as 50% of their emissions in combination with a full link are favorable compared to a situation with no link. Though welfare gains from linking are reduced by compensation in the EU, they are still positive compared to a situation without linking. Again, not all EU regions benefit equally. Compensation transfers up to 20% of emissions would be beneficial for all the EU regions in FullLink (relative to NoLink).

For HalfLink, where ToT effects negatively impact the EU, a maximum compensation of 20% of their emissions is beneficial in terms of aggregated EU welfare. Yet, it is also the case that some EU regions never gain in welfare, regardless of the size of compensation transfers. For scenarios where the EU gains as a whole but not all individual EU regions do, internal distribution mechanisms need to be implemented to compensate the losing EU regions.

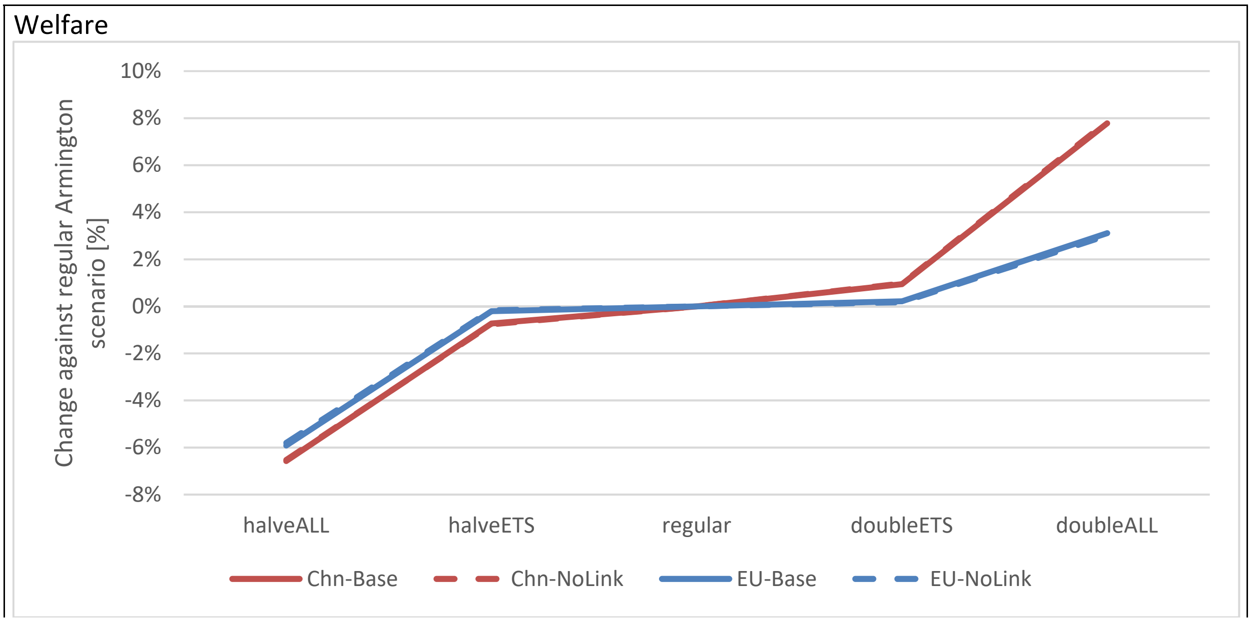
While it makes sense for the EU to pay transfer payments to China under full trading in order to induce China to agree to a joint trading system, the resulting welfare gains in China are rather small. Under FullLink, adjusted allowance endowments of 50% increase welfare compared to NoLink by 0.1%. In the case of 20% transfers under HalfLink (the maximum that is still beneficial for the EU as a whole), 0.2% are gained in terms of welfare.

3.4 Armington elasticities scenarios

While the two former sets of scenarios were concerned about different climate policy actions of the EU and China (restricting emissions trading / agreeing on transfers), the last set of scenarios is about different assumptions regarding the underlying trade elasticities. This implies that also the Baseline and the NoLink scenarios, which do not include further climate policies or linking of ETS, are affected. Before we turn to the gains from linking under different Armington elasticities, we investigate the effects of adjusting these elasticities.

Fehler! Verweisquelle konnte nicht gefunden werden. shows the development of key variables for the Baseline and the NoLink scenarios relative to the corresponding scenarios with regular Armington elasticities. It turns out that Armington elasticities (i.e. restriction or relaxation of international trade) have a much stronger influence on welfare than a restriction of traded allowance volume or transfer of allowances. The relative changes against a baseline with regular Armington elasticities are in the range of -7% to 8% compared to changes below 1% for “restricted trading” scenarios. Effects are significantly stronger for adjusting all elasticities compared to only ETS elasticities. While the direction of welfare effects is the same in China, in the EU as a whole, and in all individual EU regions (all lose when Armington elasticities are reduced, and gain when they are increased, which is in line with the usual gains from trade), China is much more sensitive to these changes than the EU. This is driven mainly by a strong reaction in Chinese exports (-18% against regular Armington elasticities, when Armington elasticities of all sectors are reduced in the baseline and a 6% increase when Armington elasticities of all sectors are increased). Furthermore, Chinese imports decrease with increasing Armington elasticities. The EU exports hardly react to the altered Armington elasticities (minimal increase with higher elasticities), while imports into the EU increase with elasticities. Adjusting only ETS elasticities does not affect EU welfare.

For China, the relative changes in welfare correspond to stronger relative changes in emissions; as an example, a welfare increase of 8% in doubleAll corresponds to an increase in emissions of 12.5%. This is because China is a net exporter of emissions embodied in trade (see e.g. OECD statistics on emissions embodied in international trade https://stats.oecd.org). With increasing trade, their exported emissions increase. Also note that in halveAll China´s emissions decrease so strongly that the carbon price reduced to 1.3$/t$CO_2$ and strongly weakens the NDC target[9]. [TS1][PS2]For the EU, being a net importer of emissions embodied in trade, as well as for all EU regions, the effect is the opposite. As Armington elasticities increase, the EU outsources the production of emission intensive EITE sectors, so that EU emissions from ETS sectors decrease. As domestic production is replaced with imports, emissions decrease. When only the Armington elasticities for ETS sectors are doubled, the national emissions increase by a small amount because of a slight increase in production and emissions from the transport sector.



---

[9] This result is in line with other modeling studies that show a non-binding NDC target for China (e.g., Liu and Wei 2016).

