

The Effects for Brazil of Linking Emissions Trading Schemes in the context of the Heterogeneity of Trading Partners

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ABSTRACT

International climate negotiations have recently underlined the relevance of international cooperation via carbon pricing to tackle climate change. With Emissions Trading Schemes (ETS) emerging in developed and developing regions around the world, linking these systems may become a future option. This raises the question as to the appropriateness of linking these ETS systems. This paper analyses the impact of a hypothetical ETS covering electricity and energy-intensive sectors for Brazil, using a global economy-wide model - the EPPA6. Additionally, we simulate links with a developed region (Europe) and two developing regions (Latin America and China). We find that linking Brazil with a heterogeneous partner such as Europe results in larger emission reductions, technological substitution towards alternative energy and losses in GDP and welfare, as both regions have ambitious targets; whereas linking with China is more cost-effective due to the contrasting stringency of targets. A link with regions of similar energy and economic profile produces moderate reductions and negative distributional impacts, especially where the targets are less ambitious such as is the case for Latin America. Accordingly, there are advantages and disadvantages associated to each proposed trading situation, with Brazil presenting an import profile for emissions permits in all scenarios. A more appropriate ETS design to seize mitigation opportunities cost-effectively for Brazil includes a less stringent cap or an alternative sectoral ETS coverage.

Keywords: sectoral ETS linkage, Brazil, EPPA6, developing country, developed country

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1. INTRODUCTION

The climate policy architecture under the Paris Agreement envisions international cooperation to achieve significant progress on emissions mitigation. By including provisions

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for carbon pricing at international level, to comply with Nationally Determined Contributions (NDC), the accord provides the foundation for a new architecture in which linkages of national climate policies play an important role, particularly market-based measures.

The literature highlights potential opportunities and benefits from the use of market-based instruments to facilitate emissions reductions whilst enhancing economic performance, mostly via integration of Emissions Trading Schemes (ETS). In a two-way ETS cooperation, emission allowances are mutually recognised for the purpose of compliance with the local cap. This type of international cooperation creates a price for pollution, which equates marginal abatement costs between regulated jurisdictions, thereby increasing the access to abatement options and making it possible to attain the proposed mitigation target at a minimum cost to society.

Those aggregated cost savings could be an important argument against political resistance to link ETS systems. Further, it could be used as an opportunity to incentivise jurisdictions to commit to targets that are more ambitious, and to agree upon a linkage that can also generate funds to re-invest in more reductions. This climate finance may be economically appealing for the price signal it provides to attract investments on sustainable infrastructure (Studart and Gallagher, 2015) or to promote clean technology investments and economic efficiency (Farid *et al.*, 2016; IETA, 2016), particularly for developing countries.

From the point view of an effective cooperation agreement, the stringency of mitigation goals is one key determinant, given that it affects carbon prices. In general, emission caps reflect factors such as economic and environmental profile, or the level of development of each participant. Therefore, it is important to consider a climate partner with comparable ambitions and similar medium to long-term emissions trends (Green *et al.*, 2014; Haites, 2014; Edenhofer *et al.*, 2007) for the optimum mitigation (Kachi *et al.*, 2015; Burtraw *et al.*, 2013). Different levels of climate ambition can prevent the link from occurring (Zetterberg, 2012; Sterk *et al.*, 2006) or instead, hinder the achievement of emissions reductions.

Moreover, the broad participation of jurisdictions, sectors and emissions is also relevant since a larger sectoral and geographic market results in a greater heterogeneity of abatement options across regulated entities. Thus, it guarantees increased aggregate efficiency gains through the trade of allowances (Görlach *et al.*, 2015). In addition, carbon leakage and competitiveness concerns can be addressed, as well as market liquidity and price stability issues (Ranson and Stavins, 2013; Flachsland *et al.*, 2009; Mehling and Gölach, 2016).

A comprehensive worldwide system is considered to be effective, at least in terms of climate protection and access to less costly abatement options (Flaschland *et al.*, 2009). Thus, as the number of linked ETS systems increase, the greater the appeal for a global international ETS (Haug *et al.*, 2015; Merkel and Hollande, 2015). Nevertheless, irrespective of how recommendable a global participation might be, its likelihood or feasibility is very limited in the short term. In this sense, linked ETS systems could be viewed as a precursor to, and a stimulus for, a top-down future ETS approach, especially within the Paris Agreement architecture.

To date, a small number of active national and subnational carbon markets are involved in, or are open to the concept of, ETS linkages. Examples include the California, Quebec and Ontario link (the Western Climate Initiative, WCI) and the Regional Greenhouse Gas Initiative (RGGI) in the northeast of the USA. The European Union Emissions Trading Scheme (EU ETS), the largest and most consolidated system in the world, displays a willingness to link with other compatible systems, which means other ETS systems with similar environmental integrity and system architecture could potentially link. There is currently a Norway-EU linkage.

The number of existing ETS systems worldwide is on an upward trend and may become more common post-2020, as approximately 91 Parties declared an interest to access international markets for mitigation purposes, including both developed and developing regions (IETA, 2016). Recently, a Chinese ETS has been launched, following some years of experience with subnational pilot markets². This is the first national ETS implemented in a developing country, albeit plans, or at least investigations in this regard are emerging in other countries. Once ETS systems are initiated, linking will thereafter be an option.

The ultimate success of linking will depend on the participating jurisdictions and the design of the arrangements in each link, since heterogeneity between partners may affect the outcomes. In fact, coping with the degree of heterogeneity that characterises climate policies

² After being beset by delays, China launched an ETS in December, 2017. Covering only carbon emissions from approximately 1700 companies, the Chinese ETS is expected to become the largest in the world as it projects a gradual increase in the scope (the plan is to cover eight sectors: petrochemical, chemical, building materials, steel, nonferrous metals, paper and aviation). Details on the ETS design are laid out in the Work Plan for the construction of the National ETS. In short, it is designed to regulate the power sector (including combined heat and power, as well as captive power plants of other sectors) in order to meet the intensity targets committed in the Paris Agreement by 2030, although initially the system accounts for only 30% of national emissions (ICAP, 2018). An initial three-phase roadmap has been adopted, with an annual period of compliance. At first, the plan is to develop market infrastructure, followed by a simulation trading phase and by 2020 to deepen and expand trading. Further phases and allocation rules are yet to be defined. However, free allocation based on sub-sector benchmarks is expected during the trial allocation, as well as banking of allowances.

is very challenging when engaging in an international linkage (Mehling *et al.*, 2017). The literature to date mostly focuses on linkage heterogeneity, in terms of policy instruments, political jurisdiction and targets (Metcalf and Weisbach, 2012; Mehling *et al.*, 2017; Bodansky *et al.*, 2014; Lazarowicz, 2009).

For the purpose of this analysis, international cooperation is structured by linking sectoral ETS programmes at national level, in the context of the heterogeneity of trading partners. This heterogeneity is a dimension here characterised by differences in both macroeconomic and energy generation profile among potential participants. Ultimately, development level differences are assumed to play a role on deciding on the partner for the link. This scope will shed light to the best policy situation, as it identifies which linkage is most beneficial and politically feasible.

Previous studies investigated the effects of sectoral ETS linkage under different circumstances. For instance, international trading was investigated among all developed regions and electricity sectors of developing regions in Hamdi-Cherif *et al.* (2010). Similarly, Gavard *et al.* (2011) designed a national US-ETS in a linkage with a hypothetical electricity ETS system in China. Hübler *et al.* (2014) assessed a Chinese ETS regulating energy-intensive industries, electricity, heat, petroleum and coal products considering a potential cooperation with the EU ETS. Gavard *et al.* (2016) modelled a sectoral ETS on electricity and energy-intensive industries in the EU ETS, the US and China, simulating autarky and linkage scenarios. These studies evidenced an increased adoption of low carbon technologies, a lower international leakage and generally, a greater degree of acceptance from developing countries to participate in the carbon market set by developed countries.

The framework introduced as part of this paper considers linkage implications of a hypothetical Brazilian ETS with the same sectoral coverage. Among developing countries, Brazil has been an early adopter of climate commitments from an international perspective. With approximately 4% of global emissions between 1990 and 2014 (SEEG, 2016), Brazil agreed to promote a cut of 37% and 43% of 2005 emissions levels by 2025 and 2030 respectively, in addition to a commitment to stop illegal deforestation.

In the proposed Brazilian NDC, a great emphasis is given to reduce emissions from land use change and deforestation, which contributed to 27.5% of total emissions in 2010. Further strategies are planned for the agriculture sector, as the share of emissions correspond to 32% of the Brazilian emissions profile (MCTI, 2014). Notwithstanding the relatively low carbon intensity of the energy mix, Brazil still relies on the production and consumption of

fossil fuels, which have the potential to hinder a genuine mitigation towards sustainable levels. Energy and industrial sectors combined, contribute 36.3% to total emissions³. Therefore, climate policies aimed at energy-related sectors are also required to help achieve national climate goals, for example, through carbon pricing.

The Brazilian government has been supporting, in association with the World Bank - Partnership for Market Readiness (PMR), a comprehensive group of studies based on carbon pricing for the post-2020 period⁴. Despite that, Brazil has not yet defined or even decided on whether to implement a domestic ETS. However, the arrangements for market instruments in the Paris Agreement may encourage Brazil to design a carbon trading system. By taking the lead, Brazil may encounter new opportunities for climate cooperation with developed systems such as the EU ETS, or with emerging schemes such as the Chinese ETS, or a hypothetical Latin American ETS⁵.

The implications of such proposals have to date not been investigated, as carbon pricing and related linkages have just emerged as a reasonable option for developing countries. This mostly reflects the late incorporation of climate issues into the domestic agenda, that is, the secondary relevance given to environmental issues in light of other national political priorities. To design appropriate climate policies for national circumstances, the level of development is particularly important. Besides the influence it exerts on the capacity to mitigate and to promote sustainable development, it also determines the best policy option to balance costs with mitigation associated benefits, whilst concurrently enabling human development (Clarke *et al.*, 2016). By envisioning carbon pricing mechanisms and linkages, developing countries need to be aware of the financial opportunities from ETS systems.

