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International market mechanisms under the Paris Agreement: A cooperation between Brazil and Europe☆

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ABSTRACT

Using the Economic Projection and Policy Analysis (EPPA6) model, this paper assesses Emissions Trading Scheme (ETS) cooperation between Brazil and Europe, using harmonised sectoral coverage (electricity generation and energy-intensive sectors). Land Use, Land-Use Change and Forestry (LULUCF) related emissions, which are significant in Brazil, are excluded from trading in the analysis, for two main reasons: (i) in an effort to closely align with existing provisions of the EUETS and (ii) to encourage other sectors of the economy to broaden their mitigation effort to comply with national climate targets. As a result, the relatively decarbonised electricity sector and the energy-intensive sectors in Brazil adopt ambitious targets under the proposal. The effects of the proposal are examined under three scenarios: a national ETS policy, a bilateral cooperation, and a global cooperation. Results show that a domestic ETS reduces emissions and promotes technological substitution towards alternative energy for both participants. Cooperation scenarios imply lower emission reductions in Brazil compared to a domestic ETS, where importing allowances from Europe is more cost-effective. For Europe, cooperating with Brazil has very limited impact on further mitigation. The global scenario sees both regions opt to acquire carbon permits from other regions where abatement costs are lower.

1. Introduction

More than 180 Parties of the United Nations Framework Convention on Climate Change (UNFCCC) met in Paris from 30 November to 12 December 2015 to negotiate a new global and legally binding deal for addressing climate change mitigation in the 21st Conference of the Parties (COP-21). Previous international negotiations had achieved little progress, which brought about significant discussion on the importance of setting up a climate pact in which all countries were committed.

Culminating in the first truly global international treaty, it brings together all countries into a common cause so that a low carbon, resilient and sustainable future may be feasible, as originally advocated by the UNFCCC. The bottom-up framework involves a global long-term action plan committed to keep global warming well below 2 °C and make efforts to limit the temperature increase to 1.5 °C by 2030. The paradigm consolidated in COP-21 recognises the historical, current and future responsibilities of the Parties, including developed and developing countries, signalling to the collective need to switch from the consumption of fossil fuels to clean sources of energy.

The Paris Agreement, as it became known, was entered into force earlier than expected on 4th November 2016. It will become effective from 2020 when approximately 105 Parties,[1] accounting for more than 55% of total global Greenhouse Gas (GHG) emissions, have deposited their instruments for the agreement ratification.

There would not appear to be general consensus on the potential of the agreement to promote sufficient positive outcomes. On one hand, some studies emphasise that the multilevel climate governance of the agreement represents a diplomatic and political success (Dimitrov, 2016; Sirkis, 2016; Soto, 2016). On the other hand, there is limited progress on certain elements not fully assigned in the agreement, such as the lack of enforcement mechanisms, or provisions for compensating loss and damages caused by extreme weather events (Barata and Kachi, 2016; Vieira and Vernet, 2016). Under this perspective, these aspects may lead to a misleading climate goal, predominantly focused on economic development (Boff, 2015).

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[1] The US president has recently publicly announced the intention to withdraw the USA from the agreement, which may pose serious risk to the common objective of tackling climate change and its effects on the planet.

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In fact, the document establishes the climate goals and the framework for international climate action, but does not specify the details in depth. Most of the specifications were postponed until 2017 and 2018, as decided during the first conference session of the Paris Agreement in Marrakesh (COP-22). For example, a decision on the rules governing market and non-market mechanisms that have been set up under the accord's Article 6, which provides the opportunity to expand the reach of carbon pricing, still have to be negotiated over the coming years.

Although not explicitly referenced as a market-based approach, the provisions introduced by Article 6 allow the use of "internationally transferred mitigation outcomes" (or the concept of exchange of carbon credits), to comply with the Nationally Determined Contributions (NDCs). These NDCs have been prepared for each Party in order to publicly communicate the future trajectory of emissions, and the domestic mitigation measures for achieving them. IETA (2016) indicates that the level of commitment declared by 91 Parties is conditioned on access to international markets. It also considers a mechanism to contribute to mitigation, and to support sustainable development (in place of the CDM from the Kyoto Protocol), along with a framework for non-market approaches.

Because the global atmosphere is a public good, and there is an inherent free-riding stimulus, combating climate change requires effective international cooperation, which needs to be codified in a combination of strategic policy instruments such as command-and-control (regulatory) and market-based policies. In recent years, carbon pricing and trading has emerged as the preferable policy instrument to achieve greenhouse gases (GHG) reduction in many developed countries, and developing countries have also started to consider it.[2]

Among developing countries, Brazil has assumed a pioneering position when it comes to climate commitments. Being responsible for approximately 4–5% of global emissions between 1990 and 2014 (SEEG, 2016), it has firstly voluntarily committed to reduce emissions during the Kyoto Protocol period by between 36.1% and 38.9% by 2020, compared to emissions in 1990. When ratifying the Paris Agreement, Brazil has agreed to promote a further cut of 37% and 43% of 2005 emissions levels, by 2025 and 2030 respectively. This is considered to be more stringent than the previous pledge at COP15 in Copenhagen, since it commits to ending illegal deforestation.

To date, the movement towards the adoption of carbon pricing mechanisms is still at an early stage in Brazil. Discussions in this regard have increased significantly since the enactment of the National Plan for Climate Change Mitigation in 2009, which has considered economic instruments as a means of achieving national targets by 2020. In addition to that, the growing number of jurisdictions accommodating carbon pricing mechanisms for their climate policy instruments provides lessons, and would appear to support Brazil to adopt similar strategies to accomplish their NDC proposals.

However, whether or not to implement a domestic carbon pricing system in Brazil is still an open question. The government, in association with the World Bank - Partnership for Market Readiness (PMR), is supporting a comprehensive group of studies based on carbon pricing.[3] The aim is to bring lessons from existing initiatives that could be applied to a similar system in Brazil, whilst evaluating requirements and potential implications of market-based instruments for domestic mitigation.

Moreover, the arrangements for market instruments presented in the Paris Agreement should encourage Brazil to design a carbon trading system. By leading the way in Latin America, Brazil may encounter new opportunities for climate cooperation with developed systems such as the European Union Emissions Trading Scheme (EU ETS), or other emerging schemes in the region. Hence, further international cooperation may emerge from increased acceptance of carbon trading mechanisms. In this sense, whilst not providing rules for an international carbon price, the Paris Agreement has created the foundation for expanding the reach of market-based mechanisms, notably through international cooperation.

Under this perspective, we propose an economic evaluation of the feasibility and effectiveness of international climate cooperation between Brazil and Europe using the MIT CGE (Computational General Equilibrium) model, the Economic Projection and Policy Analysis (EPPA6). There is a long history of economic relations and cooperation between the two regions, with Europe being the second major Brazilian trade partner in 2016 with 18.1% of total exports (MRE/DPR/DIC, 2016).

This paper investigates the environmental implications and associated costs of adopting market-based instruments, more specifically an Emissions Trading Scheme (ETS), for complying with EU and Brazilian NDCs during the Paris compliance period (2020–2030). The study involves proposing a particular design for the cooperation based on an integrated ETS system, in which the Internationally Transferred Mitigation Outcomes (ITMOs) generated by reduced emissions, can be exchanged between participant Parties. In order to model a more realistic system design, the proposed Brazilian ETS coverage mimics the EU ETS, and regulates only the electricity generation and energy intensive industries. For the purpose of this analysis, Land Use, Land-Use Change and Forestry (LULUCF) related emissions are excluded. Additionally, it aims to verify if linking ETS systems between developed and developing countries, or at a global level, which present different energy and emissions profiles and mitigation commitments, is recommendable.

This analysis takes into account the emission reduction pledges to estimate the economic and environmental effects of cooperating, evaluating the appropriateness of this climate strategy for helping both jurisdictions to achieve a low carbon economy. This is considered from three different perspectives: a national scenario, where the EU ETS, and the hypothetical Brazilian system, do not cooperate internationally; a bilateral cooperation system between the two; and finally, a global cooperation system where all Parties join the international cooperation. Whilst previous studies have explored carbon market linkages involving developing countries (Xu et al., 2017; Gavard et al., 2016; Hamdi-Cherif et al., 2011), there has been no detailed analysis of an ETS system for Brazil.