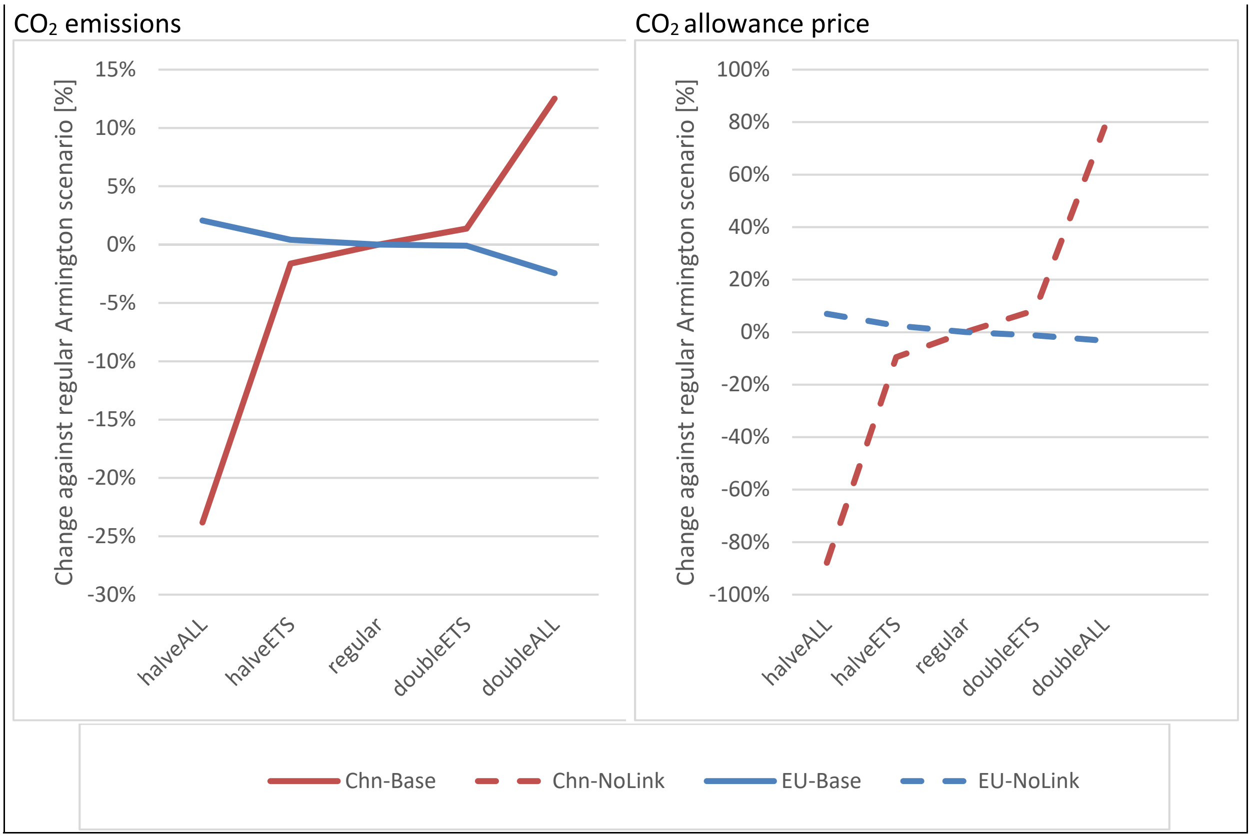


Figure 4: Implication of different "Armington elasticities" for (1) no-climate policy (labelled "Base") and (2) NoLink scenarios (labelled "NoLink") in 2030. All changes are relative to the regular Armington scenario with the same linking assumption. Note that CO_2-emissions in NoLink are by design always equal to the regular case and are thus not shown. Also, there is no allowance price in the baseline.

The effects for welfare in NoLink are almost identical to those in the Baseline for China, overall EU as well as the single EU regions. Overall CO_2 emissions remain unchanged, because both the EU and China reach their given targets themselves, regardless of Armington assumptions. The impact is now on carbon prices, which change in line with the emission changes in the baseline. Higher Armington elasticities in all the sectors (doubleAll) increase baseline emissions and carbon prices under NoLink in China and decrease them slightly in almost all EU regions.

After explaining the effects of altering Armington assumptions on the Baseline and NoLink scenarios, we now turn to our focal question, which is how gains from linking ETS change for different trade elasticities. For this, we compare the FullLink and HalfLink scenarios relative to the respective (i.e., with the same Armington assumption) NoLink scenarios. The results of these comparisons are displayed in Figure 5.

As in the "restricted trading" and "adjusted allowance endowments" scenarios, also in all "Armington elasticities" scenarios China benefits significantly more when linking is restricted to 50% compared to full linking, while for the EU full linking is preferable. Both for China and the EU the effects of altered Armington elasticities only in ETS sectors are negligible (flat slope between halveETS and doubleETS in Figure 5), both in FullLink and HalfLink, because trade in ETS goods and trade in ETS emission allowances are substitutes, and the trading of allowances offsets effects from altered Armington elasticities. This argument is also supported by the lack of significant changes in emissions and allowance prices for half/doubleETS relative to the regular case. For HalfLink, also adjusting all Armington elasticities does not affect these results much. This is different for FullLink, where altered elasticities in all sectors (halve/doubleAll) have visible effects. Now, trade in goods and trade in allowances are not full substitutes anymore, and the trend observed in the Baseline - higher Armington elasticities increase emissions in China and decreases emissions in the EU - is visible. Most importantly, higher Armington elasticities decrease the EU´s gains from linking its ETS to the Chinese ETS, while they increase the gains for China. This makes the gains from trading more equal. On the contrary, lower Armington elasticities imply a more unequal distribution of the gains from trading. Under HalfLink this relationship is less pronounced, but one interesting result is that for HalfLink and doubleAll both China and EU gain welfare by the same percentage.