According to Somanathan (2008), the role of a developing country integrating an ETS with a developed country, is expected to be as an exporter of allowances, where it could have access to the market advantages and profit from entering the linkage. However, it is not

³ The emissions profile includes also waste management and treatment, with a share of 4.3%.

⁴ The legal principle for implementing market-based mechanisms to emissions mitigation has been previously set up in the National Climate Change Plan (or PNMC in Portuguese) under Articles 4 and 6, even though there is a lack of detailed information on the market regulation.

⁵ Several studies have investigated the effects of climate change mitigation in Latin America in terms of macroeconomic implications, abatement potential, financial investments and technological change in addition to adaption measures. Whilst in Feld and Galiani (2015) mitigation is only indicated to Latin America in the presence of a global binding agreement (it could allow the region to exploit existing comparative advantage), Clarke *et al.* (2016), Kober *et al.* (2016) and Van der Zwaan *et al.* (2016) suggest better responses from a constraint on emissions, if Latin America take on less ambitious emission reductions. Associated costs to undertake these reductions via carbon tax vary from US\$15/tCO₂ to US\$50/tCO₂ by 2030. However, there is no indication on the use of an ETS to meet expected mitigation in the region.

evident whether or not this linkage is feasible or desirable, notably in the case of a weak institutional capacity. It may discredit the domestic ETS, thereby affecting the linkage with the developed country ETS. This could also occur in a South-South ETS linkage⁶, depending on the ETS design and the regulation supporting the agreement.

In theory, a greater difference in carbon prices across regulated jurisdictions prior to the linkage produces greater cost savings from linking (Dellink *et al.*, 2014). Generally, existing ETS governance frameworks should involve a well-coordinated linked system so as to enhance mitigation and to diminish linkage problems or inefficiencies from heterogeneity of policies associated with local preferences. This approach is based on a harmonised ETS design and counterfactual price, and ensures not only that the greatest degree of compatibility possible is achieved, but also that the differences between ETS systems are eliminated (Flachsland *et al.*, 2009; Metcalf and Weisbach, 2010; Haites, 2014; Ranson and Stavins, 2013; Mehlin and Gorlach, 2016).

Geographic proximity, as well as a history of economic or political cooperation, are highlighted to be among the main conditions by which effective linkages may emerge (Tuerk *et al.*, 2009; Ranson and Stavins, 2016). To date there has been no detailed analysis of the economic or environmental implications of a proposal where Brazil links through ETS with another developing country (China), a regional organisation of developing countries (Latin America) or a developed-world programme (EU ETS).

In this context, this paper conducts a two-fold investigation and examines the proposed climate policy using environmental (emissions and energy), economic and distributional impacts as evaluation criteria. Firstly, it identifies the heterogeneity of the proposed partners (Brazil, EU, China and Latin America) in terms of their macroeconomic profile and energy mix, highlighting sectoral emissions levels and the stringency of targets. This allows characterisation of the extent to which a proposed partnership may be appropriate.

The second part discusses the feasibility of the policy proposal, with the aim of understanding to what degree international coordination via an ETS may cope with several political challenges without undermining sustainable development. In fact, gathering multiple actors that may diverge in their perceptions of costs and benefits from climate action, can render the linkage to be perceived as unsuitable for respective economic and environmental interests. An appropriate level of ambition is therefore fundamental from each party.

⁶ This refers to cooperation between developing countries, which generally face similar development contexts and challenges.

This research serves as a basis to evaluate ETS policy proposals among developing countries compared to a developed-developing country linkage. The paper is organised in the following way. In Section 2, we introduce the EPPA6 model and an overview of the scenarios. Section 3 presents the macroeconomic performance and energy generation profile of Brazil, Europe, Latin America and China based on the 2015 database available in EPPA6. Further, it presents the main modelling results for the proposed ETS linkages. Whilst assessing if the evaluation criteria are achieved, the investigation provides suggestions on the most appropriate partnership in case of climate coordination. Section 4 offers some concluding remarks and policy implications.

2. MODELING FRAMEWORK

The analysis of this paper extends the Economic Projection and Policy Analysis (EPPA) model in its most recent version - EPPA6 ⁷(Chen *et al.*, 2015). The modeling is set up to represent a hybrid climate policy approach, with a focus on sectoral ETS trading.

2.1. Characteristics of the EPPA model

The EPPA6 model is a recursive-dynamic computable general equilibrium model (CGE) of the global economy developed by the MIT Joint Program on the Science and Policy of Global Change. The model was developed as a nonlinear complementarity problem in the General Algebraic Modelling System (GAMS) programming language (Brooke *et al.*, 1998), using the syntax of the MPSGE (Mathematical Programming System for General Equilibrium) algorithm developed by Rutherford (1999).

EPPA6 is solved for a sequence of global market equilibrium considering "myopic" expectations of economic actors that provides a representation of the global economy (Chen *et al.*, 2015). This assumption in EPPA means that current period investment, savings, and consumption decisions are made on the basis of prices in each 5 year period (Paltsev *et al.*, 2007). As a CGE model, EPPA6 can represent the global production and consumption of various sectors of each regional economy and the associated greenhouse gas emissions (GHG), being interconnected to other regions through international trade. Additionally, it is able to incorporate emissions constraints on regions, gases or sectors within different policy arrangements.

⁷ Free public version is available at: <https://globalchange.mit.edu/research/research-tools/human-system-model/download>.

The model considers a long run simulation horizon (2010-2100). It is solved at 5 yearly intervals. By projecting scenarios of world economic development and emissions trends, it enables analysis of the economic impact of mitigation and energy policies, as well as welfare and equity measures. It was adopted in this policy analysis to answer the questions posed with regard to the sectoral ETS applied in a hybrid framework, and thereafter, the international cooperation in the period 2020-2030.

Version 6 of the model is calibrated using the Global Trade Analysis Project Version 8 (GTAP 8) database, with a benchmark year of 2007 (Narayanan *et al.*, 2012). The GTAP dataset comprises a detailed representation of national and regional input-output structure, which includes bilateral trade flows in goods and services, intermediate inputs among sectors and taxes or subsidies imposed by governments (Dimaranan and McDougall, 2002; Aguiar *et al.*, 2016). The level of aggregation in EPPA6 is exhibited in Table 1, with developed and developing regions being explicitly represented. In order to comply with the main objectives of the paper, Latin America is unified as one potential trading partner, i.e. it is treated as the sum of Latin America (LAM) and Mexico (MEX), as Latin America (LAM), Mexico (MEX) and Brazil (BRA) are treated as separate entities in the model.

Table 1

Aggregation of regions, sectors and backstop technologies in EPPA6

Regions	Sectors	“Backstop” Technologies and production factors
United States (USA) Canada (CAN) Mexico (MEX) JAPAN (JPN) Australia and New Zealand (ANZ) Europe (EUR) ⁸ Eastern Europe (ROE) Russia (RUS) East Asia (ASI) South Korea (KOR) Indonesia (IDZ) China (CHN) India (IND) Brazil (BRA) Africa (AFR) Middle East (MES) Latin America (LAM)	<u>Agriculture</u> Crops (CROP) Livestock (LIVE) Forestry (FORS) <u>Non-Agriculture</u> Food production (FOOD) Services (SERV) Energy-intensive (EINT) Other industry (OTHR) Transport (TRAN) Ownership of Dwellings (DWE) <u>Energy supply</u> Coal (COAL) Crude oil (OIL) Refined oil (ROIL)	First generation biofuels (bio-fg) Second generation biofuels (bio-oil) Oil shale (synf-oil) Synthetic gas from coal (synf-gas) Hydrogen (h2) Advanced nuclear (adv-nucl) IGCC w/ CCS (igcap) NGCC (ngcc) NGCC w/ CCS (ngcap) Wind (wind) Bio-electricity (bioelec) Wind power combined with bio-electricity (windbio) Wind power combined with gas-fired power (windgas) Solar generation (solar) <u>Factors of production</u>

⁸ The European Union (EU-27) plus Croatia, Norway, Switzerland, Iceland and Liechtenstein.

Rest of Asia (REA)	Gas (GAS) Electricity (ELEC)	Labor Capital Natural Resources Land
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Source: Based on Chen *et al.* (2015).

The data is aggregated into 18 regions, 14 sectors (agricultural, non-agricultural and energy supply) and 14 “backstop” technologies⁹ for generating low-carbon energy, including some renewable technologies such as wind and solar generation. Additional data sources on energy use and energy consumption (IEA, 2012), CO₂ emissions¹⁰ related to cement production (Boden *et al.*, 2010) and CO₂ emissions related to land use change (Riahi *et al.*, 2007) are also used.

For each country or region, all sectors have production functions describing the use of primary factors (capital, labour, and energy resources) and energy and intermediate inputs for producing goods and services in each of these periods. The level of consumption is modelled through a representative agent¹¹ that seeks to maximise utility by choosing how to allocate its income from factor payments (wages, capital earnings, resource rents) across consumption or savings (Gurgel and Paltsev, 2014; Chen *et al.*, 2015). The government is a passive entity, which finances government consumption and transfers with revenue from taxes paid by households and producers. Deficits and surpluses generated return to consumers as lump sum transfers.

Production sectors transform primary factors and intermediate inputs into goods and services in order to maximise profits, given the available technology and market prices. Producers receive payment in return from supplying those products to domestic or foreign agents. Similar to other CGE models, EPPA6 uses nested Constant Elasticity of Substitution (CES) with several inputs in order to specify preferences and production technologies. International trade is accommodated via Armington assumption (Armington, 1969), with the exception of crude oil, being a homogeneous good. All markets reach a simultaneous equilibrium when zero-profit, market-clearing and income balance conditions are satisfied in the static part of the model.