This analysis contributes to the literature by specifically analysing the effects of an ETS linking proposal involving a proposed ETS for Brazil. In this paper, what is specific to the Brazilian case compared to previous linkage literature for other developing countries such as China (Gavard et al., 2016; Hübler et al., 2014), is the level of ambition (target) applied to the regulated sectors along with the fact that the electricity sector is relatively low carbon in comparison to Europe. Results highlight differences in relevant factors such as carbon price,

[2] Currently, there are two operational schemes in developing countries, namely in China and the Republic of Korea. After being beset by delays, China launched its ETS at national level in December of 2017, following some years of experience with subnational pilot markets. It is expected to become the largest in the world by covering carbon emissions from approximately 1700 companies and projecting a gradual increase in the scope (ICAP, 2018a). The nationwide Korean ETS is active since 2015 and is currently in the second phase of the programme. There are some discussions on a potential collaboration with New Zealand (World Bank et al., 2017). An increasing number of jurisdictions in developing countries are planning, or at least exploring the potential for cooperation through ETS, with major developments in Latin America. For example, a pilot Mexican ETS is scheduled to be initiated in 2018, which envisions future linkages. At the same time, Colombia and Chile are both investigating the implementation of an ETS, following the existing carbon taxes in force. This is supported by the dialogues taking place on regional carbon pricing in the context of the Pacific Alliance (formed by Chile, Colombia, Mexico and Peru) for voluntary market-based mechanisms in Latin America (World Bank et al., 2017). In addition, Egypt and Vietnam have announced their plans to implement a national ETS that could be linked to others in the mid-term to long-term.

[3] See more information at: https://www.thepmr.org/country/brazil-0.

level of emissions, GDP, consumption, trading revenues and energy substitution towards cleaner sources.

The remainder of this paper is organised as follows. Section 2 characterises cooperation through international market mechanisms. Section 3 describes the modelling methodology and policy assumptions applied to quantify the effects of cooperation via an integrated ETS. Section 4 presents the policy simulations, macroeconomic and energy specificities, and interprets the results. Section 5 offers policy conclusions.

2. Background

2.1. Cooperation through international market mechanisms

In the Paris Agreement framework for climate action, all Parties have formal obligations, diverging only in how the contributions are achieved. In order to facilitate overall emissions abatement, different provisions were incorporated into the plan for increasing flexibility as described in Article 6: a cooperative mechanism based on a top-down voluntary cooperation for allowing the trading of ITMOs; an alternative mechanism to contribute to mitigation and support sustainable development substituting the previous Kyoto flexibility system; and finally, non-market measures.

We focus the investigation on the cooperative approach as a means to help participants meet annual emissions reductions. According to this perspective, international transfers may be conducted by linking ETS systems or other national climate policies. In addition, other types of cooperation related to the existing elements of Article 6 can be adopted, such as clustered carbon market clubs[4] (Nordhaus, 2015; Espagne, 2016), or even a more centralised approach via the UNFCCC.

Most characteristics of the cooperative perspective are identified at articles 6.2 and 6.3 of the Paris agreement, which includes specifications for the voluntary nature of the cooperation, how it involves the use of ITMOs towards the NDC, whilst also ensuring environmental integrity and transparency along with robust accounting[5] (UNFCCC, 2015). The voluntary basis of a cooperative agreement reflects the idea that the market provisions structure must only be imposed on those adhering to the integrated system (Barata and Kachi, 2016).

In our quantitative analysis, we assume that countries voluntarily take part in a joint framework of climate cooperation through the linkage of ETS systems. In the climate policy literature, this type of cooperation is usually depicted in traditional theory as an efficient way to create economic opportunities for achieving overall emissions reductions across jurisdictions (Dellink et al., 2014; Tuerk et al., 2009).

Under this climate strategy, there is an interaction of regional carbon regulations so that it leads to a reduction or elimination of differences in the marginal cost of abatement between the participants. As a result, a wider range of mitigation options become available, providing overall efficiency gains (Kachi et al., 2015; Anger, 2008). International cooperation is expected to create larger international markets, thus potentially increasing market liquidity (Ranson and Stavins, 2013) and price stability (Flachsland et al., 2009).

On the other hand, some research has alleged that ETS systems have a limited capacity to drive positive climate outcomes (Sirkis, 2016).[6] In this context, and due to some financial incentives, it may encourage those participants not willing to reduce emissions, to make less effort to do so, or to not reduce emissions at all (Lohmann, 2006). Fundamentally, the critical problem of adhering to market-based instruments and expanding their reach stems from the commodification[7] of emissions since it can exacerbate social and environmental inequalities[8] through unequal distribution of income, and unequal exposure to the negative ecological effects of economic activity[9] (Böhm et al., 2012). Irrespective of how applicable the market mechanisms are, there is no guarantee of avoiding further negative effects on the environment, or being consistent with sustainability.

Climate cooperation via an ETS at international level may occur in different ways. In a two-way ETS linkage, emissions transfers are mutually interchangeable and accepted for compliance purposes, with a full equalisation of prices. If country A is unable to easily curb emissions at lower cost, the alternative is to acquire additional units from country B, who finds it relatively cheaper to undertake extra abatement or to invest in new technologies for mitigation, and benefits by selling unused units. The financial flows would go from country A, the buyer of units, to B, which has invested in emissions abatement.

Both countries benefit from the linkage: from the cost savings of emission reductions to the potential funds generated to re-invest in more reductions. For developing countries, this climate finance is supposedly appealing in economic terms, in terms of providing a price signal for attracting investments in sustainable infrastructure (Studart and Gallagher, 2016) and promoting clean technology investments and economic efficiency (Farid et al., 2016; IETA, 2016). However, Gavard et al. (2011) show that a sectoral ETS linking may yield, instead, only moderate increases in the generation of low-carbon energy whereas a rise in electricity price can be observed, with a negative impact on welfare. Notwithstanding the increasing degree of acceptance from developing countries to participate in carbon markets set by developed countries, as reported by ICAP (2018b), Gavard et al. (2016) show that success is dependent on the allocation of permit revenues which can compensate potential negative effects.

In order to deliver the environmental and economic outcome envisaged by policymakers, the linked system has to be designed accordingly, thereby requiring some degree of harmonisation (Comendant and Taschini, 2014). One main recommendation in the literature is to negotiate the ETS design upfront so as to reconcile sufficient common features to ensure compatibility and prevent disruption of the linked system (Quemin and Perthuis, 2017; Tiche et al., 2016; Burtraw et al., 2012). Such negotiation is very difficult since design differentials reflect domestic preferences (Pizer and Yates, 2015). Instead of contributing to environmental efficiency and effectiveness, the lack of harmonisation may impair the objectives of international cooperation (Sterk et al., 2006). Therefore, overcoming the obstacles to guarantee the alignment of basic features, signals a move towards a greater level of cooperation.

[4] The idea of forming Climate Clubs tends to lure policymakers, due to the potential benefits provided by wider diversity strategies available such as scientific cooperation, trade partnership and alliances for enhancing innovation and climate initiatives. Further, it can involve different economic actors into a common cause, for example, countries, cities, companies and NGO's. The positive effect of joining a Climate Club in the context of the Paris Agreement in the first place is to support fulfilling the NDCs but it may originate a rebound effect of boosting ambition levels in the Club (La Rovere, 2016).

[5] In the context of climate mitigation targets, the term "accounting" refers to a framework that makes mitigation commitment and progress comparable, in order to evaluate achievability of targets (Prag et al., 2013). Thus, robust accounting quantifies properly the anthropogenic emissions changes according to the sources or removals by sinks as a result of mitigation actions by countries or other entities.

[6] The author argues that if the ETS is limited in scope, the effectiveness will also be limited. If targets are set to simply rationalise the achievement of already established goals, the ETS will not necessarily trigger a deep decarbonisation of the economy.

[7] In summary, the commodification concept is referred to as the institutional, symbolic and material changes through which a good or service that was not previously meant for sale gets into the market exchange arena (Bakker, 2005; Kallis et al., 2013).

[8] According to Lohmann (2006), inequalities are magnified by carbon pricing mechanisms. Firstly, by creating transferable rights to pollute and awarding them to large emitters can cause disproportional effects on small islands and coastal communities, particularly in developing and less affluent parts of the world. Further, the refusal to phase out fossil fuel energy tends to heighten anxiety and conflicts around the world.

[9] In this paper, we will not focus on this aspect specifically.

In this context, some elements may pose technical barriers for the cooperation to materialise, among them differences in the cap stringency, price management (or cost-containment)[10] measures, and the recognition of offsets[11] (Zetterberg, 2012). Cap and stringency requirements, including the method[12] on which the cap is based, depend on factors such as the economic and environmental profile, or level of development. In this sense, a well-functioning cooperation will also depend on how strategies are aligned to benefit participants, without disregarding such particularities.