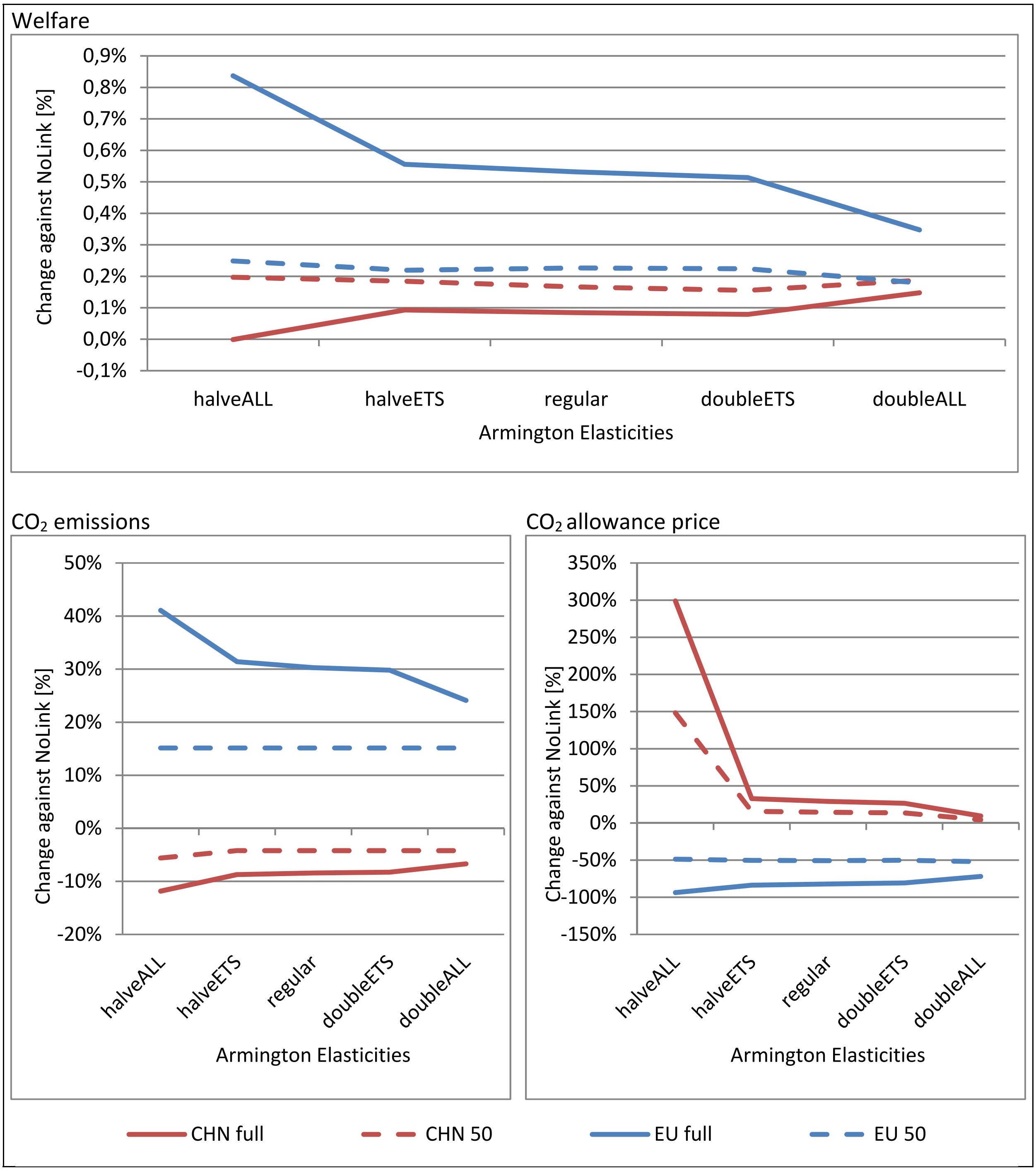


Figure 5: Main results of the „Armington elasticities“ scenarios in 2030. All changes are relative to the NoLink Scenario with the same Armington assumption; e.g. EU CO_2 emissions in a fully linked ETS (EU full) under "halfAll" Armington assumption are ca. 41% higher than in NoLink under "halfAll" Armington assumption.

When ETS are fully linked, all individual EU regions exhibit the same pattern as the EU. Yet, it can happen even in FullLink (in our setting in France), that with higher Armington elasticities in all sectors, linking decreases national welfare. In HalfLink, there is no Armington scenario where all individual EU regions concurrently gain in welfare relative to NoLink.

As for welfare, changes in CO_2 emissions are only significant, when we alter all elasticities (halve/doubleAll) and implement fully linked emission trading. In this case, CO_2 emissions in the EU and all of its individual regions decrease with higher Armington elasticities and the resulting increasing imports into the EU. This is because domestic production decreases and the EU imports more embodied carbon. For China, the opposite is true: emissions increase with higher Armington elasticities and resulting in increasing exports plus decreasing imports, depending also on the EU demand for allowances. As Chinese emissions from ETS sectors increase with higher Armington elasticities (the incentive for China to abate gets lower with increasing opportunities for exports), also the allowance price increases with higher Armington elasticities. This also leads to a higher allowance price in the fully linked EU-Chinese ETS. However, the CO_2 price in a joint EU-China ETS is still much lower than in NoLink or HalfLink scenarios, regardless of the Armington assumptions.

When Armington elasticities are halved in all sectors and allowance trading with the EU is allowed (both half and full trade), the total CO_2 target in China is not binding anymore. ETS emissions are lower than in the scenario without allowance trading because China decreases its emissions to sell allowances to the EU. Also, emissions from non-ETS sectors, which in the scenario without allowance trading equalize these decreases, are low in the scenarios with the lowest Armington elasticities and do not equalize the reduced ETS emissions. Thus, the total combined CO_2 emissions of the EU and China are slightly lower in these scenarios than they are in the other scenarios, and the CO_2 price for non-ETS emissions in China becomes zero.

4. Discussion

The the purpose of this paper is to identify the gains associated with linking an EU and a Chinese ETS for the ETS sectors. Table 5 summarizes these gains for all sets of scenarios. We are aware that the changes are partly small, as is often the case for comparable scenarios (see also Böhringer et al., this issue), yet we see a clear pattern resulting from the policy interventions.

We find that in almost all scenarios, linking the EU and the Chinese ETS proves beneficial to both regions, to different degrees. In most scenarios, the EU gains more than China (0.53% rel. to 0.08% under NDC targets and full trading). Exceptions (in red) are:

- if trade between EU and China is restricted to less than 30% of what is traded without restrictions;
- if the EU transfers 10% or more of their allowances to China and trading volume is restricted to 50% of what is traded without restrictions;
- if under NDC targets Armington elasticities are doubled for all sectors, and trading volume is restricted to 50% of what is traded without restrictions.

Table 5 Gains (in terms of welfare relative to NoLink scenarios) from linking the EU and Chinese ETS for all scenarios

"Restricted trading" scenarios

Scenario Region	10	20	30	40	50	60	70	80	90	100
CHN	0,06%	0,11%	0,14%	0,16%	0,17%	0,16%	0,15%	0,14%	0,11%	0,08%
EU	0,03%	0,07%	0,12%	0,17%	0,23%	0,29%	0,35%	0,41%	0,48%	0,53%

"Adjusted allowance endowments" scenarios

Region	Scenario Linking	100%	110%	120%	130%	140%	150%
CHN	FullLink	0,08%	0,09%	0,11%	0,12%	0,13%	0,14%
	HalfLink	0,17%	0,19%	0,21%	0,24%	0,27%	0,30%
EU	FullLink	0,53%	0,51%	0,50%	0,48%	0,46%	0,44%
	HalfLink	0,23%	0,14%	0,06%	-0,05%	-0,18%	-0,33%

"Armington elasticities" scenarios

Region	Scenario Linking	halfALL	halfEITE	Regular	doubleEITE	doubleALL
CHN	FullLink	-0,001%	0,09%	0,08%	0,08%	0,15%
	HalfLink	0,20%	0,18%	0,17%	0,16%	0,19%
EU	FullLink	0,84%	0,56%	0,53%	0,51%	0,35%
	HalfLink	0,25%	0,22%	0,23%	0,22%	0,18%

Thus, although it is clear that for the EU linking is generally beneficial, there are possibilities to distribute the gains in favor of China and thus avoid increasing welfare inequalities between the two regions. The scenario with halved Armington elasticities in all sectors and fully linked ETS yields no positive welfare impacts for China, which is the least favorable option for China. In the current situation, where trade-barriers are clearly on the rise and voices are talking about a de-globalization, such a scenario might become more likely.

