Supplementary Methods, Discussions, Figures, Tables and References for:

Developing green: the case of the Brazilian manufacturing industry

This file includes:

I. Supplementary Methods
II. Supplementary Discussions
III. Supplementary Figures
IV. Supplementary Tables
V. Supplementary References

I. SUPPLEMENTARY METHODS

This study adopts an *ex ante* perspective by introducing the analysis of scenarios of future pathways for climate change mitigation in Brazil. The *ex ante* (or forward-looking) analysis concerns simulating the introduction of mitigation policies and measures, under different scenarios, that encourage green innovation and investment. The aim of this supplementary section is to describe the methodology adopted in the quantitative impact assessment of different mitigation scenarios on key variables of economic, energy and environmental systems, such as fossil fuel use, carbon dioxide (CO_2) emissions, GDP, employment and trade balance.

I.I. SCENARIO BUILDING

The analysis is based on scenarios, which are "*a plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g. rate of technological change, prices) and relationships*" (IPCC, 2014). A reference, or baseline, scenario (these terms are used interchangeably in the present study, following IPCC (ibid.)), establishes the pathway against which change is measured. Change is introduced in mitigation scenarios, which describe how the system responds to the implementation of mitigation policies and measures.

Reference scenario. The reference scenario is based on the IEA World Energy Outlook 2014 Current Policies Scenario (IEA, 2014), which reflects public policies and measures that had been formally adopted as of mid-2014. In this scenario, business-as-usual (BAU) is assumed, whereby Brazil and other developing countries follow a typical fossil fuel-intensive development path and developed countries do not introduce additional mitigation policies in relation to those that are already in place. In this scenario, Brazilian energy, environmental and economic systems are assumed to behave normally (i.e. "as usual") as there are no climate change mitigation policies. Developed countries are assumed to carry on with mitigation policies that are in place, but they are not assumed to take further action to address climate change. For example, it is assumed that the European Union maintains its Emissions Trading System as it is and that the South Korean cap-and-trade system is introduced from 2015.

The mitigation target announced as part of Brazil's voluntary NDC (i.e. to reduce GHG emissions by 37% by 2025 and, indicatively, 43% by 2030 in relation to 2005; Brazil, 2015) is not included in the reference scenario for three main reasons. First, the reference scenario of interest in the present study is the counterpoint to a greener development path that avoids the use of pollution-intensive technologies. Second, Brazil's NDC does not represent a transformation of the country's industrial system, as it leaves the uptake of fossil-fuel intensive technologies by manufacturing sectors, which are the focus of the present study, largely overlooked. We reiterate that Brazil has already met the bulk of the target (41% against the target of 43% by 2030) between 2005 and 2012 owing to reduced deforestation and despite growing burning of fossil fuels (Brazil, 2016). Finally, the federal government is in the process of defining how actions and measures to meet the target will be implemented and financed, as Brazil's National Strategy for NDC Implementation and Financing is still at design stage[1]. The mitigation scenarios described below help to demonstrate how green fiscal

[1] See http://www.mma.gov.br/clima/ndc-do-brasil

reforms (GRFs) targeted at manufacturing sectors could contribute to deliver Brazil's economy-wide commitment.

GFR scenarios. These scenarios capture the impacts from Brazil actively pursuing an alternative development path that aims to reconcile socioeconomic development and environmental sustainability – with a focus on climate change mitigation – by implementing GFRs. It is assumed that reforms are implemented to trigger, shape and catalyse a greener development path in Brazil. The main difference in relation to the reference scenario is that Brazil introduces a portfolio of fiscal policies to induce the uptake of modern low carbon technologies by manufacturing industries.

The GFR is defined to be the reduction of distorting taxes on investments and the provision of concessional financing for investments in green technologies by manufacturing industries. In addition, a carbon tax is introduced such that the fiscal reform does not reduce the government's primary balance (or primary budget result), which is defined as the government's revenue minus its expenditure, excluding interest payments on consolidated government liabilities (OECD, 2008). As a result of the reform, the tax burden will have shifted away from green investments toward carbon-intensive practices and technologies without hurting public finances.

The tax exemption proposed is to reduce distorting taxes on green investments, which increase their costs. It is estimated that the tax burden on investments in Brazil is more than six times that of Australia and Mexico, and over twenty-six times that of the United Kingdom, for an identical investment (i.e. installing a new standard iron and steel plant) in these countries (CNI, 2014). In the Brazilian manufacturing sectors, total tax costs amount to 24.3% of investments (FIESP, 2010). This means that nearly a quarter of the investment cost is attributable to taxation. The high tax burden on investments is a result of the complexity of Brazil's tax system (ibid.). Of the 24.3% (see Figure I), 16.8% is direct tax cost (i.e. from unrecoverable taxes), including customs duty ("Imposto sobre Importação" – II) and value added tax ("Imposto sobre Produtos Industrializados" – IPI) on capital goods. The remaining 7.5% is indirect (i.e. financial) tax cost of recoverable taxes. Recoverable taxes (i.e. those taxes businesses must pay but which will eventually be recovered when the government refunds them) can take many months, and sometimes years, to be recovered in Brazil, whereas in the United Kingdom, for example, they can be immediately recovered in cash (CNI, 2014; FIESP, 2010). Put differently, there are financial costs involved as businesses must bear the cost of these taxes until they are recovered. Indirect tax costs are attributable mainly to subnational value added tax ("Imposto sobre Circulação de Mercadorias e Serviços" – ICMS) and social security contributions ("Programa de Integração Social" – PIS – and "Contribuição para o Financiamento da Seguridade Social" – COFINS).