In order to prevent economic and equity concerns related to the lack of stringency in the ETS design harmonisation, it is fundamental to consider cooperation partners with comparable ambitions, climate policies, and similar medium to long-term emissions trends (Green et al., 2014; Haites, 2014; Edenhofer et al., 2007). Since these elements reflect environmental ambition and aggregate goals for the integrated system, improper alignment or unequal decisions may interfere in the environmental effectiveness of the policy (Kachi et al., 2015; Burtraw et al., 2012).

In principle, scope, coverage and other differences in the design, such as the point of regulation and opt-in and opt-out provisions, do not seem to represent a technical barrier in order to take part in the climate cooperation. In fact, a completely equivalent sector in two independently-designed schemes is rather unlikely, because countries have differing emissions profiles and have to choose accordingly which sources to include (Baron and Bygrave, 2002; Metcalf and Weisbach, 2012). Thus, some caution is necessary for linking systems that differ in the sectors or gases included, especially because it may raise competitiveness concerns. This is an aspect which has to be carefully negotiated for developing countries aiming to design an ETS, and link it to existing developed-world programmes.

In line with that, choosing the right partner is also an important consideration on coordinated climate issues. Mostly, this decision is determined by geographic proximity,[13] legal compatibility, potential distributional effects, and the respective ETS elements, amongst other factors. However, for a developing country such as Brazil, a climate alliance would be appropriate if it promotes emissions mitigation simultaneously with economic considerations, in order to help technological development and transition towards a low carbon economy.

This paper considers cooperation between Brazil and Europe, predominantly due to their historical international trade relations, in which Europe plays an important role for Brazil. In addition, it reflects the willingness of the EU ETS to link with other compatible systems (i.e., that present the same basic environmental integrity, share the same emission unit and have a binding ETS nature based on an absolute cap on emissions). Since the EU ETS is the most developed and consolidated ETS system, a cooperation with Brazil could result in potential technical, economic and environmental benefits for both parties.

To date, the EU ETS has only agreed to integrate with the Swiss ETS, which has not yet been launched. Jotzo and Betz (2009) evaluate a plan to bilaterally integrate the proposed Australian ETS with the EU ETS, which was afterwards aborted in 2012. The impact of linking the EU ETS to the US system was evaluated in Chapman (2009), Zetterberg (2012) and Marschinski et al. (2012). The studies from Marschinski et al. (2012) and Hübler et al. (2014) investigate a proposal for integrating the EU ETS with a Chinese ETS. Similarly, Gavard et al. (2016) modelled a sectoral ETS on electricity and energy-intensive industries in the EU, the US and China, simulating autarky and linkage scenarios. Other potential linkages also explored in the literature are the EU ETS and South Korea integrated system. Some empirical evidences also consider a multi-region integrated ETS in which the EU ETS takes part (Xu et al., 2017; Anger and Böhringer, 2006; Dellink et al., 2014).

Economic and environmental opportunities from an international climate cooperation between a Brazilian ETS and the EU ETS, or a Brazilian ETS with other existing and emerging schemes, has not yet been explored. The Brazilian literature has so far mainly evaluated the stringency and achievability of pledges under international commitments on climate policy without international cooperation such as the study of Gurgel and Paltsev (2014) and Gurgel (2012), along with some modelling exercises of a Brazilian ETS regulating energy-intensive sectors (Domingues et al., 2014; Rathmann, 2012), and considering overall macroeconomic effects of carbon pricing at sectoral level (Wills and Lefevre, 2012). Results mainly suggest a negative impact of the domestic ETS on GDP and welfare, particularly if all sectors are regulated.

Due to the complexity associated with implementing a bilateral linkage as part of the climate architecture, addressing climate change requires cooperation whereby regulatory and market mechanisms are considered appropriately. Domestic use of carbon pricing instruments still faces political and economic opposition in Brazil, as well as in other emerging economies. However, international coordination can provide efficiency gains when compared to a sectoral or domestic ETS, along with significant emissions reductions that could compensate the sector-specific costs of an ETS, ultimately giving rise to political acceptability. Harmonisation may have the potential to avoid distributional effects and help to effectively provide environmental and economic benefits. The focus of this investigation is to understand whether a combined ETS between Brazil and Europe would, thus, satisfy the main objectives of the climate policy.

2.2. Macroeconomic profile and energy pattern before policy implementation

A climate policy should be appropriate for national circumstances, and economic specificities play a major role in influencing the capacity to mitigate, as well as overall performance. In this paper, the climate coordination is proposed among countries with different macroeconomic structure and size, as exhibited in Table 1. There is a substantial heterogeneity between both analysed regions. The economy of

[10] The price floor restricts the auction volume below a fixed price and the price ceiling sets a maximum allowance price. These elements are designed to control the range of allowance prices, which have implications on both linked schemes. Once those measures exist in one ETS it propagates to the other (Comendant and Taschini, 2014). If before the linkage, price management measures differ among the schemes, when the schemes are linked prices can also be affected. In both cases, some issues may arise from the supply side of the allowances, essentially regarding allowance prices which can be difficult to align as they reflect the political objectives and priorities of the ETS programmes (Burtraw et al., 2012).

[11] In the Kyoto Protocol, there were international credits (offsets) generated through promoting emission reduction projects outside the domestic economy – the Clean Development Mechanisms (CDM) or Joint Implementation (JI) projects. In an ETS cooperation, when schemes with differing offset provisions link existing offset credits in one ETS become available in the linking partner ETS, at least indirectly (Kachi et al., 2015). This occurs because offsets are treated as equivalent to allowances for compliance within the ETS. In light of this interchangeability, and without harmonisation of offsets rules, allowances that could have been sold to the no-offset system are liberated. Therefore, ICAP-PMR (2016) suggests robust rules for offsets to be aligned in order to harmonise the environmental integrity of units. Some caution is necessary to decide on the amount of offsets allowable for compliance purposes, the type of offset eligible, the stringency of standards and the potential for double counting. The EU ETS has so far permitted the use of offsets but it does not envisage the continuous use of this mechanism post-2020.

[12] If one cap is based on absolute emissions whereas the other is based on intensity, the policy objectives may be undermined. Hence, although it is not technically impossible, it is complex and likely to generate adverse economic, distributional and environmental effects (Kachi et al., 2015).

[13] Ranson and Stavins (2013) found evidence that geographic proximity is the most significant predictor for entering a linkage. The authors argue that linkages resemble trade agreements and similarly, "jurisdictions located near to each other may have similar environmental goals and economic conditions and may have a history of mutually beneficial engagement on other issues" (p.8).

Table 1
Macroeconomic and emissions statistics for Brazil and Europe (constant 2010 bi US$) in 2015.
Source: World Bank (2018).

	Brazil	Europe
GDP per capita	11352	35226
GDP	2338	17955
Final consumption expenditure	1923	13723
Total CO2 emissions (Mt of CO2)	451	3201
Carbon intensity	0.19	0.18

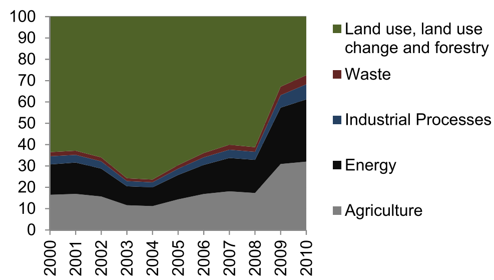


Fig. 1. CO2e* Emissions share (%) by sector in Brazil. * In terms of Global Warming Potential (GWP) values of 1995.
Source: MCTI (2018).

Europe is stronger, being of course, a wealthier region with a higher GDP per capita and level of consumption. Although the carbon intensity is very similar, it is lower for Europe. Whilst emissions from Brazil totalled 451 million tonnes of CO2, Europe emitted 3201 million tonnes of CO2 in 2015.

The energy use pattern is closely related to the emissions profile. Over the last decade, land use, land use change and forestry (LULUCF) emissions have been the major source of emissions in Brazil, as depicted in Fig. 1.[14] More recently, there has been a redirection of emissions composition, where emissions from agriculture (32%) and energy (29%) have gained momentum. Fig. 2 shows that a significant share of total emissions accrue from energy and transport in Europe, with 56% and 22% respectively. Industrial processes contribute with 9% of the European, and 7% of the Brazilian total emissions.

The greatest difference between both regions is related to electricity generation. Compared to other regions, Brazil has a unique electricity sector, which is considered to be significantly decarbonised. According to Fig. 3, 77% of total electricity production in Brazil is low carbon, with hydro being the predominant source. The energy mix in Europe is relatively diversified, but alternative technologies predominate with 57%. The majority of electricity is produced from nuclear (27%) and coal (26%). In 2015, industry consumed 40% of electricity production in Brazil and 36% in Europe. As observed in Fig. 4, the final consumption of renewable energy from industry is greater in Brazil with 74% compared to 32% in Europe (IEA, 2018).