Overall, our results indicate that the EU, should it aspire to link the EU ETS to the Chinese ETS, will have to take measures to make the linking of an EU and Chinese ETS more beneficial for China. This is true especially since the linking of ETS becomes more popular and other regions will compete for the cheap Chinese allowances. As with other studies, we find that a restriction of traded volume can significantly increase benefits for China. In our "restricted trading" scenarios we found China´s gains in welfare highest when allowance trading is restricted to 50% of the volume traded in the FullLink scenario. Even though this reduces the benefits for the EU, these are still significant and about twice as high as those of China. Also, any allowance trading with China, be it restricted or not, is beneficial for the EU in terms of welfare.

Transfer payments from the EU to China are modelled through changing the allowance allocation to the EU and Chinese ETS sectors, keeping total emissions of both regions constant over all "adjusted endowments" scenarios. Thus, EU emission targets for the ETS sectors become stricter, and Chinese emission targets for the ETS sectors become weaker by the same amount of emissions. Transfers through adjusted allowance endowments are most valuable to China under restricted trading, while the effects for China are minimal for full trading, and thus not a solution for more equalized welfare gains. For the EU, transfers through adjusted allowance endowments also imply little losses for full trading but come at a significant cost in case of restricted trading. In our scenarios, if more than 20% of allowances are transferred to China and trading is restricted to 50%, potential benefits from trading are eliminated. It should also be noted that – as mentioned in section 3 – adjusted allowance endowments are no longer a good representation of more general transfer payments under restricted trading since the resulting emission reduction efforts change. Still, our findings indicate that under restricted trading, transfer payments have little benefit for the EU. Thus, if at all, one should consider trade restrictions and adjusted allowance allocation as complements.

If we consider restricted trading on the one hand, and transfers through adjusted allowance endowments on the other hand as two uncombined alternatives, then China benefits more from the former compared to the latter. This holds even in the scenario where the EU transfers 50% of their allowances to China, which is a very extreme and politically unlikely scenario. Yet, even these high transfers through adjusted endowments would still be much more beneficial to the EU than restricting trading. The welfare gain is almost 50% higher when 50% of EU allowances are transferred to China than it is under HalfLink without transfer payment. Hence, the potential trading partners prefer different linking scenarios: While the EU benefits more from full trading and would possibly pursue transfer payments as a measure to make linking more attractive to China, China will aim for a restriction of the trading volume. Analyzing possible outcomes of such hypothetical negotiations from a political economy perspective could provide fruitful avenues for future studies.

Since trade in goods and trade in allowances are to some degree substitutes in the ETS sectors, gains from trading for both partners are higher for lower trade elasticities in ETS sectors. In times of increasing international trade restrictions, this is an important finding. Since China is more vulnerable to trade restrictions than the EU, linking could become more attractive under less open trading (i.e. lower Armington elasticities): welfare losses could be equalized to some degree by trading emission allowances when trading of goods is restricted. This is especially true for ETS sectors, since through emission trading losses arising from the trade restrictions in ETS sectors can be equalized. However, we find that the implications of altering Armington assumptions are much larger than the welfare gains which can be achieved by linking ETS. This stresses the potentially large negative effects of protectionism and trade conflicts.

Having a scenario with a negative welfare effect resulting from linking ETS (even though the loss is negligible) confirms the possibly ambiguous effects found in Flachsland et al. (2009). Unlike Fujimori et al. (2016), who found linking to cause negative welfare effects for China, and excepting the scenario mentioned above, linking is beneficial in all scenarios considered in our study. However, Fujimori et al. (2016) analyzed a globally linked ETS, not just a link between China and the EU. Hübler et al. (2014) do evaluate a link between China and the EU for a case of restricted linking[10]. Similar to our study, they also find positive welfare effects for China in all but one scenario, albeit rather small ones (about 0.1 percentage point lower welfare loss with linking, relative to a BAU without climate policy). Also in Liu and Wei (2016) linking ETS between the EU and China is for both regions always preferable to a comparable situation with separate ETS. They highlight the fact that the EU always favors a different scenario than China, which also holds true for most of our scenarios, where the EU always favors full linking over restricted linking, whereas the opposite is true for China. Thus, should a link between the EU and Chinese ETS be aspired, the actual design would have to be negotiated carefully. While our

---

[10] Trading is restricted to one-third of the EU´s reduction (against 2005 emissions) in each year in Hübler et al. 2014.

results differ from those in Gavard et al. (2016) in that unrestricted allowance trading is not beneficial in their study, the inverted U-shape we find for China´s welfare under different degrees of linking (see **Fehler! Verweisquelle konnte nicht gefunden werden.**) is well in line with their finding of a non-linear relationship between the degree of linking and welfare effect. In Li et al. (2019), the authors find that in terms of welfare, unrestricted allowance trading is preferable over restricted allowance trading not only for the EU but also for China. Still, the authors conclude that restricted allowance trading should be sought after in the mid-term, as such restriction can reduce the negative side effects of full linking, which are not depicted in welfare: the decelerated development of EU's renewable energy production (stemming from the opportunity to buy allowances from China rather than mitigating domestic emissions) and the reduced international competitiveness of China's energy intensive sectors (stemming from higher carbon prices in a fully linked ETS). Such argument in favor of restricted allowance trading gains additional weight against the background of the findings from our study, in which China benefits more under half linking compared to full linking.

We are not aware of any other study analyzing the effects of linking the EU and the Chinese ETS for a disaggregated EU. Therefore, our results provide new insights into whether linking benefiting the EU as a whole will also benefit its member states. The results reveal that unanimous gain in all the EU sub-regions is not systematic and depends on factors such as the degree of linking, choice of mechanism, and the emission target to be met. Overall, all the EU regions experience welfare gains only in the "restricted trading" scenarios, when trading of more than 60% of allowances occurs. Thus, for strengthening the case in support for linking and consequently increasing the likelihood of political acceptance for linking the EU ETS to the Chinese ETS, the creation of transfer mechanisms within the EU is essential.