⁹ These technologies consist of new or alternative energy technologies.

¹⁰ Other non-CO₂ GHG emissions and urban pollutant emissions are accounted for in EPPA6 from EDGAR database Version 4.2 ((European Commission, 2011), including: methane (CH₄), perfluorocarbon (PFC), sulfur hexafluoride (SF₆), and hydrofluorocarbon (HFC).

¹¹ EPPA6 accounts for three economic agents: consumers (households), producers and government. Households own primary factors, offer these to producers and receive income from the services provided (wages, capital earnings and resource rents).

The dynamics of the model are determined by exogenous factors (GDP projections for BAU growth, labor endowment growth, factor-augmented productivity growth, autonomous energy efficiency improvement (AEEI) and natural resources assets) and endogenous factors (savings, investment¹² and fossil fuel resource depletion) (Chen *et al.*, 2015).

Scenarios of climate policy are forecasted based on the model theoretical assumptions and driven by economic growth, which in turn results from savings and investments as well as productivity improvement in labor, energy and land that are exogenously specified (Gurgel and Paltsev, 2014; Octaviano *et al.*, 2015). The higher the growth in gross domestic product (GDP) and income levels, the greater the demand for goods produced by each sector. This ultimately leads to higher production costs, as these goods use finite natural resources in the production cycle.

A constraints on emissions alters the relative economics of technologies as advanced technologies become available cost-effectively and compete with traditional energy technologies on an economic basis. ETS simulations with EPPA6 have a solution in which the least-cost abatement is achieved for each sector and type of emission, and prices are equilibrated if emission trading is allowed. In this case, as a result of limiting emissions, a shadow value of the applied constraint is calculated. This is interpreted as a price obtained under the potential permit market in the ETS. Modelling a sectoral ETS required adjusting the model to allow sector-specific permits trading at international level. Further details on EPPA6 may be found in Chen *et al.* (2015).

2.2. Sectoral ETS and mitigation objectives

In earlier UNFCCC sessions, the main involvement developing countries had with carbon markets was through the Clean Development Mechanism (CDM), being project hosts without binding pledges. Conversely, in the Paris Agreement both developed and developing regions affirmed long-term mitigation goals.

Brazil has committed to reduce emissions by 37% and 43% of 2005 levels by 2025 and 2030 respectively. For modelling purposes, the only disregarded sectors in the mitigation applied target are land use change and deforestation. Given that these sectors represent a relatively high share of total Brazilian emissions, controlling emissions from those sectors

¹² Savings and consumption are represented in the household's utility function by an aggregated Leontief approach.

would automatically prevent other sectors from broadening mitigation effort to comply with national climate targets.

Although there is no explicit reference to any intention of setting up a market-based policy, irrespective of whether a cap-and-trade system or a carbon tax, the PNMC does allow the use of these instruments in Brazil. This paper therefore proposes an ETS design for Brazil which could facilitate linking with other schemes. The ETS design was defined to mimic the EU ETS, serving as a realistic prototype for other planned systems.

The restrictions on emissions represent the regulation stringency. The same sectoral and emissions coverage as the EU ETS are applied to Brazil and other trading partners so that the ETS regulates electricity generation (ELEC) and energy intensive industry sectors (EINT), and only CO₂ emissions are subject to the absolute cap. The ETS sectors are assumed to be allocating tradable allowances between them¹³. There is no specified limit on the amount of sectoral permits that can be traded.

For the European system we applied the emission reduction linear factor of 1.74% per annum from 2013-2020 and 2.2% from 2021-2030 as already specified for the EU ETS¹⁴. In the modelling exercise no distinction is made on the EU ETS phases, the bank of unused oversupply of carbon allowances or the existence of the New Entrants Reserve (NER 300 programme). In addition, the aviation sector is not regulated in the EU ETS¹⁵.

For Latin America, the reduction target used in this simulation is between 5% and 15% of BAU emissions, whilst it ranges from 30% to 40% of BAU emissions¹⁶ in Mexico. Climate policy through an ETS is increasingly taking shape in the region (ICAP, 2018). Examples include the recent approval in Mexico of a mandatory ETS schedule to initiate in 2020¹⁷, or the explicitly intention of Chile and Colombia to set up an ETS in the medium term. These three jurisdictions, together with Peru, are exploring regional cooperation on Measurement, Reporting and Verification (MRV) in the context of the Pacific Alliance as

¹³ EPPA6 model assumes GHG permits are allocated as an endowment to the representative agent, who sell permits to sectors and consumers. It may be thought as an auction mechanism, where revenue accrues as a lump sum transfer to families.

¹⁴ The limitation of using the EU ETS targets is that we could not incorporate the EU commitment to reduce emissions of 40% of 1990 levels by 2030 in the model. Instead, the EU achieves approximately 38% of 2005 levels.

¹⁵ Although it is subject to the carbon tax applied to non-ETS sectors.

¹⁶ According to previous studies (Clarke *et al.* 2016; Van der Zwaan *et al.*, 2016), emissions reductions ranging from 20% and 50% in Latin America can provide a reasonable abatement level that is consistent with the 66% chance of keeping temperature change below 2 °C.

¹⁷ An initial ETS simulation was launched in Mexico back in October 2017. The legal framework regulates over 100 companies in order to gain experience and learn-by-doing until the pilot phase implementation of the Mexican ETS. In future, the carbon tax and the ETS will coexist and ETS link with Chile is envisioned, according to ICAP (2018).

well as envisioning possibilities of linking in the long term. This is in line with the official pledge made under the Paris Declaration on Carbon Pricing in the Americas¹⁸ in 2017, which recognises the development of a carbon market at different levels as an useful and effective instrument to mitigate emissions.

Whilst there is no evidence that a Latin American ETS will be negotiated in the short run, the Chinese ETS is already functioning. In the modelling, the mitigation target applied for China is between 45% to 60% of the GDP intensity in the 2020-2030 period¹⁹ - translated into absolute reductions.

Additionally, a supplementary policy is included by means of a hypothetical (endogenous) carbon tax on the remaining non-ETS sectors. It was included to mimic other domestic abatement measures and to avoid carbon leakage from ETS to non-ETS sectors. This tax prevents carbon emissions in those sectors from exceeding BAU levels and reflects the aggregate marginal abatement costs (MACs) of these sectors. The tax is generated by the model in order to induce each sector to cut emissions by the same national percentage target.

All other regions in the model follow the same hybrid market approach domestically, with the CO₂ constraints being in line with their pledges under the Paris Agreement from 2020-2030, based on the information available on the UNFCCC website²⁰.

The approach of imposing a sectoral carbon tax on non ETS sectors may not be realistic, but an ETS alone is unlikely to allow a country to achieve its Paris emissions reduction targets. The sectoral carbon tax captures in a simplified way the several alternative sectoral measures a country may use to mitigate emissions, given the current limitations in bringing all sectors into an ETS system.

2.3. Scenarios

We simulated five scenarios to evaluate the effects of linking a Brazilian sectoral ETS. In all trading partner scenarios, allowances flow from the region with the cheapest abatement cost, thereby equalising prices and guaranteeing a cost-effective policy. The ETS linkage is

¹⁸ More details in this regard are available at IETA's website: http://www.ieta.org/resources/News/Press_Releases/2017/Declaration%20on%20Carbon%20Pricing_FINAL.pdf.

¹⁹ In order to translate the GDP intensity cap into absolute reductions, emissions and GDP were firstly obtained from the BAU simulation. Hence, the absolute cap results of applying the emissions/GDP ratio from BAU into the emissions target.

²⁰ Since EPPA6 is aggregated into regions and pledges are determined at a national level, the mitigation goals were defined taking into consideration the most representative country in the region where data is available or the average of the pledges committed.

modelled to cover carbon emissions from electricity²¹ and energy-intensive sectors. There was no limit specified on the amount of sectoral permits that can be traded, nor was there any specific provisions on the distribution of revenues. Finally, a carbon tax was applied to non-ETS sectors, completing the hybrid approach designed.

It is worth noting that emissions from land use change and deforestation were disregarded, given the relevance of these sectors to total Brazilian emissions and existing climate strategies. In several Latin American countries, those emissions also predominate, thereby being a critical element for abatement (Clarke *et al.*, 2016). Thus, controlling these emissions in this modelling exercise would automatically prevent other sectors from broadening their mitigation effort to comply with national climate targets.

Scenarios to quantify the effects and evaluate the best alternative available in terms of partnership are described below:

- BAU: no emission constraint is applied.
- PRE_LINK: the pre-link scenario establishes an ETS where electricity and energy-intensive industries are capped at a level consistent with the national mitigation objectives. This structure also holds for other regions of the model. Permits for polluting are obtained at national level, which generates a counterfactual carbon price.
- LINK_BRA_EU: this first post-link scenario corresponds to an international sectoral ETS system formed by Brazil and Europe, with constraints compatible to the PRELK scenario.
- LINK_BRA_LA: in this second post-link scenario, carbon trading is allowed between Brazil and Latin America from 2020 onwards.
- LINK_BRA_CHI: this post-link scenario considers a third candidate to link with Brazil, that is, China.

3. RESULTS AND DISCUSSIONS

3.1. Economic profile and energy generation in the BAU scenario before policy implementation

²¹ According to Van der Zwaan *et al.* (2016) and Clarke *et al.* (2016), including the electricity sector in climate policies implemented in Latin America is particularly pertinent because it represents the most rapidly growing carbon emitting sector. In addition it is relatively more adaptable to decarbonisation, which can often be realised at lower costs. For example, emissions related to land use are very representative in Latin America, thereby requiring further strategies for the sector.

This paper assumes that Brazil may decide the trading partner in advance. In this context, the proposed allies are investigated with regard to domestic macroeconomic profile and energy use pattern, which is closely related to emissions, in order to identify differences compared to Brazil.