Of particular note is the distinct scale of energy consumption from industry in Brazil and Europe, as well as the composition. From Fig. 4, for example, biofuels represent 42%, and electricity 22%, of industrial energy consumption in Brazil, whilst electricity and natural gas are the major sources of energy used in industry in Europe, with 34% and 31%, respectively.

At the same time, the economic activity of energy-intensive sectors in Europe is greater than in Brazil, with an output value (at basic prices)

[14] There are differences in terms of the methodology for grouping the emissions sources in each region. For example, in the Brazilian case emissions from transport are included in the energy sector whereas in Europe it is displayed as a separate sector. Thus, the figures are included for illustrative purposes only, which highlight differences in the GHG emissions patterns between the regions.

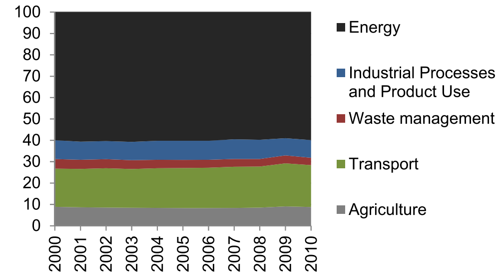


Fig. 2. CO2e* Emissions share (%) by sector in Europe. * In terms of GWP values of 1995.
Source: EEA (2018).

of US$0.5 trillion. This is approximately five times less than European energy-intensive sectors, whose output value is US$2.6 trillion (WIOD, 2018). However, Table 2 reveals that the share of some EINT sectors of Brazil as a percentage of GDP is slightly greater than those of Europe. This is the case for mineral products, being responsible for 1.9% of Brazilian GDP compared to 0.4% in Europe. Table 3 also shows greater carbon intensity for the majority of energy-intensive industries in Brazil, with ferrous metals and metal products being the exception. This is due to the relatively higher consumption of coal and oil in several Brazilian industries compared to Europe. On the other hand, the production of metal products in Europe is more important to domestic output than in Brazil. Overall, the greatest difference in carbon intensity is in non-ferrous metals, which is 46 times lower for Europe compared to Brazil.

Hence, two aspects need to be highlighted. The first is that differences between the energy mix of Brazil and Europe are significant. With an already significantly decarbonised electricity sector, further reduction of emissions from the electricity sector in Brazil will be costly. Thus, there are potentially more alternatives for substituting fossil fuel-based energy sources with low-carbon sources in the electricity sector in Europe. From the energy-intensive sector perspective, the relevance for national economic activity is very similar between both regions, but the scale and sources of energy consumed in the production processes vary.

For modelling purposes, emissions related to LULUCF are disregarded, even though they are significant in Brazil. The primary reason for this approach was to mimic the EU ETS sectoral coverage. Additionally, controlling LULUCF emissions in this modelling exercise would automatically mean that this sector would take the majority of the burden to reduce emissions, thereby preventing other sectors (specifically the EINT and ELEC sectors) from broadening their mitigation effort to comply with national climate targets. In fact, the ETS coverage in most of the active systems has comprised a reduced number of sectors with large emitters of CO_2, typically the power and energy-intensive sectors, where Measurement, Report and Verification (MRV) are more accurate and easier to implement.

3. Methodology

For modelling the cooperative approach of a bilateral link between the EU ETS and a hypothetical Brazilian ETS we use the Economic Projection and Policy Analysis (EPPA) model in its most recent version - EPPA6[15] (Chen et al., 2015). This is a computable general equilibrium model (CGE) developed by the MIT Joint Program on the Science and Policy of Global Change. EPPA6 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

[15] Free public version is available at: https://globalchange.mit.edu/research/research-tools/human-system-model/download.

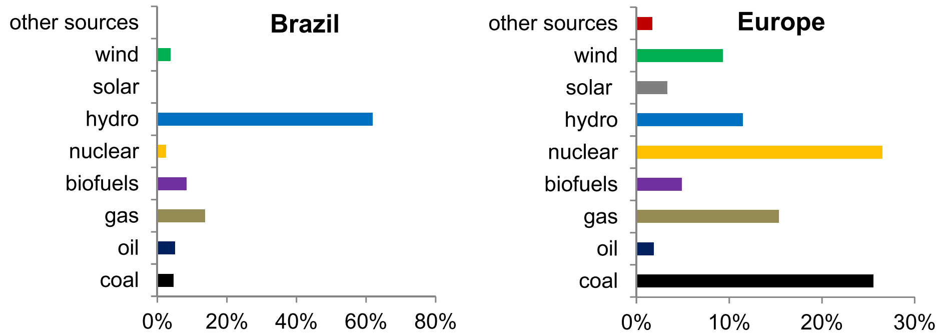


Fig. 3. Total electricity production by fuel (%) in 2015.
Source: IEA (2018).

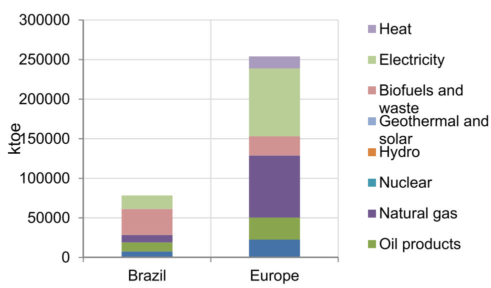


Fig. 4. Final energy consumption from industry in 2015.
Source: IEA (2018).

Table 2
Output share (% of GDP) of EINT sectors in 2010.
Source: WIOD (2018).

	Brazil	Europe
Total, of which	8.7%	7.1%
mineral products	1.9%	0.4%
paper products - publishing	1.2%	1.1%
chemical products	2.2%	1.9%
rubber and plastic products	0.7%	0.7%
other non-metallic mineral	0.7%	0.6%
metal products	2.1%	2.4%

Table 3
Carbon intensity of EINT sectors in 2011 (t CO_2/MUS$).
Source: GTAP9 database.

	Brazil	Europe
mineral products	890.2	230.2
paper products - publishing	92.5	27.0
chemical, rubber and plastic products	101.2	59.6
ferrous metals	197.7	250.1
non-ferrous metals	1703.3	36.8
metal products	5.7	9.2

Equilibrium) algorithm developed by Rutherford (1999).

This version is based on the social accounting matrixes from the Global Trade Analysis Project Version 8 (GTAP 8) database, with a benchmark year of 2007 (Narayanan et al., n.d.). The level of aggregation is presented in Table 4 and includes developed and developing regions. The data is aggregated into 18 regions, 14 sectors and 14 "backstop" technologies[16] for generating energy, including renewable technologies such as wind and solar generation. Additional data sources on energy use and energy consumption (IEA, 2012), CO_2 emissions[17] related to cement production (Boden et al., 2010) and CO_2 emissions related to land use change (Riahi et al., n.d.) are also used.

The model considers a long run simulation horizon, being solved at 5 yearly intervals. EPPA6 enables projecting scenarios of world economic development and emissions trends. It also projects the economic impact of proposed mitigation and energy policies, welfare and equity measures. It was adopted in this policy analysis because it is an adequate tool to indicate the economic and environmental effects of the policy assumptions regarding the Brazilian ETS design, the EU ETS and thereafter, the international cooperation framework in the period 2020–2030.

As a multi-region and multi-sector CGE model, EPPA6 provides a detailed representation of production and consumption of various sectors in each region, with corresponding greenhouse gas emissions (GHG). It also includes explicit treatment of inter-industry interactions and keeps track of bilateral trade in all goods. EPPA6 is a dynamic recursive model, i.e. it is solved for a sequence of global market equilibrium considering "myopic" expectations of economic actors,[18] that provides a representation of the global economy (Chen et al., 2015), which includes the regions investigated here (European Union and Brazil).

There are production functions for all sectors describing the use of primary factors (capital, labour, and natural resources), energy and intermediate inputs for producing goods and services in each of these periods. The level of consumption is modelled through a representative agent[19] that seeks to maximise utility by choosing how to allocate its income with respect to the utilisation of goods and services (Gurgel and Paltsev, 2014). The level of production of each economic sector results from the choice among primary factors and intermediate inputs in order to maximise profits, given the available technology and market prices. Statically, all markets reach a simultaneous equilibrium when zero-profit, market-clearing and income balance conditions are satisfied. Dynamically, EPPA6 is exogenously specified[20] and endogenously determined.

[16] These technologies consist of new or alternative energy technologies.