In this study, we focus on the gains associated with linking under NDCs and model these as absolute reduction targets both for the EU and China, in line with the overall EMF36 round (Böhringer et al., this issue). However, China´s ETS integrates an intensity target (see International Energy Agency (IEA)). This implies the possibility for different absolute CO_2 emissions (see e.g. Liu and Wei 2016) and, thus, different results also for carbon prices and, thus, incentives to link. Hübler et al. (2014) implement scenarios with different assumptions regarding China´s economic growth. This is relevant not only with regard to the intensity target, but also concerning the current situation, in which the world faces unforeseeable consequences of the COVID-19 crisis, international trade dispute, and possible de-globalization. However, the overall trends and findings we derive here are not likely to be qualitatively affected by our absolute reduction approach. Another dimension not covered in our study is the interaction of ETS with other climate or energy policies. Liu and Wei (2016) model a combination of linking EU and Chinese ETS plus introducing renewable subsidies and find important interactions between the two policies. Furthermore, we do not include transaction costs or political barriers that might hinder the linking of ETS. While this aspect is beyond the scope of our CGE study, one should keep in mind that these barriers can seriously hamper or even prevent the linking of ETS, be it economically feasible or not (see e.g. Hawkins and Jegou 2014, Flachsland et al. 2009). All these aspects could be subject to future studies on the feasibility and effects of linking the EU and China's ETS.

5. Conclusions

In this study we analyze the assumptions under which linking between an EU ETS and a Chinese ETS in the energy intensive sectors and the power sector is beneficial for each of the trading partners. Furthermore, we disaggregate the EU and analyze our modelling results also at the sub-EU level. We find that restricted allowance trading is more beneficial to China than full allowance trading, and maximized when the traded volume of allowances is restricted to 50% of the volume traded in a fully linked system. For the EU, full allowance trading is always more beneficial than restricted allowance trading. Another option to make the linking of ETS more attractive to China would be to transfer payments from the EU to China. The EU could favor this option in combination with a full link over a situation with restricted allowance trading but no transfer payments. For China, the opposite is true: restricted trading is favored over transfer payments.

While changes in international trade (modelled in our “Armington elasticities” scenarios) affect China more strongly than the EU, linking of ETS would become more attractive with less open trade, especially if trade barriers aim at ETS sectors: Here, trading of emission allowances could offset the loss originating from decreasing trade of goods. Generally, all trading partners benefit from more trade-openness, and linking ETS further increases these benefits.

In addition to the different options favored by the EU on the one hand and China on the other hand, there are also competing interests among the single EU regions in several scenarios. Namely, regions which are net allowance sellers in a separate EU ETS (not linked to the Chinese ETS) face potential losses when the cheaper Chinese allowances enter the European allowances market. Consequently, even though the linking of EU and Chinese ETS is beneficial to both the EU and China in all our scenarios except one, designing options which can be agreed upon by all trading partners will be difficult, both inside the EU and between the EU and China. This holds especially true when political feasibility is also considered. The possible outcomes of hypothetical negotiations on designing a joint EU–Chinese ETS from a political economy standpoint should be evaluated in future studies.

Acknowledgements

We thank Duan Maosheng (Tsinghua University) and Sergey Paltsev (Massachusetts Institute of Technology) for their helpful comments on the first draft, and two anonymous reviewers for their equally helpful comments on the second draft. Funding: This work was supported by the German Federal Ministry of Education and Research (BMBF) [grant number 01LA1816A].

Publication bibliography

Aguiar, Angel; Narayanan, Badi; McDougall, Robert (2016): An Overview of the GTAP 9 Data Base. *Journal of Global Economic Analysis* 1(1), pp. 181-208.

Alexeeva, Victoria; Anger, Niels (2016): The globalization of the carbon market. Welfare and competitiveness effects of linking emissions trading schemes. In *Mitig Adapt Strateg Glob Change* 21 (6), pp. 905–930. DOI: 10.1007/s11027-014-9631-y.

Böhringer, Christoph; Schneider, Jan; Peterson, Sonja; Winkler, Malte (this issue): Carbon Pricing after Paris - Overview of Results from EMF 36.

Flachsland, Christian; Marschinski, Robert; Edenhofer, Ottmar (2009): To link or not to link. Benefits and disadvantages of linking cap-and-trade systems. In *Climate Policy* 9 (4), pp. 358–372. DOI: 10.3763/cpol.2009.0626.

Fujimori, Shinichiro; Kubota, Izumi; Dai, Hancheng; Takahashi, Kiyoshi; Hasegawa, Tomoko; Liu, Jing-Yu et al. (2016): Will international emissions trading help achieve the objectives of the Paris Agreement? In *Environ. Res. Lett.* 11 (10), p. 104001. DOI: 10.1088/1748-9326/11/10/104001.

Gavard, Claire; Winchester, Niven; Paltsev, Sergey (2016): Limited trading of emissions permits as a climate cooperation mechanism? US-China and EU-China examples. In *Energy Economics* 58, pp. 95–104. DOI: 10.1016/j.eneco.2016.06.012.

Hawkins, Sonja; Jegou, Ingrid (2014): Linking Emissions Trading Schemes. Considerations and Recommendations for a Joint EU-Korean Carbon Market. In *ICTSD Global Platform on Climate Change, Trade and Sustainable Energy; Climate Change Architecture Series* (Issue Paper No. 4), checked on 3/8/2017.

Hübler, Michael; Voigt, Sebastian; Löschel, Andreas (2014): Designing an emissions trading scheme for China—An up-to-date climate policy assessment. In *Energy Policy* 75, pp. 57–72. DOI: 10.1016/j.enpol.2014.02.019.

IEA (2018): World Energy Outlook 2018. International Energy Agency (IEA), checked on 7/4/2020.

International Energy Agency (IEA): China’s Emissions Trading Scheme. Available online at https://www.iea.org/reports/chinas-emissions-trading-scheme, checked on 8/18/2020.

Li, Mengyu; Weng, Yuyan; Duan, Maosheng (2019): Emissions, energy and economic impacts of linking China’s national ETS with the EU ETS. In *Applied Energy* 235, pp. 1235–1244. Available online at https://www.sciencedirect.com/science/article/abs/pii/S0306261918317549, checked on 12/12/2019.

Liu, Yang; Wei, Taoyuan (2016): Linking the emissions trading schemes of Europe and China - Combining climate and energy policy instruments. In *Mitig Adapt Strateg Glob Change* 21 (2), pp. 135–151. DOI: 10.1007/s11027-014-9580-5.

Nong, D.; Siriwardana, M. (2016): The most advantageous partners for Australia to bilaterally link its emissions trading scheme. In *Paper presented at the 57th Annual Conference of the New Zealand Association of Economists. Auckland, New Zealand.*

Ostrom, Elinor (2010): A multi-scale approach to coping with climate change and other collective action problems. In *Solutions* 1 (2), pp. 27–36. DOI: 10.1002/9781444328523.