For that purpose, we present some basic statistics from BAU scenarios in 2015. The model is calibrated to project long-term scenarios based on this data. The higher the emissions in the BAU scenario, the more emissions reductions are required to meet the abatement goal, and consequently, the higher the associated costs. Thus, the baseline scenario provides the starting point for all abatement scenarios in this analysis. Additionally, it serves as a basis for the discussion of proposed linkage policies in Section 3.2.

In Table 2, CO₂ emissions from coal, oil and gas are displayed by sector for each participant. Europe and China stand out as the greatest emitters. On the other hand, all potential partners, including Brazil, share a similar pattern of carbon emissions, in which combined emissions from ROIL, ELEC, EINT and TRAN sectors correspond to 90.8%, 91.1%, 91.0% and 94% of total CO₂ emissions in Brazil, Europe, Latin America and China, respectively. In this case, among the regulated ETS sectors, only in Brazil do the EINT emissions exceed those from the ELEC sector.

Table 2

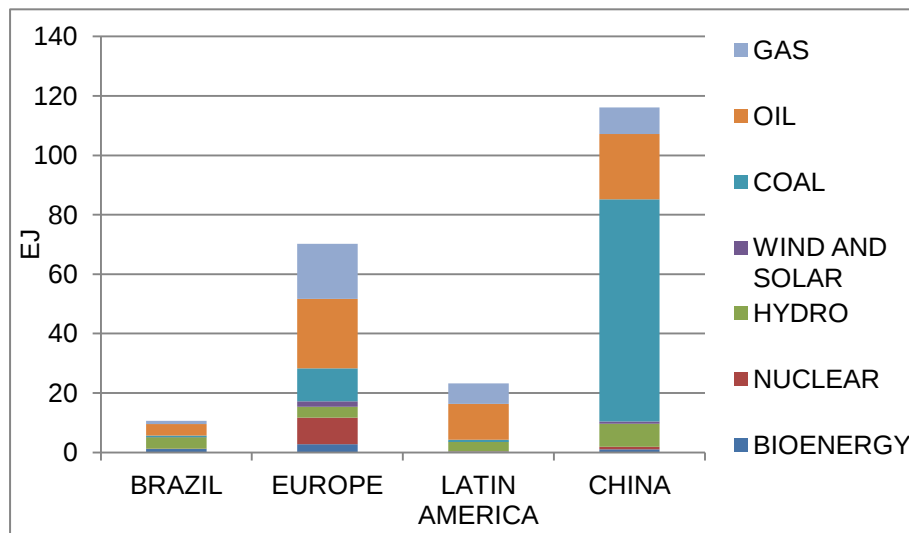
CO₂ emissions from coal, oil and gas in 2015

	BRAZIL	EUROPE	L.AMERICA	CHINA
CROP	9.3	25.6	19.9	62.6
LIVE	3.6	11.9	5.2	44.6
FORS	0.8	2.6	1.3	5.9
FOOD	3.6	42.9	12.0	68.6
ROIL	86.3	574.6	153.7	1713.7
ELEC	23.7	1022.2	268.9	4407.0
EINT	84.0	440.3	195.6	1327.6
OTHR	8.9	57.7	30.9	206.5
SERV	3.9	132.9	24.6	113.4
TRAN	103.9	757.5	326.5	357.6

Energy use profiles, for both traditional and alternative energy, are depicted in Figure 1. The total amount of energy in Brazil is 10.6EJ, of which 49% is from low carbon technologies. Two main energy sources predominate in the Brazilian energy mix with 73% i.e., oil and hydro energy.

Figure 1

Primary energy use in Brazil, Europe, Latin America and China in 2015



Latin America presents the second lowest level of energy use. It totals 23.2 EJ, distributed into 19EJ from oil and gas, and 3.1EJ of hydro. In Latin America oil constitutes a large portion of the energy system, followed by consumption of gas and hydropower²².

The most noticeable difference compared to Europe and China is that Latin America generally uses little coal, implying that abatement potential by rolling back its consumption is limited. In Europe, 75% of the total energy use of 70.2EJ is fossil fuel-intensive, with 21% from coal. From the 17.3 EJ of alternative energy consumption, the most representative is nuclear technology, with 8.9EJ. In Figure 1, the European energy profile is, however, the most diversified amongst all. Overall, energy mix in China relies heavily on coal and accounts for approximately 64% of total energy use. With respect to alternative energy in China, hydroelectricity plays the predominant role with 74% of generation, with the remainder from bioenergy, nuclear and renewables.

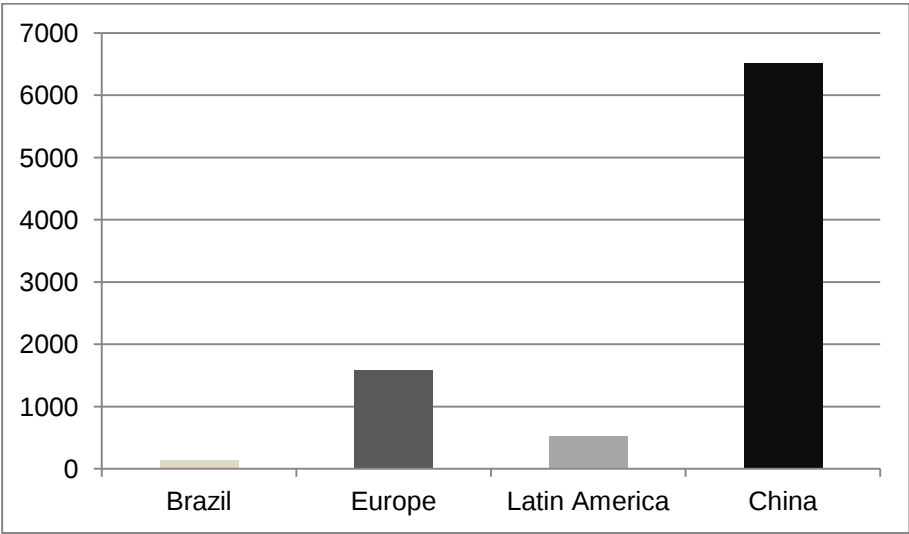
In short, oil is mostly used in Brazil, Latin America and Europe, but coal consumption predominates in China. Overall consumption of alternative energy in Brazil, Latin America and China relies on hydroelectricity, whereas nuclear technology is significant in the European energy mix.

²² According to Clarke *et al.* (2016), most countries in Latin America have a minimum reliance on coal. In terms of natural gas consumption, Argentina and Mexico present the largest share in the energy mix. On the other hand, Brazil and Colombia are more reliant on the use of hydropower.

Under a carbon emissions constraint, changes in energy prices tend to stimulate low-carbon technological developments and consequently, facilitate emission reduction obligations differently in these countries. Yet, the degree of mitigation will depend on different factors, with economic costs being the most relevant as it affects abatement from the electricity sector and energy-intensive industries. As illustrated by Figure 2, the covered ETS sectors in Brazil emit the lowest level of emissions compared to the potential trading partners, at less than 150 million tonnes of CO₂. This corresponds approximately to 2% of China’s, 8% of Europe’s and 25% of Latin America’s sectoral ETS emissions in 2015.

Figure 2

Sectoral CO₂ emissions in 2015 (million tonnes)



Among the investigated countries, Brazil displays a unique energy mix, basically due to the national production and consumption of hydroelectricity and oil. This ex-ante analysis has encountered differences between Brazil and potential partners in terms of the volume and sources of emissions. Figure 2 suggests a significant discrepancy in sectoral volume of emissions from Brazil and Europe, but even more so when compared to China. This is in accordance with differences in the energy pattern previously presented.

Heterogeneity in macroeconomic characteristics is in line with the outlined energy profile pattern compared to Brazil. Table 3 highlights macroeconomic indicators such as GDP, consumption levels, investments, exports and imports, etc. In comparison to other developing countries in the study, the Brazilian economy is very representative as an economy. For instance, investments and government expenditures resembles with Latin America’s, although Brazil is the only country amongst all to incur lower investments than

public spending. Whether GDP and consumption do not deviate considerably, it indicates Brazil can be economically as strong as Latin America. In fact, regional circumstances are bound up in a wide range of issues having to do with the lack of basic infrastructure to boost economic efficiency, equity and fairness and, ultimately, economic progress. In light of that, an appropriate level of abatement is fundamental as to avoid potential negative impacts.

Table 3

Macroeconomic profile in 2015

	BRAZIL	EUROPE	L.AMERICA ²³	CHINA
GDP per capita (US\$)	8078.5	34579.4	7993.8 ²⁴	4829.3
GDP (US\$billion)	1645.3	18272.1	3088.5	6806.8
Consumption (US\$billion)	968.2	11541.9	1978.0	2665.4
Investment (<i>in current value</i>)	26.6	421.2	64.0	258.1
Government Expenditures (<i>in current value</i>)	36.1	349.0	35.3	89.0
Exports (<i>in current value</i>)	19.5	195.0	69.0	194.5
Imports (<i>in current value</i>)	14.5	292.2	57.3	127.5
Total CO2 emissions (Mt)	1114.2	3545.7	2001.0	9673.5
Land use change emissions (Mt)	712.3	-214.6	655.1 ²⁵	168.5

International trade of goods and services corroborates these homogeneities with Latin America, given the relatively small amount of trading that flows in and out of both economies as opposed to the higher values traded by China and Europe. It is worth noting that only Europe faces trade balance deficit. In general, developed countries tend to import raw material from developing countries, whose trade performance is altogether export-led. Yet, distributive effects emerge from this trade pattern. In order to avoid additional distributional implications associated to linking sectoral ETS, considering trade and consumption appears to be also a relevant aspect to take into account when selecting a linking partner.

²³ The sum of LAM and MEX, as aggregated in EPPA6.

²⁴ This is the average of and aggregation between Latin America and Mexico, corresponding to US\$6431.0 in the former and US\$9556.6 in the latter.