[17] Other non-CO_2 GHG emissions and urban pollutant emissions are accounted for in EPPA6 from the EDGAR database Version 4.2 ((European Commission, 2011), including: methane (CH4), perfluorocarbon (PFC), sulfur hexafluoride (SF6), and hydrofluorocarbon (HFC).

[18] The assumption of myopic expectation 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).

[19] EPPA6 accounts for three economic agents: consumers (households), producers and government.

[20] Referred to Chen et al. (2015), exogenous factors are GDP projections for BAU growth, labour endowment growth, factor-augmented productivity growth, autonomous energy efficiency improvement (AEEI), and natural resource assets.

Table 4
Regions, sectors and backstop technologies in EPPA6.
Source: Based on Chen et al. (2015).

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

[a] The European Union (EU-27) plus Croatia, Norway, Switzerland, Iceland and Liechtenstein.
[b] Energy-intensive industries in EPPA6 consist of those producing paper products, chemicals, mineral products, ferrous metals, metal products and cement.

4. Evidence of the cooperative approach applied to Brazil and Europe

4.1. Climate policy scenarios

There are several options for specifying climate and energy policy in EPPA6. The model is able to represent emissions constraints, carbon taxes, energy taxes and technology regulations for specific gases, sectors and regions of the world. For instance, imposing emissions constraints on one region under the existing model functionality implies determining if permits are: i) not tradable across sectors or regions (resulting in sector-specific permit prices in the region), ii) tradable across sectors within regions but not across regions, which results in region-specific permit prices, or iii) tradable across sectors and regions, generating an international permit price.

In this policy analysis, the assumption is that cooperation occurs in the form of an ETS linkage between Brazil and Europe to help achieve their NDC pledges under the Paris Agreement. Aiming at a greater level of climate coordination with the European system – the EU ETS, we incorporate some of its design elements into the proposed Brazilian ETS and harmonise the sectoral coverage.

In addition, restrictions on emissions representing the regulation stringency were imposed in absolute terms, to align as closely as possible with the EU ETS, but only CO_2 emissions are subject to the cap. To capture this multilateral and sectoral framework, EPPA6 has been extended to allow trade between sector-specific permits at international level. This means that permits of the Brazilian electricity and energy intensive sectors are tradable with the EU ETS permits, and vice versa, equalising permit prices across the two systems.

The Brazilian commitment to reduce emissions by 37% and 43% by 2025 and 2030 respectively is applied to both regulated ETS and non-ETS sectors.[21] This is important to minimise the occurrence of carbon leakage between sectors, with is beyond the scope of this paper to evaluate. The only disregarded sector in the mitigation applied target is land use change and deforestation. According to a study of Ferreira Filho and Horridge (2017), in order to meet Brazilian Paris' commitments additional efforts to reduce energy emissions are required in addition to the major compromise to eliminate illegal deforestation.

The ETS sectors are assumed to be allocating tradable allowances between the two covered sectors, while the remaining non-ETS sectors are regulated via other domestic abatement measures. We impose a sectoral specific carbon tax to mimic these abatement measures. The tax is set in order to induce each sector to cut emissions by the same national percentage target. We recognise this approach will lead to less cost effective abatement options at national level, but we believe it 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 in to an ETS system.

All other regions of the model choose domestic policies based on the same arrangements, in which there is an ETS covering emissions from the ELEC and EINT sectors, and other supplementary climate and energy policies for non-ETS sectors. These constraints on CO_2 are also in line with their pledges under the Paris Agreement (Table 5), and the sectoral ETS and non-ETS sector's cap match in all scenarios. The only exception regarding the emissions cap is Europe, where instead of using the NDC commitments, we opt to apply the already specified EU ETS emission reduction target of 21% and 43% from 2021 to 2030.[22] The majority of regions committed to a level of mitigation based on BAU emissions, apart from China and India which based their targets on GDP intensity.

[21] The Brazilian NDC has defined only the target for the whole economy. The distribution of the target among the different sectors is yet to be specified. In the absence of a sectoral definition in the Brazilian NDC, we opted to assume the same target for all economic sectors, including the ETS sectors.

[22] The European Union has committed to cut at least 40% GHG emissions from 1990 levels by 2030, where ETS sectors would have to reduce emissions by 43% and non-ETS by 30% compared to 2005 levels respectively. In our simulations, and due to modelling limitations, emissions reductions from BAU in 2030 correspond to a reduction of approximately 55% from 1990 levels. In other words, the target captures, in a similar and slightly more ambitious manner, the mitigation effort committed by the EU in the NDC. Imposing the carbon constraint in relation to BAU projections still makes the EU more restrictive in terms of emissions compared to other regions of the world, therefore it does not alter the direction of the results. For other regions in the model the base year varies due to lack of data, particularly in the case of regions composed by a group of countries. Since each Party decided the targets individually, we opted to standardise and use BAU projections as a reference. Where possible, we used data from EPPA6 for 2007 levels. In general, the NDC specify national targets so it made sense to assume that national targets and ETS targets are similar, which for modelling purposes are equal. In short, thus, all regions in the model follow the same framework as the one applied to Brazil and Europe (constraint on ETS and non-ETS sectors) supposing (optimistically) that measures to address climate change and comply with the NDC targets will be implemented everywhere.

Table 5
Emission reduction targets relative to BAU for the regions in the modelling exercise.
Source: Based on UNFCCC Data (2015).

Region	2020	2025	2030
AFR	34%	38%	42%
ANZ	24%	26%	28%
ASI	15%	17%	20%
BRA	18%	37%	43%
CAN	20%	25%	30%
CHI	45%	50%	60%
EUR	21%	32%	43%
IDZ	26%	23%	29%
IND	25%	30%	35%
JPN	20%	23%	26%
KOR	30%	33%	37%
LAM	5%	10%	15%
MES	5%	8%	10%
MEX	30%	35%	40%
REA	5%	7%	10%
ROE	15%	20%	25%
RUS	25%	27.5%	30%
USA	17%	28%	38%

To estimate the economic and environmental implications of adopting the cooperative approach in the period 2020–2030, we distinguish three policy scenarios, as well as the business as usual (BAU) or reference scenario, where there is no mitigation policy. The NATIONAL scenario implements a domestic sectoral ETS climate policy in all regions without setting up an international cooperation to allow carbon trading. The COOPERATION scenario is identical to the NATIONAL scenario and additionally allows a sectoral ETS linkage between EU and Brazil. Finally, the GLOBAL scenario considers an international market mechanism regulating the ELEC and EINT sectors for cooperation among all regions of the model (previously described in Table 3), which is based on the same design features in order to minimise carbon leakage, not evaluated in this paper.[23] Despite being a very unlikely scenario at least in the short term, the GLOBAL scenario provides some understanding of the potential effectiveness of global international cooperation to address climate change using market mechanisms, compared to bilateral or multilateral cooperation agreements.

4.2. Results and discussion

Results from the policy simulations show that in addition to the abatement efforts from other economic sectors, introducing a market for pricing the carbon content associated with energy and industrial production changes the total level of emissions in Brazil and Europe, depending on the type and level of cooperation.

The emissions reduction path of all three policy scenarios are presented in Fig. 5. Simulations show virtually no impact for Europe of linking with Brazil, which is due to the large size of the EU ETS compared to the Brazilian ETS. For Brazil, a cooperative approach implies greater emissions reductions than the domestic ETS in 2020 and the opposite effect from 2025 onwards. In this case, mitigation efforts are reallocated to Europe which sells permits to Brazil. This trading pattern results from the relatively stringent carbon constraint applied to Brazil, the exclusion of LULUCF emissions and because of the already low-carbon energy mix in the region. If, conversely, LULUCF emissions were subject to the carbon constraint, it would imply lower efforts and costs on ETS and non-ETS sectors to mitigate emissions. Due to existing mitigation opportunities available in the LULUCF sector, its inclusion in the ETS system, via offsets for example, could stimulate Brazil to further abate and export permits to Europe.

[23] Carbon constraints are placed on every region and the cost of producing energy intensive goods increases for all. Some leakage could still occur due to the effects of other features in EPPA (Paltsev et al., 2007).

The level of mitigation in the GLOBAL scenario is the lowest in both Brazil and EU among the climate strategies analysed. By accepting to join a global sectoral ETS scheme, Brazil and the EU become net importers of allowances from the rest of the world. For both jurisdictions, mitigation in the GLOBAL scenario is lower because abatement efforts are reallocated across all global regions, as there are more cost effective mitigation opportunities available worldwide. This is particularly the case in Russia, Canada, India and China, where abatement effort is more significant according to modelling results.