Paltsev, Sergey V. (2001): The Kyoto Protocol. Regional and Sectoral Contributions to the Carbon Leakage. In *The Energy Journal* 22 (4), pp. 53–73. DOI: 10.5547/ISSN0195-6574-EJ-Vol22-No4-3.

Peters, J. C. (2016): The GTAP-power data base: disaggregating the electricity sector in the GTAP data base. In *Journal of Global Economic Analysis* 1 (1), pp. 209–250, checked on 1/30/2019.

Peterson, Sonja; Weitzel, Matthias (2016): Reaching a climate agreement. Compensating for energy market effects of climate policy. In *Climate Policy* 16 (8), pp. 993–1010. DOI: 10.1080/14693062.2015.1064346.

Tuerk, A.; Sterk, W.; Haites, E.; Mehling, M.; Flachsland, C.; Kimura, H. et al. (2009): Linking of Emissions Trading Schemes: Synthesis Report. Climate Strategies. Available online at https://www.mcc-berlin.net/fileadmin/data/pdf/Publikationen/Tuerk_Sterk_Haites_Mehling_Flachsland_Kimura_Betz_Jotzo_2009_Linking_Emissions_Trading_Schemes.pdf, checked on 4/26/2017.

UNFCCC (2015): Paris Agreement. Available online at https://unfccc.int/documents/37107, checked on 3/29/2021

UNFCCC (2020): NDC registry. Available online at https://www4.unfccc.int/sites/NDCStaging/pages/All.aspx, checked on 3/29/2021.

UNFCCC (2021): Nationally determined contributions under the Paris Agreement - Synthesis report by the secretariat. Available online at https://unfccc.int/documents/268571, checked on 3/29/2021.

Appendix A: A short non-technical description of the DART Kiel model

The DART Kiel model is a multi-region, multi-sector, recursive dynamic CGE model. The version used in this study is based on the GTAP 9 data base for 2011 (Aguiar et al. 2016) and the related GTAP-9 Power data base (Peters 2016) and contains the following sectors and regions.

Table A 1 DART Kiel regions

Europe	
GBR	United Kingdom, Ireland
SCA	Denmark, Finland, Sweden, Norway
DEU	Germany
FRA	France
BLX	Benelux
SEU	Southern Europe: Austria, Italy, Spain, Portugal, Malta, Greece, Cyprus
EEU	Czech Republic, Slovakia, Slovenia, Hungary, Estonia, Latvia, Lithuania, Bulgaria, Romania, Croatia, Poland
REU	Rest EU incl. Iceland, Liechtenstein, Switzerland, Albania, Belarus, Ukraine,
Americas	
CAN	Canada
USA	USA
BRA	Brazil
OAM	Other Amercias
Russia & Asia & Pacific	
RUS	Russia
IND	India
ANZ	Australia, New Zealand
JPN	Japan
CPA	China, Kong-Kong
KOR	Korea
OAS	Other Asia
Africa & middle East	
MEA	Middle East, North Africa
AFR	Sub Saharan Africa

Table A 2 DART Kiel sectors

Energy & Electricity		Other	
Col	Coal	EIT	Energy Intensive Sectors
Cru	Crude oil	TRN	Transport Aggregate
Gas	Natural gas	AGR	Agriculture & Food
Oil	Refined oil products	MFR	Other manufactured goods
ENuclear,	Electricity from Nuclear	SER	Services
ECoal	Electricity from Coal	CGD	Savings good / Aggregate Investment
EGas	Electricity from Gas		
EWind	Electricity from Wind		
EHydro	Electricity from Hydro		
EOil	Electricity from Oil		
ESolar	Electricity from Solar,		
EOther	Electricity from Other		

The economic structure for each region covers production, consumption, investment and governmental activity. Markets are perfectly competitive. Prices are fully flexible. For each region, the model incorporates three types of agents: the producers, distinguished by production sectors, the representative private household and the government.

Producer Behavior

All industry sectors are assumed to operate at constant returns to scale. Output of each production sector is produced by the combination of energy, non-energy intermediate inputs, and the primary factors labor and capital (land in the agricultural sector). Figures A1 and A2 show the nested production structure for non-energy goods and fossil energy.