²⁵ As in Brazil, land use change emissions represent an important share of total emissions in the rest of Latin America. The distribution across the region varies, with substantial participation of Mexico, Chile, Colombia and Argentina in addition to Brazil (Clarke *et al.*, 2016). Accordingly, the need to introduce climate policy with emphasis on land use and deforestation are greater than in other regions.

Therefore, in addition to the energy profile and national environmental objectives, Brazil shares similar trade patterns and consumption levels with Latin America in comparison to Europe and China. The similarity of development levels implies closer environmental and economic objectives between Brazil and Latin America. Whether this could diminish the burden of the climate policy and facilitate negotiations of the ETS linkage, benefits of linking with a broader carbon market implemented in a bigger economy can be significant.

3.2. Sectoral mitigation, carbon prices and distributional effects

The findings presented in this section are dependent on the core assumptions we made in Section 2.2. Results reflect the design of the market mechanisms in which the linkage architecture takes place. In order for Brazil to decide on the most appropriate partner to link with, certain aspects such as emissions, energy mix and carbon price impacts need to be taken into account.

Emissions from the sectoral ETS in Brazil are presented in Figure 3 and carbon prices are displayed in Figure 4 while Figure 5 show carbon prices of the partners when in a state of autarky. Overall abatement costs of the climate policy for regulated sectors are affected by the carbon price, whether in autarky or in a linked-ETS situation. The difference is that sectoral trading leads to a carbon price equalisation between the jurisdictions involved, eliminating marginal abatement costs divergences. For the Bra ETS, in the absence of international carbon trading (i.e. the PRE_LINK scenario), emissions from the power and energy-intensive industries in Brazil are 98.6 million tons in 2030, i.e. 74.3 million tons less than BAU emissions, and the corresponding CO₂ price US\$202.4/tCO₂.

Figure 3

CO₂ emissions from the sectoral ETS in Brazil

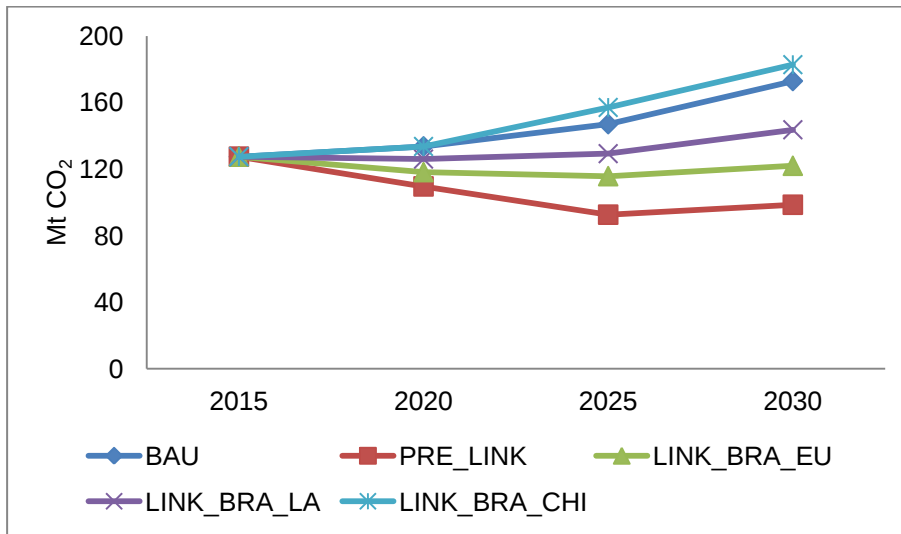
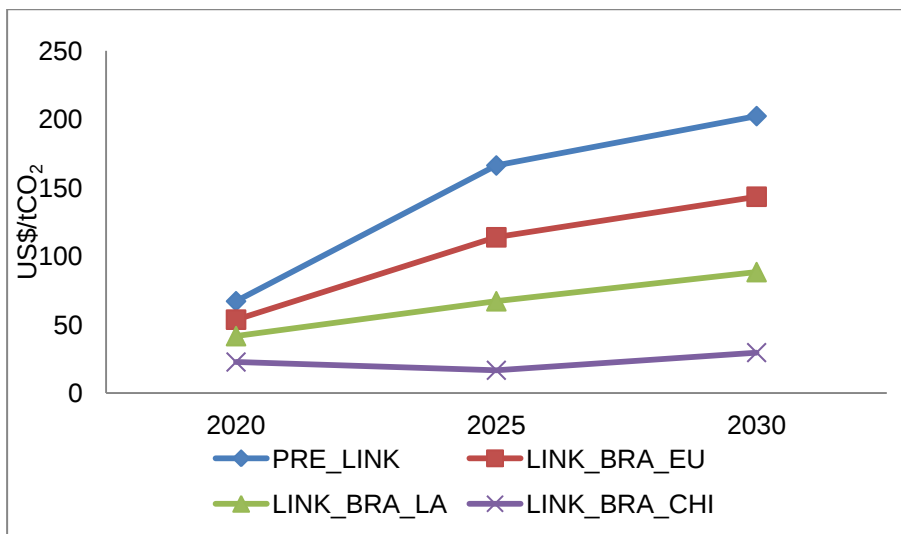


Figure 4

CO₂ prices in Brazil under different scenarios

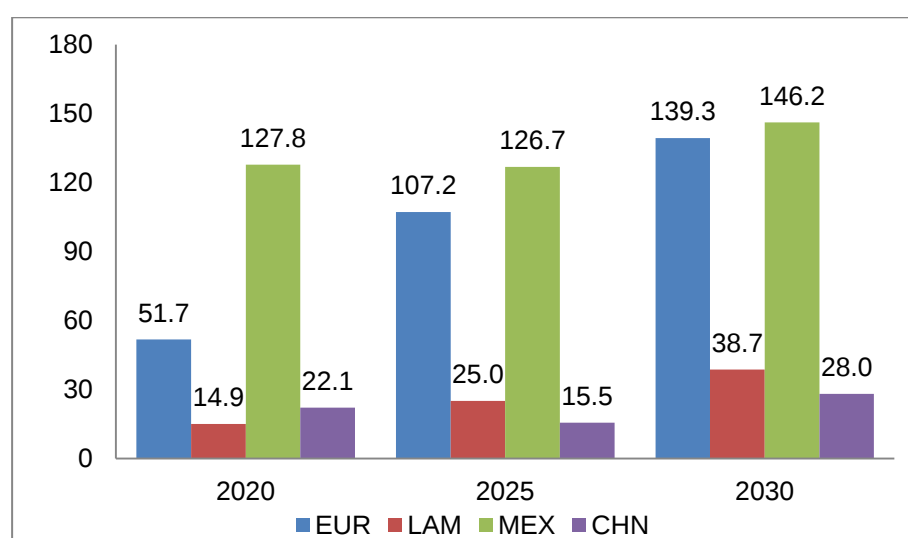


If trading is allowed between Brazil and Europe (LINK_BRA_EU), 23.4 million tonnes of carbon permits are imported from Brazil and the carbon price is equalised across the two systems at US\$143.4/tCO₂ in 2030. Previous studies on linking the EU ETS to emerging ETS systems report an equalised CO₂ price between 15.4€ and 35€, depending on the ETS assumptions in terms of growth, allocation method or mitigation target (Gavard *et al.*, 2016; Hübler *et al.*, 2014).

In this analysis, the linking price is relatively higher and it is almost pegged to the EU's autarky price of US\$139.3/tCO₂ in 2030, depicted at Figure 5. The price symmetry among scenarios occurs due to Europe's sheer size relative to Brazil's, as the volume of emissions in the EU ETS corresponds to approximately ten times that of the Brazilian ETS, thereby making marginal abatement costs not much lower than in Europe. In this linkage, Brazilian sectoral emissions are 122 million tonnes and those from the EU ETS are 1135.3 million tonnes in 2030²⁶, a reduction of 37% compared to BAU emissions and only 2% less than in autarky.

Figure 5

CO₂ prices in the PRE_LINK scenario for the partners: EUR, LAM, MEX²⁷, and CHN



In the Brazil-Latin America scenario (LINK_BRA_LA), Brazil is also a net importer of carbon permits from the covered sectors in Latin America, with a transfer of 45.1 million tons of CO₂. In comparison to the PRE_LINK scenario, this amount represents an addition on the emissions permits from covered sectors in Brazil of 46%, which are purchased at US\$88.4/tCO₂ in 2030. For Latin America, the linkage implies a reduction of 46.8 million tons from the domestic ETS situation in 2030. Allowances cost less to Latin American

²⁶ Information available at the European Environmental Agency website (https://www.eea.europa.eu/data-and-maps/daviz/ets-esd-lulucf-and-aviation#tab-googlechartid_chart_21) projects the EU ETS emissions and the cap to be approximately 1640.4 and 1332.7 million tonnes of CO_{2e} in 2030, respectively. This discrepancy between numbers from the EPPA6 simulation and the official projections for the EU ETS occur as a result of emissions coverage (nitrous oxide and perfluorocarbons, for example, included in the actual EU ETS) and additional sectors covered (e.g. commercial aviation included in the actual EU ETS). EPPA6 attempts to reproduce accurately the observed data in the baseline year. Therefore, it exhibits the same trend, but does not necessarily achieve the same level of reduction due to model assumptions and calibration factors.

²⁷ Mexico is included here because it represented in EPPA6 as a single region. In the Latin America linkage, it also participates.

covered sectors in the PRE_LINK scenario, approximately US\$40/tCO₂. This carbon price is consistent with previous research (Clarke *et al.*, 2014; Kober *et al.*, 2016), where the costs of emitting carbon range from about US\$15/tCO₂ to US\$50/tCO₂ to obtain a 20% emission reduction.