According to the simulation, together the ELEC and EINT sectors contribute to approximately 35% of the Brazilian total CO_2 emissions over the period in the NATIONAL and COOPERATION scenarios. From the European total CO_2 emissions perspective, the ETS emissions share diminishes from 48% to 45% over the period with a domestic or cooperative climate policy. If a global policy is applied, ETS emissions increase in both Brazil and Europe, accounting for 47% and 56% of total CO_2 emissions in 2030, respectively. The ELEC and EINT sectors in Europe are more fossil fuel-intensive than in Brazil which has an electricity mix predominantly generated from hydroelectricity, considered to be a low-carbon source of energy.

Fig. 6 presents the emissions reductions achieved in those sectors relative to the BAU scenario in Brazil. Results indicate a greater effort to cut emissions on the ETS sectors under a national policy, given the level of stringency of the climate policy applied. However, under a bilateral cooperation with Europe or a global agreement, Brazil would prefer to buy allowances due to its relatively stringent mitigation target in comparison to the average pledges of the rest of the world, as shown in Table 5.

In Brazil, the ELEC sector under the National scenario shows significant progress to decarbonisation when compared with the BAU scenario in 2030. Simultaneously, EINT emissions also decrease in the same period in Brazil for the National scenario. However, there appears to be further potential to decrease emissions in the EINT sector. This may be as a consequence of higher mitigation costs facing energy-intensive industries that have less carbon abatement options or technological alternatives to substitute fossil fuel-based energy sources with renewable energy. This is an area which warrants further investigation, being outside the scope of the current research.

The effect of the modelled EU ETS on the ELEC and EINT sectors is depicted in Fig. 7. In terms of the role of each sector in the ETS, the National scenario shows a significant decrease in emissions from the ELEC sector and a slight decrease in emissions from the EINT sector, when compared to the BAU scenario in 2030. Here, if Europe agrees to cooperate with Brazil by linking their systems instead of pursuing domestic policies, the level of abatement for the ELEC and EINT sectors in both circumstances remains very similar. This reflects the size of the ETS market for allowances in the COOPERATION scenario, which is still limited relative to the EU scenario. This occurs because Brazil has a smaller ETS market with limited ability to trade allowances.

However, under a global ETS system, the EU can find cheaper allowances in the international market, since there are more mitigation opportunities available worldwide in the ELEC and EINT sectors, and EU mitigation targets are stronger than in other regions. Interestingly, regardless of the policy scenario, effective reductions are primarily derived from the ELEC sector.

One of the primary effects of regulating carbon emissions is to control energy sources. Fig. 8a exhibits the modelling results for energy use as a proxy for measuring energy substitution or technological improvements induced by the climate policy. According to it, in comparison to BAU, use of coal, gas and oil in Brazil declines more if only a domestic sectoral ETS is applied. However, the COOPERATION scenario is still a better strategy than a global international cooperation with respect to driving changes in fossil fuel-based energy sources towards renewables.

Among alternative sources of energy in Fig. 8b, hydro and bioenergy play a major role in the Brazilian economy in all scenarios for 2030.

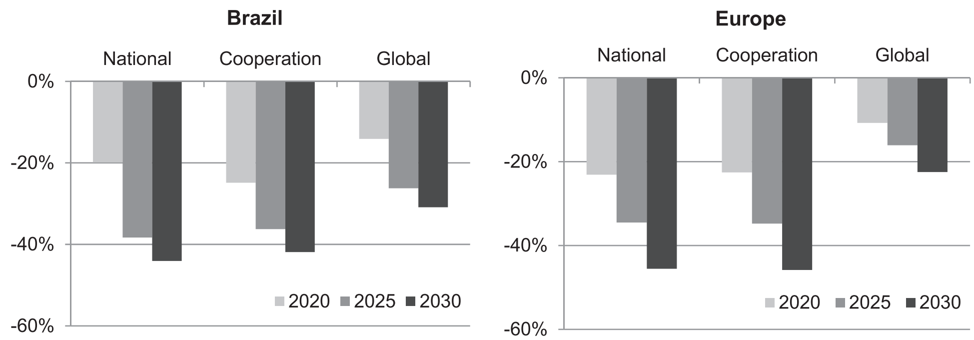


Fig. 5. Total* CO_2 emission reduction from BAU under alternative scenarios. * Excluded emissions from land use change.

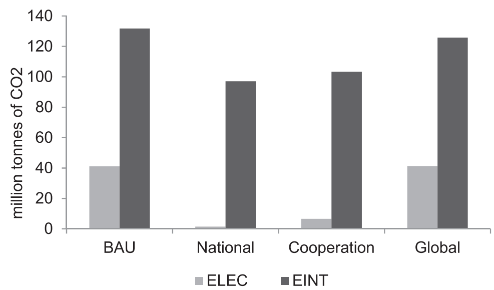


Fig. 6. CO_2 emissions from ELEC and EINT sectors in Brazil in 2030.

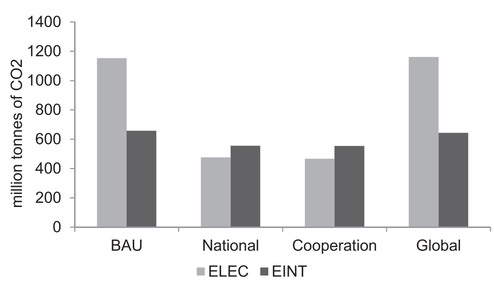


Fig. 7. CO_2 emissions from ELEC and EINT sectors in Europe in 2030.

There is a slight increase in nuclear in the COOPERATION scenario (6%), with a more pronounced increase in bioenergy (31%) and hydro (13%). Whilst wind and solar represent less than 1 EJ, the policy results in an increase in their use. The substitution effect towards less fossil-fuel based energy is best realised when a domestic ETS takes place, since mitigation efforts are more costly for Brazil in the cooperation scenario as it buys allowances from the EU during the period.

Whilst oil consumption predominates in Brazil, being correlated to use in the transport sector, Europe displays a more balanced energy use structure. In Fig. 9a, a visible effect of Europe continuing to rely on market instruments to pursue the proposed emission reduction target is a decrease in the use of coal (57%), gas (25%) and oil (40%) if a domestic ETS or linkage with Brazil is implemented. In this context, both NATIONAL and COOPERATION scenarios induce greater reductions on energy derived from fossil fuel sources. A coordinated ETS between Brazil and Europe curbs more fossil fuels relative to the NATIONAL scenario, while the GLOBAL scenario allows the EU to keep using more fossil fuels and develop less alternative energy than the other two mitigation scenarios.

Investing in renewable energy has become essential to the European energy sovereignty, as described in the climate energy policy package. Our results in Fig. 9b demonstrate that nuclear tends to be used more than the other low-carbon energy sources regardless of the strategy adopted, with approximately 10 EJ. Even though bioenergy and wind and solar still account for a small percentage relative to nuclear, with a share of 24% and 16% respectively, they best respond to the climate policy. However, the energy-related substitution effect is very similar in both the NATIONAL and COOPERATION scenarios. This suggests that the EU can drive some changes in the economic system to aggregate low carbon energy technologies over time, with potential for promoting the energy innovation required and thus, securing energy savings.

Mitigation policies directly affect domestic production levels to the extent that carbon pricing increases overall abatement costs for regulated sectors, which decrease energy use to avoid the additional cost. Fig. 10 shows the permit price resulting from the sectoral ETS implemented under the three different conditions for achieving the Paris commitments of Brazil and Europe. The ex-ante carbon price is more expensive in Brazil than in Europe from 2020 to 2030. In Brazil, it amounts to approximately US$69 in 2020 and reaches US$204 per tonne of CO_2 in 2030 whereas the EU ETS carbon price varies from US $100 to US$165 per tonne of CO_2 in the period.

With the equalisation of CO_2 prices in the COOPERATION scenario, the CO_2 value is cheaper than adopting a domestic ETS in Brazil only from 2025 to 2030. In this period, the carbon price under the cooperation agreement represents for Europe a very slight cost increase per tonne of CO_2 emitted by the ELEC and EINT sectors. Abatement costs in the GLOBAL scenario are less expensive with a price that ranges from US$ 22 in 2020 to US$ 45 in 2030.