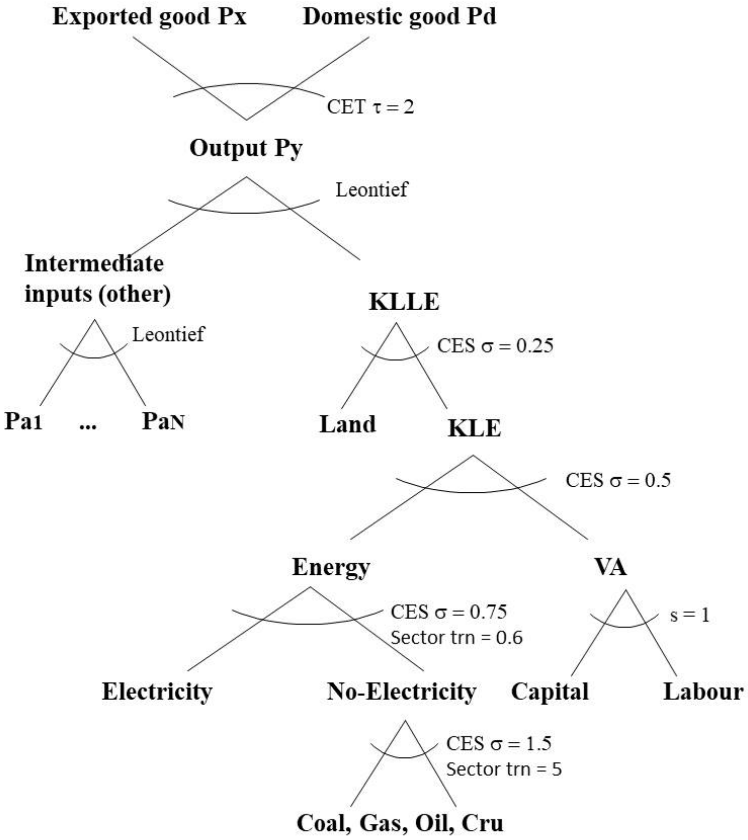


Figure A 1: Nesting of non-energy production

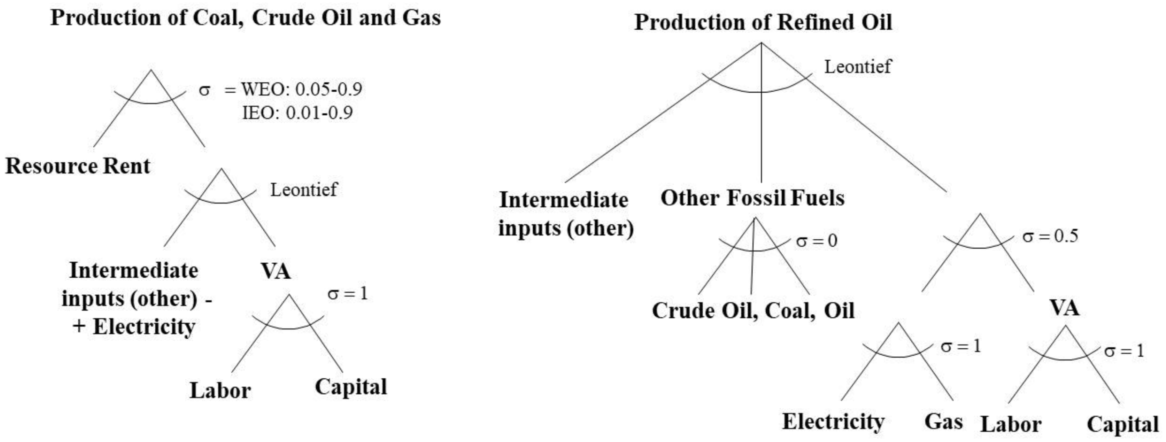


Figure A 2: Nesting of fossil fuel production

Electricity production is differentiated between coal, gas, oil, hydro, nuclear, wind and solar based electricity plus other electricity. The elasticity of substitution between the different types of electricity is 12. Note that we do not use the baseload-peak load disaggregation proposed in Peters (2016), but aggregate e.g. GasBL and GasP to EGas.The nesting structure is depicted in Figure 2:

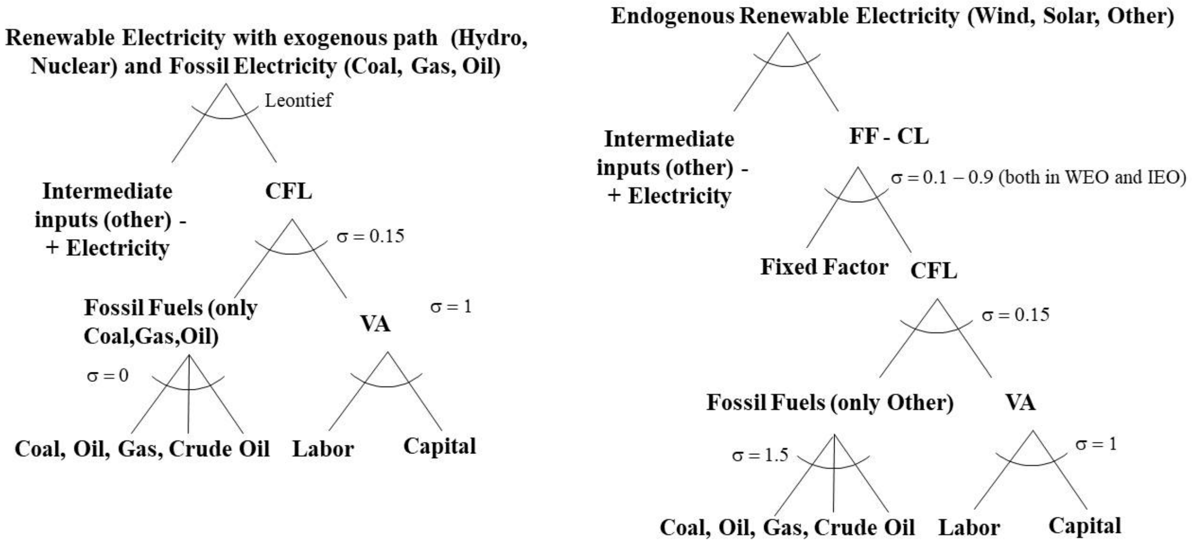


Figure A 3: Nesting of electricity production

Composite investment is a Leontief aggregation of Armington inputs by each industry sector. Investment does not require direct primary factor inputs. Producer goods are directly demanded by regional households, governments, the investment sector, other industries, and the export sector.

Consumption and Government Expenditure

The representative household receives all income generated by providing primary factors to the production process. Disposable income is used for maximizing utility by purchasing goods after taxes and savings are deducted. Private consumption is calibrated to a LES, which divides demand into subsistence and supernumerary consumption based on a Stone-Geary utility function. Households first spend a fixed part of their income on a subsistence quantity for each commodity and allocate their supernumerary income to different commodities according to fixed marginal budget shares which are the product of average budget shares and income elasticities of demand. This division of total consumption into fixed subsistence and flexible supernumerary quantities allows for a calibration to non-unitary income elasticities and non-homothetic preferences. To avoid that, the LES will eventually converge to a Cobb-Douglas system and approach homothetic preferences when income grows, the subsistence quantities are updated with population growth in each period following Schünemann and Delzeit 2019[11], which also includes further information on the LES calibration.

The third agent, the government, provides a public good which is produced with commodities purchased at market prices. Public goods are produced with the same two-level nesting structure as the household "production" function (see also Figure A4). The public good is financed by tax revenues.

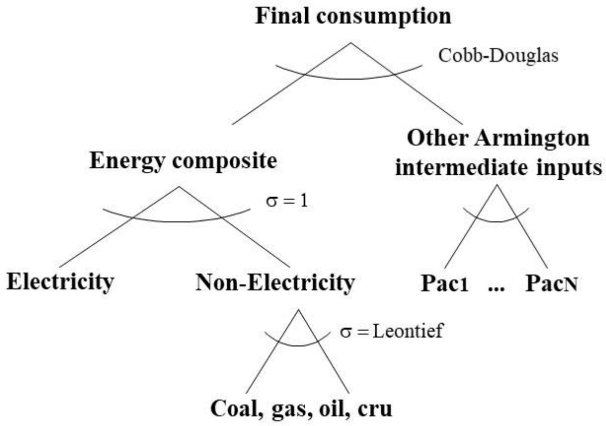


Figure A 4: Nesting structure of final consumption

Foreign trade

The world is divided into economic regions, which are linked by bilateral trade flows. All goods are traded among regions, except for the investment good. Following the proposition of Armington (1969), domestic and foreign goods are imperfect substitutes, and distinguished by country of origin. Transport costs, distinguished by commodity and bilateral flow, apply to international trade but not to domestic sales.

On the export side, the Armington assumption applies to final output of the industry sectors destined for domestic and international markets. Here, produced commodities for the domestic and for the international market are no perfect substitutes. Exports are not differentiated by country of destination.