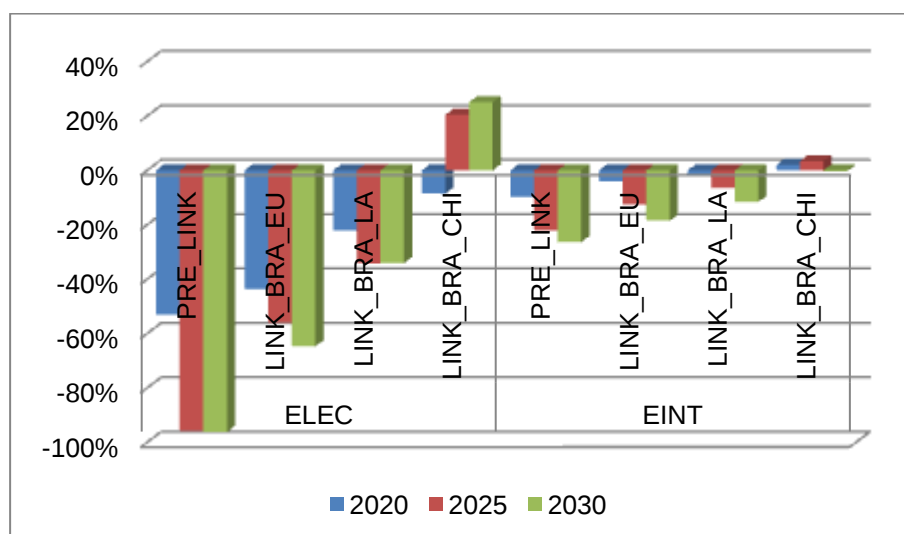
Similarly, in the case of an integrated Brazil and China system (LINK_BRA_CHI), Brazilian carbon permits corresponding to 84.2 million tons are imported from China in 2030, totalling 182.7 million tonnes from electricity and energy-intensive sectors. Carbon prices are equalised at US\$29.5/tCO₂, which results in an 85% drop in Brazilian price from the PRE_LINK scenario. In this case, the carbon price is lower and emissions reductions are limited comparative to BAU scenario and other linking scenarios.

This is understandable as the carbon price in the Brazilian ETS is higher than the Chinese ETS, where carbon permits cost US\$28/tCO₂, and additionally, the limit on sectoral emissions is greater. However, when linking a more stringent ETS to a less ambitious system, the resulting lower aggregated ETS emissions appears to be detrimental for succeeding in the overarching purpose of the coordinated mitigation. In this context, the Brazil-China linkage could be problematic in comparison to the LINK_BRA_EU scenario. However, whether it is advisable or not will depend on the costs incurred by the regulated entities and any impacts on production levels.

The intra-jurisdiction mitigation from an ETS applied in Brazil under different scenarios is described in Figure 6. The majority of emissions reductions in Brazil stem from the power sector in all scenarios, which has more alternatives for substituting fossil fuel-based energy sources with renewable energy. It is observed that, the greatest mitigation level is achieved by the electricity sector in autarky, when it almost fully decarbonises in the simulation. This level of decarbonisation reflects the relatively higher ambitious target that Brazil, alone, is committed to in the context of a domestic ETS. Conversely, a linking agreement enables the total cap, and required abatement of participating jurisdictions to be lower than within an isolated trading system.

Figure 6

ELEC and EINT emissions reduction from BAU in Brazil

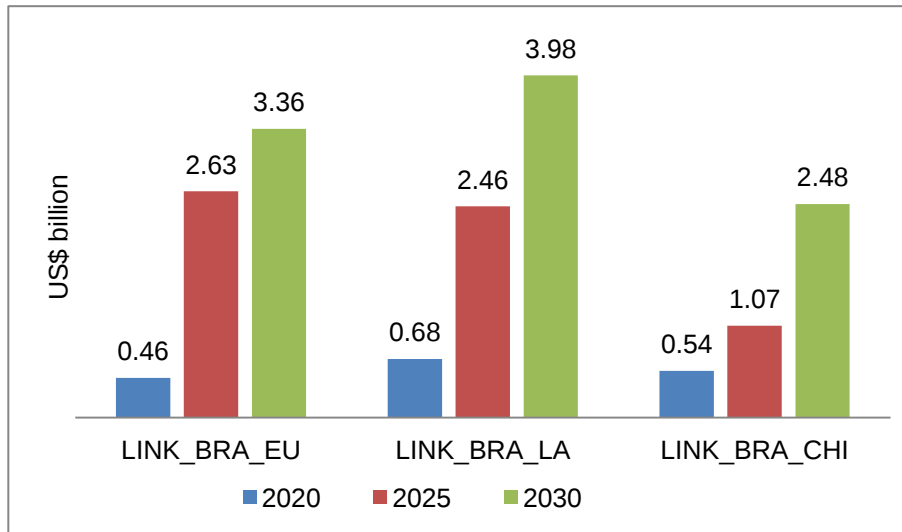


Among linkage scenarios, allowing permits to be exchanged with Europe produces the deepest reductions in both sectors, with approximately 65% reduction in the electricity sector and 19% reductions in energy-intensive industries by 2030. Conversely, linking with China from 2025 onwards has the reverse effect, that is, a rise in CO₂ emissions relative to BAU projections, particularly those from the power sector whose emissions increase by 25% in 2030. This raise in sectoral emissions in the LINK_BRA_CHI scenario suggests an associated increment in the sector's production, thereby implying a higher demand of carbon permits. In the Latin America link with Brazil, intra-jurisdiction and mitigation is moderate compared to Europe and China. As outlined before, this finding is closely related to the level of ambition admitted to Brazil and its potential trading partners, which tend to be economically benefitted by the reduced costs to mitigate by trading permits.

Financial transfers from trading are displayed in Figure 7 below and sectoral mitigation from candidate partners in Table 4. Two effects are highlighted: intra and inter flow of permits. As the price increases along the years, there is also a growth in the cost of carbon for the covered sectors.

Figure 7

Total financial transfers of CO₂ permits (in 2007 US\$ billions)



In LINK_BRA_EU, Brazilian's electricity sector has to purchase carbon permits to a total of US\$1.9 billion whereas the energy-intensive industries imports amount to US\$1.5 billion in 2030. These permits are mostly supplied from the European ELEC sector, since it presents more abatement options or technological alternatives to mitigate emissions, thereby receiving US\$3.0 billion²⁸. At the inter-jurisdiction level, trading enables ELEC and EINT in Europe, but the latter in a much lower level, to sell permits to Brazil. Since the ETS provokes proportional reductions in relation to BAU in both PRE_LINK and LINK_BRA_EU scenarios, linking engenders economic benefits for Europe by obtaining additional income, especially if emissions allowances were exported via auctioning.

In Gavard *et al.* (2013) and Gavard *et al.*, (2016) Europe is also better off in a developed-developing country sectoral link, more specifically, in terms of the macroeconomic effects and trading pattern. This investigation, however, differs from existing literature as the developing country assumes a position of permit-importer from the developed country participating in the link. The different trading pattern is here identified as a consequence of the ETS modelled, which imposes a very deep cut in emissions from the electricity and energy-intensive industries in Brazil. In fact, the electricity sector in Brazil is relatively low-carbon when compared to the European's, that is, it has fewer opportunities to further decarbonise. If the ETS was regulated to comprise emissions from land use change, for instance, Brazil would likely sell carbon permits.

²⁸ If linking to a developed country, Europe has a buyer profile of emissions in Dellink *et al.* (2014).

Table 4

Sectoral emissions reduction in comparison to BAU (%): Europe, Latin America and China

Sector	Parters	Europe		Latin America		China	
	Scenarios	PRE_LINK	LINK_BRA_EU	PRE_LINK	LINK_BRA_LA	PRE_LINK	LINK_BRA_CHI
ELEC	2020	-19.1	-19.8	-20.3	-25.5	-18.2	-18.6
	2025	-33.8	-35.6	-28.5	-36.4	-13.8	-14.7
	2030	-49.4	-51.2	-34.1	-42.6	-20.2	-21.2
EINT	2020	-4.4	-4.6	-10.8	-11.8	-10.4	-10.6
	2025	-9.4	-10.0	-12.4	-16.5	-6.7	-7.2
	2030	-12.4	-12.9	-15.8	-20.6	-10.2	-10.9

On the other hand, Brazil becomes a buyer of emissions not only if linked to the EU ETS but also if linked to other developing regions, indicating that the intra and inter-trading pattern of ETS linkage is determined by the ETS design, with focus on the level of mitigation. For example, the LINK_BRA_LA scenario evidences that the electricity sector in Brazil purchases more permits from Latin America than energy-intensive industries. A comparable trend is observed in the supply side, where the greater abatement in the Latin American electricity sector generates US\$2.8 billion in carbon permits to be exported.

Similarly, the costs for the electricity sector remain high so that it requires carbon permits to comply with the ETS cap in the Brazil-China linkage. In this case, the Brazilian demand for allowances is supplied by the Chinese ETS with financial flows of US\$2.1 billion. The amount transferred from China to Brazil is lowest among investigated candidates, which demonstrates the constraint imposed on emissions makes reductions less expensive for covered sectors comparatively. Most of the sectoral reductions in China fall on the electricity sector, which is also the main exporter of carbon permits to Brazil.

In Table 4, when joining Brazil in the designed ETS, Latin America and China face greater mitigation. For these regions, it is more economically feasible to make abatement efforts to comply with the NDC targets, which are less ambitious than Brazil's, although mitigation is only slightly greater than in the PRE_LINK scenario for China. Thus, whilst achieving further emissions reductions in Brazil goes along with increasingly costs, Latin America's and China's covered sectors benefit by obtaining income from Brazil. These findings demonstrate a reallocation of emissions and financial transfers among sectors and participants of the linked system, i.e., emissions reductions and carbon permits to a larger extent from electricity sector are transferred from the potential partners to Brazil.