A major concern arises from the carbon price harmonisation,

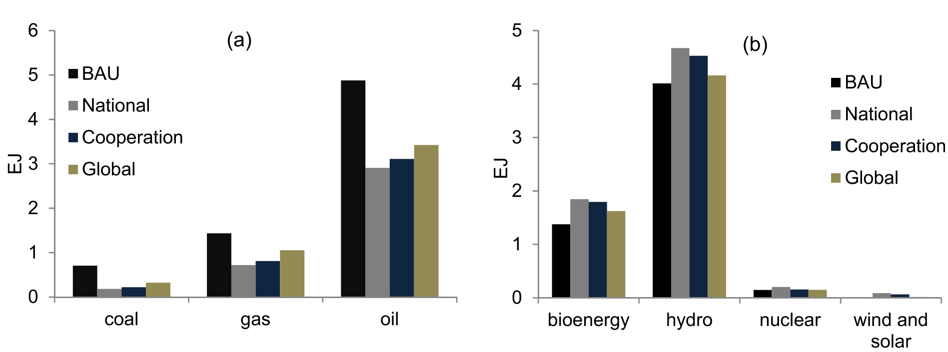


Fig. 8. Primary energy from fossil fuels (panel a) and alternative sources (panel b) in Brazil in 2030.

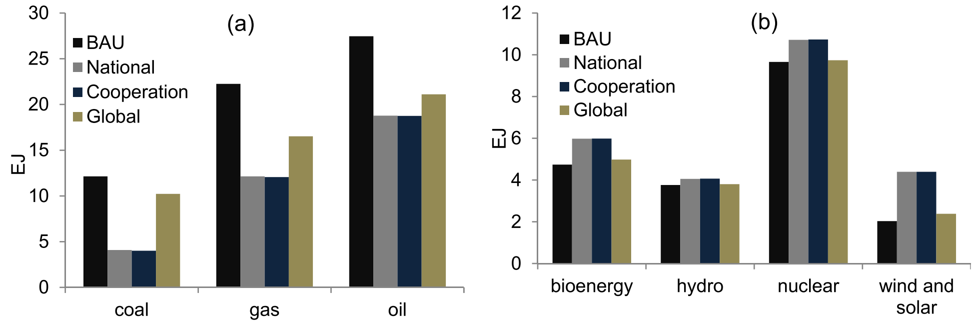


Fig. 9. Primary energy from fossil fuels (panel a) and alternative sources (panel b) in Europe in 2030.

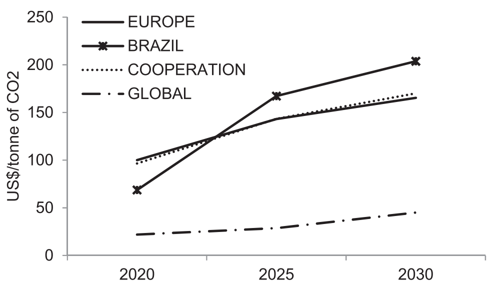


Fig. 10. Carbon prices (US$ per tonne CO_2).

particularly due to carbon price changes in the coordinated system. In view of potential competitive pressure to pass on the carbon content costs to final products, equity issues across firms, jurisdictions and income groups may emerge, affecting even those that do not participate directly in the trading.

Our investigation shows that there are more abatement opportunities in regulated sectors of Europe, where mitigation efforts create ITMOs or emissions permits, which are exported to Brazil. In the presence of a decarbonised energy mix, results demonstrate that Brazil would engage in the cooperation as a seller only if it adopts a less stringent cap, as in 2020. Considering a national or coordinated ETS policy, the similar prices in the EU and Brazil in 2020 reflect the lack of opportunities to trade allowances. It means that mitigation options in the ELEC and EINT sectors, at the targeted level of emissions, result in similar abatement costs in both regions in the short term.

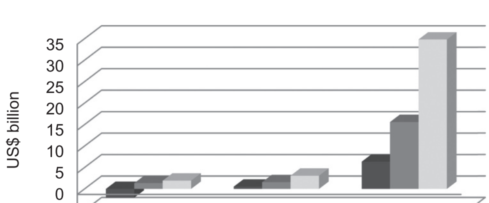
Fig. 11 shows the revenue generated by trading permits, both in the bilateral and global cooperation. In the COOPERATION scenario, the revenue indicates the amount paid by Brazil to Europe to purchase ITMOs. Considering an exchange via auctioning, the bilateral cooperation generates US$2 billion additional income for Brazil from selling permits to Europe in 2020. In contrast, there is a financial flow from Brazil to Europe of approximately US$1.3 billion and US$1.9 billion in 2025 and 2030, respectively. In a global agreement both Europe and Brazil are importers of ITMOs. The costs of implementing an ETS and a climate cooperation is lower and the financial trading flow from Brazil decreases, as noted in the GLOBAL-BRA scenario.

On the other hand, Europe becomes a buyer of allowances in the global market over the period. The trade of ITMOs from global partners to Europe accounts for US$6.3, US$ 15.6 and US$34.8 billion in 2020, 2025, and 2030, respectively. These findings demonstrate a reallocation of emissions among participants of the linked system: from Brazil to Europe along the period and from the rest of the world to both regions in the global cooperation. Under the modelled circumstances, such trading patterns define buyers and sellers in the link, which is a result of the level of ambition applied. From the economic perspective, distributive issues may arise, not just from the method of allocating allowances, i.e. via auctioning, but also in view of the overall increase in electricity prices induced by the ETS policy. As indicated in Fig. 12, regardless of cooperating with Brazil or not, changes in electricity prices are nearly the same in Europe.

By using EPPA6, we could not measure benefits from avoiding climate change but only the cost-effectiveness of climate policies. The overall cost of international market mechanisms to the economy are evaluated by changes in GDP depicted in Table 6. The economic costs vary negatively in all policy scenarios. International market mechanisms under the Paris Agreement in our analysis induce higher GDP losses in Brazil relative to baseline projections, than in Europe, especially in the long term. In fact, this effect on GDP occurs because non-ETS sectors are also subject to the NDC target. Therefore, it suggests that, by implementing this climate policy focused on energy use, Brazil is not seizing other possible mitigation opportunities, such as reducing deforestation and other Greenhouse Gases (GHG) which may be cheaper than curbing emissions only in production sectors.

The costs of mitigation are slightly alleviated within a bilateral or global cooperation via ETS in comparison to a national policy. However, the more stringent the cap, the more difficult it is to reduce emissions and therefore, negative impacts on GDP increase. For Brazil, these losses account for approximately US$106, US$100, US$85 billion in the NATIONAL, COOPERATION, and GLOBAL scenarios in 2030.

Compared to the effects on GDP in Europe, this could be a very costly climate policy for a developing country. In fact, the sectoral specific carbon taxes represented in other sectors also prevent them from trading allowances among them and find less costly mitigation options. As emissions from deforestation are not taken into account, the



	Cooperation	Global - BRA	Global - EUR
2020	-2.0	0.5	6.3
2025	1.3	1.6	15.6
2030	1.9	3.1	34.8

Fig. 11. Revenue generated from trading ITMO (in 2007 US$ billion).

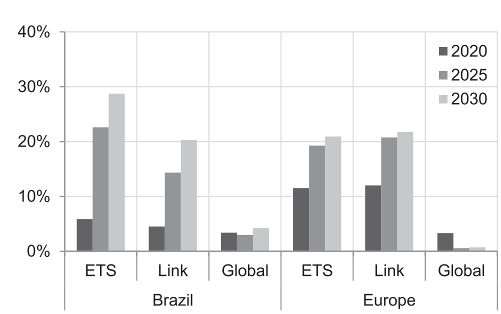


Fig. 12. Changes in electricity prices from BAU scenario.

Table 6
Changes in GDP from the BAU scenario.

Year	*National*		*Cooperation*		*Global*	
	BRA	EU	BRA	EU	BRA	EU
2020	− 2.0%	− 0.7%	− 2.4%	− 0.6%	− 1.6%	0.1%
2025	− 3.6%	− 1.2%	− 3.4%	− 1.1%	− 2.8%	− 0.1%
2030	− 4.2%	− 1.7%	− 4.0%	− 1.7%	− 3.4%	− 0.4%

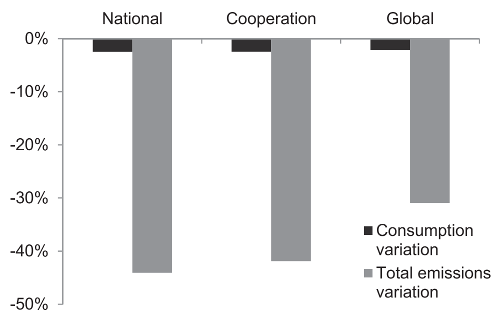


Fig. 13. Changes in consumption and total* CO_2 emissions level relative to BAU – Brazil. *Excluded emissions from land use change.

burden from implementing the climate policy package seems high in the long term. In this context, GDP changes represented here could be used as an indicator to compare future alternative ETS scenarios, which may be more politically acceptable.