Factor markets

Factor markets are perfectly competitive and full employment of all factors is assumed. Labor is assumed to be a homogenous goods, mobile across industries within regions but internationally immobile. The capital stock is given at the beginning of each time period and results from the capital accumulation equation. Capital is also region specific and a putty-lay vintage capital approach is chosen, so that only new investment is mobile across sectors. In every time period the regional capital

---

[11] Schünemann, F., Delzeit, R. (2019). Higher Income and Higher Prices: The Role of Demand Specifications and Elasticities of Livestock Products for Global Land Use. *Schriften der Gesellschaft für Wirtschafts- und Sozialwissenschaften des Landbaues e.V.*, Bd. 64, 185-207.

stock earns a correspondent amount of income measured as physical units in terms of capital services. The primary factor land is only used in agricultural sectors and exogenously given.

Coverage of GHG emissions
DART covers CO_2-emissions from the burning of fossil fuels taken from the GTAP 9 data base.

Dynamics and Calibration
The DART Kiel model is recursive-dynamic, meaning that it solves for a sequence of static one-period equilibria for future time periods connected through capital accumulation. The major driving exogenous factors of the model dynamics are change in the labor force, the savings rate, the depreciation rate and the gross rate of return on capital, and thus the endogenous rate of capital accumulation. Finally, the rate of total factor productivity (TFP) growth is used to calibrate DART Kiel to a given GDP-path. For the EMF-36 GDP baseline it was in addition necessary to reduce the growth of the labor force for a few regions since already a TFP of zero led to too high growth rates. If this was still not enough also depreciation was increased.

Finally, it turned out that the given Chinese GDP value for 2030 could not be reached with higher TFP in China alone but required import let growth in DART. For this reason, the usual Armington elasticities we increased by 1.5 worldwide. Table A3 below shows the base data and these adjustments.

The savings behavior of regional households is characterized by a constant savings rate over time. This rate is allowed to adjust to income changes in regions with extraordinary high benchmark savings rates, namely China, India, AFR, OAS and KOR. Labor supply considers population growth and the development of the share of the working force in the population.

The supply of the sector-specific factor land is held fixed to its benchmark level over time. Current period's investment augments the capital stock in the next period. The allocation of new capital among sectors follows from the intra-period optimization of the firms.

Furthermore, the baseline path of renewable electricity plus nuclear is calibrated to match the projections of the IEA. The development of electricity from hydro and nuclear is fixed at an exogenous growth path through an endogenous subsidy. For solar- and wind-power as well as other-electricity, we adjust the growth of the fixed factor and the elasticity of substitution between the fixed factor and the other inputs to calibrate to the given path that then also reacts to policy shocks.

Emissions are traditionally calibrated only on global level for CO_2-emissions from gas, coal and oil by adjusting the supply elasticity of these fossil fuels. To achieve a given regional emission level at 2030 for the EMf-36 scenarios we used regional supply elasticities of fossil fuels and in addition adjusted the autonomous energy efficiency improvement (AEEI) which is typically 1% p.a. to achieve the required emission intensity of GDP. In India even very high rates were not sufficient to bring down emission intensity sufficiently so we increased the KLE elasticity as well. Finally, the WEO baseline used in this study is based on carbon prices for the EITE sector and the power sector in Europe (27$/tCO2) China (20$/tCO_2), Canada (36.5$/t$CO_2$) and Korea (28$/tCO_2)$_{12}$. We also implemented carbon prices for WEO in EITE sectors starting in 2015 and linearly rising to the given level in 2030. To match the given CO_2 level in 2030 and for the EU the communicated targets for the EU emissions trading scheme, the prices

---

[12] The values in brackets are extrapolated from the 2025 and 2040 values given by WEO.

were slightly adjusted to 21$/t$CO_2$ in Europe, 18 $/t$CO_2$ in Canada, 15 $/t$CO_2$ in China and 14 $/t$CO_2$ in Korea.

Relevant elasticities and parameter are summarized in Tables A3 and A4. We use the same method as Böhringer et al. (this issue) to calibrate the emissions from ETS and non-ETS sectors in the EU for our Baseline. As a result, in our Baseline the total CO_2 emissions in EU ETS sectors increase by 20.6%, while in the non-ETS sectors they reduce by 0.6%, which results in an overall increase of 4.4% in emissions, all relative to Baseline.

Table A 3 Core elasticities and adjustments for EMF calibration

Elasticity	Explanation	Value	Adjustment for EMF WEO Baseline
ESUB_ES(*,r)	Elasticity fixed resource in coal, gas, cru production	Default: Coal 0.3, GAS 0.2, CRU 0.2	0-0.8 to calibrate regional emission path
ESUB_ELE(I)	ele vs Non-electricity energy	0.75	
	For Transport	6	
ESUB_NE(I)	Non-electricity energy	1.5	
	For Transport	5	
ESUB_LD(r)	land vs KLE	0.25	
esub_kle(r,i)	Energy vs Capital /Labor	0.5	IND: 0. 75; BRA: 0.85
S	Elas. KLE vs material	0	
esub_ele	Diff. ele types	12	
Va	Elas capital / labor	1	
Esub_res(*,r)	Elasticity of fixed resource EWind, ESolar, EOther	Default: 0.1	0-0.8 to calibrate path
preleexp(*,r)	exponent for increase of fixed factor EWind, ESolar, EOther		0-0.9 to calibrate path
ARMEL(i,r)	Imports from diff. regions		Min(12,1.5*armel(i,r));
	All electricity types	2.8	4.2
	COL	3.05	4.6
	CRU, GAS	12.849	12.0
	OIL	2.1	3.2
	EIT	3.239	4.9
	TRN	1.9	2.9
	AGR	2.761	4.1
	MFR	3.529	5.3
	SER	1.917	2.9
ARM_REG(I)	imports vs domestic	Min(14, 2*ARMEL)	=Min(14,1.5*arm_reg(i);

Table A 4 Further core parameters

Elasticity	Explanation	Value	Adjustment WEO
AEEI	Autonomous Energy Efficiency Improvement p.a.	1% p.a. in all regions	AFR 1%; BLX 2.5%; BRA 0%; CAN 0.5%; CHN 2.4%; EEU 1.3%; FRA 2.5%; GBR 1.5%; GER 0.7%; IND 2.8%; MEA 2.4%; OAM 1.5%; REU 2%; RUS 0.3%; SCA 2.3%; SEU 0.4%; USA 2.1%; OAS 1.8%; JPN 1.7%; KOR 0.6%; ANZ 0.8%
Dep	Depreciation	0.04	OAM: 0.045; MEA: 0.045
ffshare(i,r)	Fixed factor share in ESolar and EWind	0.1	

sub	Elasticity energy composite and other inputs for final demand	1	
wrkad	Adjustment factor in growth of labor force	1	MEA: 0.8; OAM: 0.8; CHN: 0