The overall cost of international market mechanisms to the economy is evaluated by changes in GDP at Table 5, where we also included results for welfare. These indicators reflect the macroeconomic and other general equilibrium effects of reducing carbon emissions in response to the carbon price signal. Therefore, we could not measure either the benefits from avoiding climate change²⁹ nor the economic impacts of the changed climate, but only cost-effectiveness of the climate policy. The welfare effect is expressed as equivalent variation changes in consumption level relative to no mitigation. In EPPA6, consumption serves as a proxy for welfare since it better translates both changes in income and relative prices.

Table 5

Changes in GDP and welfare in relation to BAU (%) in Brazil

BRA	GDP				Welfare			
	PRE_LINK	LINK_BRA_EU	LINK_BRA_LA	LINK_BRA_CHI	PRE_LINK	LINK_BRA_EU	LINK_BRA_LA	LINK_BRA_CHI
2020	-1.9	-1.8	-1.7	-1.6	-1.5	-1.5	-1.4	-1.4
2025	-3.6	-3.2	-3.1	-2.8	-2.3	-2.2	-2.1	-1.8
2030	-4.2	-3.9	-3.6	-3.3	-2.5	-2.4	-2.3	-2.0

In accordance with theory, in our simulations linking slightly attenuates macroeconomic effects in Brazil compared to a situation without linking by reaching higher economic efficiency. The policy-induced GDP drop becomes 0.3, 0.6, 0.9 percentage points smaller in the LINK_BRA_EU, LINK_BRA_LA and LINK_BRA_CHI scenarios, respectively, than in the PRE_LINK scenario by 2030. Likewise, the welfare losses decrease slightly through linking. It is worth noting that if allowances are distributed to covered entities via auctioning, the welfare effect can be more accentuated since the carbon cost induces an overall rise in electricity prices, which is detrimental to consumers, resulting in more GDP losses.

The model results suggest that macroeconomic effects in Brazil vary according to the stringency of targets of the trading partner. Where linkage occurs from the more to the less ambitious trading candidate, linking engenders cheaper opportunities to Brazil to purchase permits, thereby reducing abatement costs comparative to domestic ETS mitigation. Hence,

²⁹ For example, improved air quality from curbing pollutants released in the air.

the relative level of emissions reductions required in the combined ETS is lower to Brazil than without linking.

As pointed out by Gavard *et al.* (2016), unlimited sectoral trading with a developing country ETS, improves or at least makes developed regions to be less affected due to their more stringent cap. Results in Table 6 show no changes in Europe's GDP in 2020 with associated minor effects on welfare. Losses in GDP and welfare increase towards the period but still, no difference is found between PRE_LINK and LINK_BRA_EU. Similarly to Europe, the changes in Chinese GDP and welfare are also small but it alternates with a positive gain in 2025, corresponding to US\$11.2 and US\$4.0 million, respectively.

Table 6

Changes in GDP and welfare in relation to BAU (%) in the linking partners

Linking Partner	Scenario	GDP			Welfare		
		2020	2025	2030	2020	2025	2030
Europe	PRE_LINK	0.0	-0.5	-0.8	-0.3	-0.9	-1.6
	LINK_BRA_EU	0.0	-0.4	-0.8	-0.3	-0.9	-1.6
Latin America	PRELK	-1.7	-2.5	-3.3	-1.3	-1.9	-2.6
	LINK_BRA_LA	-1.7	-2.5	-3.4	-1.2	-1.8	-2.4
China	PRELK	-0.4	0.1	-0.1	-0.2	0.1	-0.1
	LINK_BRA_CHI	-0.5	0.1	-0.1	-0.2	0.1	-0.1

As a result of the general equilibrium effect, there are negative impacts on GDP and welfare in Latin America, but it does not include the aforementioned revenues gains. This is consistent with other studies analysing macroeconomic impacts of climate mitigation in Latin America (Bowen *et al.*, 2013; Tavoni *et al.*, 2013; Kober *et al.*, 2016), where both GDP and welfare is expected to range from -6% to +1% depending on the proposed targets and the resulting carbon price regime. When comparing the developing regions investigated, results show that the effect on Brazil is as significant as in Latin America, but the former experiences the deepest drop in GDP and welfare in all scenarios. Yet, sharing the carbon constraint is GDP and welfare improving to Brazil since it lowers the cost of the policy domestically and hence, the price to be paid by the economic agents.

In addition, the sectoral ETS alters the demand for fossil fuels and, as expected, the energy use profile. According to Figure 7, the role of low carbon technologies in Brazil

become more important relative to fossil fuel-based primary energy. For instance, the share of coal decreases by 69%, 63% and 47% in LINK_BRA_EU, LINK_BRA_LA and LINK_BRA_CHI scenario, respectively, whereas hydroelectricity increases 13%, 7% and 1% and renewables (wind and solar) grows 6892%, 4421% and 773% respectively, in relation to BAU. Since the expansion of hydropower may be limited, relying on other low-carbon technologies is fundamental to Brazil. In the PRE_LINK scenario, the total amount of electricity consumed is 10.6 EJ, with 6.8 EJ from alternative sources.

Table 7

Energy use in Brazil in 2030 (EJ)

	BAU	PRE_LINK	LINK_BRA_EU	LINK_BRA_LA	LINK_BRA_CHI
Coal	0.70	0.18	0.22	0.26	0.37
Oil	4.88	2.91	3.11	3.27	3.51
Gas	1.43	0.72	0.81	0.92	1.14
Bioenergy	1.37	1.85	1.79	1.73	1.44
Nuclear	0.15	0.20	0.16	0.15	0.15
Hydro	4.01	4.67	4.53	4.34	4.08
Wind and Solar ³⁰	0.00	0.09	0.06	0.04	0.01

Under the proposed sectoral design, linkages partially reverse technological changes induced by the domestic ETS in Brazil, especially the Brazil-China system where traditional sources rise from 3.8 EJ in the PRE_LINK to 5 EJ. On the other hand, the greatest substitution effect towards low carbon technologies is verified in the Brazil-Europe link, with alternative sources comprising 61% of total energy used, instead of 49% in the BAU scenario. In summary, sectoral trading between Brazil and one of the considered partners would enhance the development of low-carbon electricity technologies in Brazil but to a lesser extent than in an isolated Brazilian ETS.

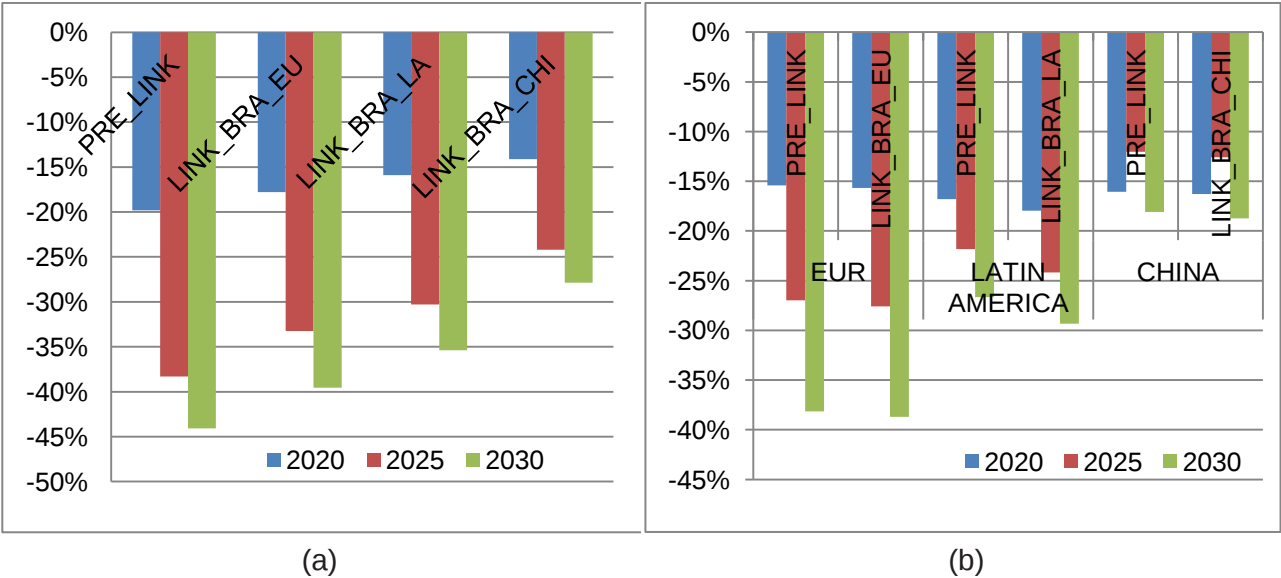
Likewise, national abatement is deeper in autarky, as depicted in Figure 8a. Here, Brazil reduces more emissions when pursuing a link with Europe. Since reducing emissions from deforestation is not modelled, both Brazil and Europe exhibit a similar level of ambition. Further, the Brazilian commitments are slightly more stringent than Latin America's, but far above the Chinese ambition. The policy responses are in accordance with these differences in the carbon constraint imposed in each jurisdiction.

³⁰ Production of wind and solar energy in Brazil represents relatively a very low share of total energy. In the BAU situation, fossil-fuel energy prevails over these energy sources due to the high costs of low-carbon technologies.

By linking, the aggregate volume of emissions is not altered compared to the PRE_LINK situation. Instead, the linkage only allows both regions to negotiate permits in a way to seize abatement opportunities among them. This explains why the effect of linking with Brazil is barely perceptible to the proposed trading partners compared to the implementation of a national ETS in Figure 8b. By 2030, there would be a drop in emissions around 38% and 18% from BAU in Europe and China, whether participating in the link or not. In contrast, the level of mitigation in Latin America is lower without joining Brazil, as there are few cost-effective opportunities for emissions abatement available. Considering the global climate perspective, the Brazil-Latin America linkage promotes very limited aggregated reductions in light of the limited volume of aggregated emissions covered compared to other potential partners.

Figure 8

Total* CO₂ emission reduction from BAU in Brazil (a) and trading partners (b)



The Brazilian case is used to illustrate the effects for a developing country to design a sectoral ETS and link it to other systems, whether trading with developed or another developing regions. It highlights in which partnership the implementation of a linkage is more appropriate to meet mitigation goals at minimum cost, while encouraging a broader participation.