The associated consumption variation relative to BAU in comparison to changes in the total CO_2 emissions level of Brazil is indicated below in Fig. 13. We note that the more emissions reductions over time, the more consumption levels in Brazil are impacted. Nevertheless, negative effects on consumption are very similar in all scenarios, ranging from 1.4% to 2.5% between 2020 and 2030. This indicates that setting up a sectoral ETS would negatively impact consumption levels due to increased costs of goods available for consumers, but at a moderate level. Thus, it would be outweighed by environmental gains from reducing domestic aggregate emissions. Since Brazil is a developing country and improvements on many aspects are necessary, including the access to consumption to households, reduced negative impacts on consumption from the climate policy are fundamental, particularly to diminish potential distributional effects. Differences in consumption and emissions among scenarios confirm that the greater the mitigation levels the more significant the potential distributive effects might be.

Likewise, the decline in consumption levels of Europe is very small in all scenarios, as depicted in Fig. 14. Also, it shows that to the extent with which the emissions reductions increase, NATIONAL and COOPERATION scenarios reveal the same impact on consumption, with a similar trend under a global agreement, varying negatively from 0.2% to 2.3%.

In fact, this analysis presents some important contribution to discussions on the relevance of establishing international cooperation through market mechanisms to collectively mitigate emissions. Firstly, it empirically corroborates with the literature demonstrating that the market design strongly influences the economic and environmental effects of the international cooperation approach we modelled. As such, accommodating a developing country into a linked-system of similar rigid commitments to a developed-country, and under a harmonised sectoral coverage, may have negative implications. Hence, this proposal could be politically difficult to support in those countries.

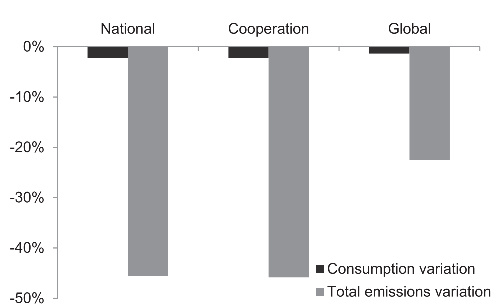


Fig. 14. Changes in consumption and total* CO_2 emissions level relative to BAU in Europe in 2030. *Excluded emissions from land use change.

For comparability issues and to prevent concerns over competitiveness or emissions leakage, the hypothetical Brazilian ETS encompasses the same sectors as the EU ETS, and also faces a mitigation target as stringent as the EU's. From an environmental perspective,[24] this ETS scope allows sectoral reductions to be achieved in Brazil mostly through substantial reductions in the ELEC sector, while the EINT sector continued to emit at practically the same level. However, total CO_2 emissions are effectively reduced, particularly in the NATIONAL and COOPERATION scenarios resulting from the binding national emissions target. Notably, Brazilian commitments under the Paris Agreement seem ambitious as the economic impacts of the ETS are greater than in the EU.

It should be noted that, in environmental terms, both domestic and bilateral ETS schemes can be considered for mitigating sectoral emissions in Brazil and Europe, despite corresponding costs. Also, a transformative shift away from the use of fossil fuels based on energy sustainability through increasing renewable energy use is better incentivised by a coordinated bilateral climate policy among them. Furthermore, results of the GLOBAL scenario suggest less reduction in emissions and fossil fuel-based sources over the years in Europe and Brazil. This occurs because other regions are also being regulated according to their binding targets. Therefore, Brazil and Europe can obtain cheaper permits abroad where abatement has lower costs than nationally or in an exclusively bilateral cooperation.

Moreover, this investigation suggests that a bilateral cooperation between Brazil and Europe would be more cost-effective to Brazil than to Europe since abatement costs are reduced when the Brazilian ETS links with the EU ETS. What ultimately makes the climate policy costly for Brazil is the sectoral ETS cap being defined with a similar level of ambition as the EU ETS cap since it increases the policy costs for the region which has relatively less carbon-intensive regulated sectors than Europe. Hence, as the stringency of the cap increases over the period, these effects tend to intensify.

Therefore, if a shared cap ambition is a prerequisite for a link, as recommended by the literature, Brazil would likely opt away from participating in a coordinated scheme. To agree on the coordination, results indicate the need to make modifications such as a less ambitious cap for the Brazilian ETS, a more comprehensive sectoral coverage and a longer-term time horizon. As a poorly designed system may lead to inefficiencies and cancel out mitigation, these could perhaps enable greater cost-effectiveness.

On one hand, integrating an international system with Europe may have potential for Brazil as it provides an opportunity to play a pioneering role on climate issues. From this prospect of linkage, other developing countries may equally choose to participate into an international agreement. Furthermore, given that the EU ETS is an established system would help overcome technical issues with respect to ETS implementation and integration with Brazil.

On the other hand, according to our analysis there are no significant advantages or disadvantages for Europe integrating a system with Brazil, which does not strongly benefit from the cooperation. This fact

[24] For environmental effectiveness, uniform monitoring, reporting, and verification requirements are necessary for permitting a comparison of the targets. Further, double counting of ITMOs has to be prevented as it risks accurate emissions reductions thereby compromising a successful linkage.

sheds light to the potential implications of choosing an unsuitable trading partner, since Brazil cannot contribute significantly on the environmental and economic responses required under the coordinated approach. From this perspective, a coordinated ETS between a developing and developed region, where the composition of the energy matrices differs does not appear the most recommendable.

Considering the modelled framework, the cooperation could revert the expected role developing regions are expected to play in a joint ETS with developed regions. In our simulations it means that associated gains from trading occur mostly in Europe due to the flow of ITMOs to Brazil. Therefore, another possibility would be to consider alternative alliances, for both Brazil and Europe, where partners are more closely aligned from a geographical, economic, political and energy profile perspective.

5. Concluding remarks

Using a dynamic-recursive computable general equilibrium model, the EPPA6, this policy research paper has quantitatively evaluated the main economic and environmental implications of a two-way ETS between Brazil and Europe. We distinguish three policy scenarios: a national ETS policy, a bilateral cooperation, and a global cooperation. We also model the business as usual (BAU) or reference scenario.

Europe has envisaged linking to non-EU emerging trading systems in the future to strengthen the EU ETS, as has been assigned in the "Linking Directive" (Directive 2004/101/EC). Since Brazil is still discussing the implementation of carbon pricing mechanisms (World Bank and Ecofys and Vivid Economics, 2017), we made assumptions on the proposed Brazilian ETS design features in line with the EU ETS characteristics, as it is the most consolidated system in the world.

Even though the energy mix and economic profile differ between Brazil and Europe, linking the EU ETS and the proposed Brazilian ETS can promote mitigation, whilst curbing emissions and triggering a change in energy use patterns. At the same time, the benefits of linking are modest, albeit it involves additional income from the trading of allowances for Europe. Similarly, the costs for meeting the climate obligations through trading are significant, at US\$143/t CO_2 in 2030. Such a price could provide a meaningful signal to drive deep decarbonisation. Nevertheless, to date carbon prices have remained persistently low in the EU ETS since it was launched, roughly hovering between €4 and €10 euros during the current third trading phase. Therefore, a rise in the EU's carbon price consistent with our modelling results is uncertain to predict, at least in the short term.

As for the global cooperation scenario, emission abatement efforts are lower in both Brazil and Europe, who opt instead to purchase allowances from other regions, where mitigation costs are lower such as in Russia, Canada, India and China. As predicted in the literature, the findings suggest that a worldwide cooperation is effective in achieving a low carbon economy, even within a different climate policy structure. 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 within the Paris Agreement architecture, starting with proposals involving developing and developed regions.

In this context, 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. One particular disadvantage is related to the fact that 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. Yet, based on the market size of the regulated sectors in Brazil and corresponding mitigation outcomes, 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.

Hence, with these results we contribute to the literature by showing that compared to the linkage literature with focus on other developing countries (such as China), the Brazilian case differentiates due to the level of ambition considered for the regulated sectors as well as the fact that the electricity sector is relatively low carbon compared to Europe. The benefits of linking may be limited however, unless a broader coverage of regions and sectors is taken into account. A clear example here is the inclusion of LULUCF related emissions for the proposed Brazilian ETS, which would imply lower abatement efforts and costs on ETS and non-ETS sectors, if included. Such an approach may make a proposed ETS in Brazil more politically acceptable. The research also shows small distributive effect in terms of household consumption. One recommendation is to match with a more appropriate trading partner in order for Brazil, as a developing country, to increase the gains from trading permits in the international market. As a first step, Brazil and Europe should consider ETS trading partners that are more closely aligned from a geographical, economic and political perspective. Thereafter, further linkages should be investigated.

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