Table 8 below summarises advantages and disadvantages of linking and characterises each proposed trading partnership based on existing requisites in the literature for a successful linkage. Among environmental, economic and political aspects, the modelling results indicate

it is very challenging to address all conditions at once, especially because opportunities for abatement vary across countries for several reasons. The level of development is particularly important not only to understand if sectoral ETS linkage are adequate to national circumstances, but also to indicate to what extent the balance between costs and benefits from mitigation via market-based mechanisms enables human development. However, the major determinant on the implications of linking is the level of ambition, which translates both the energy profile and the level of development of jurisdictions.

Table 8

Characteristics of each proposed linkage from the modelling exercise and according to the literature

Linkage characteristics	Brazil-Europe	Brazil-Latin America	Brazil-China
Comparable level of ambition	X		
Similar energy profile		X	
Similar level of development		X	
Similar marginal costs of abatement translated into carbon prices	X		
Improved market liquidity due to the broader participation of countries	X	X	
Lower costs to society			X
Incentives to develop low-carbon technologies	X	X	
Greater environmental performance: aggregate emissions reductions	X		
Geographic proximity		X	
Symbol of multilateral efforts to mitigate emissions	X	X	X
Potential for addressing competitiveness issues		X	X
Economic history of cooperation	X	X	X
Politically more acceptable at domestic level			X
Potential reduced regulatory sovereignty	X		
Technical know-how	X		X
Adverse distributional effects	X	X	X
Risk to endorse reductions targets less consistent with the socially efficient in a global perspective			X

Even though energy profile and level of development differ among Brazil and Europe, this linkage is more environmentally effective due to high overall abatement levels promised along with the fossil-fuel substitution effect it triggers. By linking with Europe, Brazil would benefit from the technical know-how, and signalise that developing countries are also willing to tackle climate change through cooperation. At the same time, this linkage could lead to lower political autonomy as some basic rules intrinsic to the EU ETS would end up being transmitted to the Brazilian ETS, for example, in the EU ETS system there is the New Entrant Reserve (NER300) or specific allocation method mechanisms.

Moreover, there are additional distributional implications to Brazil, particularly because it is the least cost-effective partnership. Considering the ETS design modelled, allowing some flexibility for the developing country appears to be reasonable so as to address the challenges and difficulties of this proposal. Examples could include, accepting less rigid commitments or transferring payments from the allocation of permits to developing countries. Yet, Europe may not perceive the prospects of linking with Brazil as attractive, as opposed to linking to a larger system, such as the Chinese ETS.

Similarly, the Brazil-China ETS is considerably heterogeneous in terms of energy profile and economic performance but also with regard to counterfactual prices. The most appealing aspect of this linkage is the lower costs for society it promotes, thereby making the cooperation more politically acceptable at domestic level. In fact, there is a long history of economic relations between Brazil and China, especially via international trade of goods and services that could facilitate negotiation. In light of the recent launch of the Chinese ETS, which tends to provide China with technical expertise, linking of ETS systems has the potential to address competitiveness issues, whilst encouraging other developing countries to take action. However, the policy may be more cost-effective mainly because China proposes an intensity-based emissions cap, which for the purposes of the model used in this analysis, was translated into an absolute cap which may result in it not being comparatively ambitious. In a linked framework, differences in the type of cap are technically difficult to regulate. Most importantly, contrasting mitigation goals may hinder the aggregate emissions reductions.

Latin America would appear to be the trading partner most closely aligned to Brazil from an energy and economic perspective. As for the link, mitigation targets are less aggressive than those taken on by Brazil. This sectoral ETS linkage among developing countries demonstrates that it is possible to curb emissions at lower costs when the level of

mitigation differs across systems. In this case, rather than transferring revenues to a developed country, the distributional effect of linking is a financial flow from Brazil to Latin America that comprises a wider abatement effort within a shared carbon price. The advantage of this regional cooperation is to culminate in a broad participation where competitiveness concerns may be addressed, especially because all sectors face a constraint on emissions, along with transformations of the energy system.

At the same time, this could be a complex negotiation since Latin America has not signalised a willingness to discuss a common climate policy. This approach is indeed very politically challenging in all linked situations. Although the link can be geographically strategic, political support or administrative costs may vary among the heterogeneous group of countries, thereby highlighting potential difficulties for the initiation stage. This is applied also for the suggested harmonisation of ETS features, as results reveal the challenge of imposing a deep carbon constraint on a small market already very low in emissions. Accordingly, it indicates that Brazil may not be seizing other possible mitigation opportunities, such as reducing deforestation and other Greenhouse Gases (GHGs), which may be cheaper than curbing emissions only in production sectors, and only based on market instruments.

This fact does not exclude or reduce the need to adopt measures in the electricity and energy-intensive sectors. Once the sectoral ETS progressively mitigates emissions, the focus will shift increasingly towards reducing emissions from other sectors. Therefore, strengthening the climate package with domestic carbon taxes to curb emissions outside the ETS is rather necessary as well as regulatory and technology policies to enhance innovation or to compensate those sectors disproportionately affected. These additional factors are relevant for further analysis.

5. Final remarks

International cooperation through carbon pricing has become an important framework to address climate change, as highlighted in the Paris Agreement. In light of that, both developed and developing regions are encouraged to adopt market measures in the future. With the number of Emissions Trading Schemes increasing around the world, the question of whether these schemes should be linked is relevant.

To date, experiences show that an ETS aggregating all sectors is still technically unfeasible. Since Brazil is discussing the implementation of carbon pricing mechanisms, we

made assumptions on the ETS design features in line with the EU ETS characteristics, as it is the most consolidated system. Thus, to comply with the NDC we applied a sectoral ETS, regulating electricity and energy-intensive sectors, along with a supplementary policy on non-ETS sectors, so as to mimic abatement in those sectors and to prevent leakage. To avoid competitiveness issues associated with carbon leakage towards other regions, we adopted the same hybrid architecture in other jurisdictions.

We consider Europe, Latin America and China as candidates to link with Brazil due to geographic proximity, and historical economic relations. Europe has envisaged linking to non-EU emerging trading systems in the future to strengthen the EU ETS, China has just launched the national Chinese ETS (December 2017) and Latin America remains a hypothetical ETS system. Whilst Europe and China have technical knowledge to manage an ETS, Latin America has not initiated any discussion in this regard. Our simulations include an autarky scenario for Brazil in addition to these three linkage scenarios (Brazil-Europe, Brazil-Latin America, Brazil-China).

Results demonstrated that differences in carbon prices are eliminated through the link and Brazil benefits from a lower carbon price if it links to any partner. In the Brazil-Europe case, carbon prices equalise at US\$143 in 2030, which is the highest price among scenarios. This occurs as a consequence of the similar stringency of targets in both entities. As a developed region, Europe is the most heterogeneous country in relation to energy and macroeconomic patterns compared to Brazil. Although emissions reductions are facilitated under this scenario, the policy cost is the largest in terms of GDP and welfare effects, with a corresponding US\$3.36 billion in payments for allowances accruing to Europe. In fact, this is the opposite of what is expected in the literature, i.e. developing countries pursuing a permit exporter pattern, due to the deep level of abatement imposed on the covered ETS sectors in Brazil, which is significantly more decarbonised than Europe.

A sectoral link with developing regions (China and Latin America) has the advantage of diminishing the carbon costs for the Brazilian ETS. In both linkages, Brazil continues to have an allowances importer profile. Whilst in the Brazil-Latin America linkage carbon prices decrease 56% from the pre-link scenario in 2030, the Brazil-China linkage carbon price is reduced by 85% in the same period. Overall economic and welfare implications fall, as a result of less aggregated emissions reductions in these linkages involving developing countries, since Latin America and China commitments in the Paris Agreement are less ambitious than those for Brazil and the EU. This result indicates that the climate cooperation

between developing countries, and considering their lower national targets, is less costly than linking to a developed ETS.

In the context of the ETS scenarios modelled, it appears that economic benefits would be an aspect which could increase interest for Brazil to link, particularly if distributional effects are limited. Among the proposed trading partners, the Brazil-China sectoral link fits this prerequisite and tends to be more politically and technically feasible, although implying a lower level of abatement. On the other hand, if in the short run Brazil prioritises a climate strategy committed to deep decarbonisation based on the development of low-carbon technologies, linking to the EU ETS is the most adequate choice. As for Latin America, political resistance for using market mechanisms to address climate issues, makes the proposed linkage extremely unlikely before 2030.

Hence, with these results we contribute to the literature by showing that the market-based system modelled in the context of partner's heterogeneity, promotes mitigation at minimum cost to society via bilateral cooperation among developing countries. Further, some recommendations can be provided in terms of ETS design and the linkage agreement. In the illustrative case of Brazil, the alignment of sectoral coverage may not seize the main mitigation opportunities in Brazil, considering that the share of low-carbon technologies in the energy mix is currently higher than fossil fuel-based sources. This, in turn, makes the electricity and energy intensive sectors more decarbonised than, for example, those of the EU ETS or China. In this instance, the link could therefore envisage additional sectors.

Another recommendation is to allow a level of abatement more appropriate to mitigation opportunities available in the developing country, if linked to a developed country ETS. Most importantly, it is desirable to introduce a degree of flexibility as to increase acceptability while reducing distributional impacts, such as revenue recycling. Nevertheless, to address the global climate problem and promote larger abatement, a sectoral ETS linkage with only developing countries (Brazil, Latin America and China), designed specifically in relation to their energy and economic profiles, may be relevant.

The approach modelled does not consider costs or benefits from avoiding climate change, climate adaptation, or other policies to support technological change at the intra-industry level. It configures a first approximation on how Brazil could incorporate carbon pricing, and link carbon markets with both developed and developing ETS schemes, in order to promote additional abatement in the most appropriate fashion.

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