In the GFR scenarios, it is assumed that tax amendments are introduced that reduce the distorting tax burden on green investments by up to 11.3 percentage points (i.e. from 24.3% to 13%). According to FIESP (2010), this reduction can be achieved by implementing the following policy measures (see Table I for a summary):

i. *Exemption of capital goods from IPI.* Even though IPI is a value added tax, it is only recoverable when it is levied on manufactured goods used as input in the production process but not on investment. The IPI on manufactured inputs (e.g. vegetable oils, rubber and chemical products) is recovered when the final manufactured product, which uses these as input, is sold; whereas the IPI on capital goods is not recovered, as capital goods are understood as investments, and not as an input to production. Exempting capital goods from IPI represents a 3.8 percentage points reduction in the tax costs of investments.

ii. *Investments Drawback*. Akin to the Brazilian Exports Drawback[2] and the Duty Drawback in the European Union[3], this reform concerns discharging businesses from paying ICMS, IPI and PIS/COFINS taxes on inputs used to produce capital goods. With Investments Drawback, taxes that are paid on intermediate products used in the production of capital goods are refunded once the capital goods are sold. This would reduce the tax burden on investments by 1.2 percentage points.

iii. *Immediate recovery of ICMS and PIS/COFINS taxes on capital goods*. Presently, it takes 48, and 12 months on average, respectively, to recover these taxes. Immediate recovery would thus relieve investments from bearing the financial cost of taxes until they are recovered, which represents a reduction of 6.2 percentage points in the tax costs of investments.

Tax reliefs are applied to green investments only, a measure which is aimed at creating an incentive for investment in low carbon technologies over polluting technologies. The estimate of a reduction in the tax burden of 11.3 percentage points is used as a reference for the upper limit of tax exemption that can be granted for green investments, since it is a level of tax reduction that is achievable, for example, by implementing the three policy measures described above. Furthermore, FIESP (2010) is the only study that was found which quantifies the degree to which the tax burden on investments could be effectively reduced in manufacturing sectors in Brazil. Non-green investments are taxed as per standard tax rates (i.e. there are no tax exemptions for these).

By reducing the cost of taxes on green investments, tax exemptions help raise private finance for mitigation. This type of fiscal incentive can help unlock private climate finance, because the bulk of the additional, green investment prompted by the fiscal incentive is paid for by the private sector (although the public sector sponsors the cost reduction, i.e. the foregone revenues from tax exemptions). In addition to reducing distortive taxes on green investments, the GFR also comprehends the provision of concessional finance for investments in green technologies to further support the uptake of low carbon technologies. It is assumed that public funding is provided in the form of grants (i.e. non-reimbursable finance) for businesses to adopt green technologies. Hence, the GFR would raise climate finance from both the private sector (by attracting more investments in green technologies) and the public sector (by injecting capital in the form of grants for low carbon investments in the economy) to sponsor green investments. Whereas tax exemptions reduce the cost of investments in green technologies, the provision of public funding reduces both costs and risks associated with these technologies (see Methods). Non-green investments resort to finance that is regularly provided in the economy (i.e. there is no additional public funding for these compared to the reference scenario).

It is further assumed that the net reduction of government primary budget balance (i.e. a net increase in budget deficit or a decrease of budget surplus) – caused by foregone tax revenues owing to tax exemptions and increased public expenditure on funding of low carbon investments – is avoided by introducing a carbon tax. The carbon tax rate is established at a level that at least compensates for

[2] Decreto Lei n. 37, 21/11/66.

[3] Commission Regulation (EEC) n. 2454/93, 02/07/1993.

the negative impact on the government budget balance at any point in time. The carbon tax rate is fixed, and does not vary over time, to avoid creating further complexities to Brazil's tax system. In addition, stability of carbon pricing is ensured, which helps mitigate uncertainties related to green investments that is an advantage compared to alternative carbon pricing mechanisms such as Emissions Trading Systems – ETS (Parry and Pizer, 2007; World Bank, 2017). Other advantages of carbon taxing in relation to ETS include greater flexibility to abate larger amounts of emissions in moments of the economic cycle where abatement is cheaper, and hence, when more resources to invest in abatement are available, in contrast to ETS (Parry & Pizer, 2007), and relatively reduced institutional requirements (World Bank, 2017). It has also been argued that price-based mechanisms such as carbon taxing are less susceptible to corruption compared to quantity-based mechanisms such as ETS (Robb et al., 2010). Furthermore, the government would be adopting a precautionary policy, by seeking to protect its finances against unexpected shocks in the economy. All fossil energy carriers (i.e. fuels) are taxed to raise revenues but also to further incentivise decarbonisation. All users of fossil fuels are taxed, except households to avoid widening the social gap in Brazil, following Dercon (2012). Because energy is an essential good, low-income households are likely to spend a larger proportion of their income on it in relation to high-income households (Kosonen, 2012). Therefore, a regressive impact of taxing fossil fuels could be obtained if household consumption was included in the carbon tax. Another way by which equity concerns are addressed in the GFR is by recycling the carbon tax revenues back into the economy by introducing incentives for green investments, which should increase wages by diffusing modern low carbon technologies that increase productivity.

In summary, the reform alleviates the tax burden on green technologies and shifts the tax burden towards polluting technologies in such a way that it neutralizes negative impact on government budget balance.

The investments that are eligible for tax exemptions and public financing, i.e. those that qualify as green investments, consist of investments in modern low carbon technologies that deliver the maximum mitigation potential by Brazilian manufacturing sectors (see Table 1). The rationale is that if these technologies become mainstream, then Brazil's manufacturing sectors would be following the least carbon intensive trajectory possible, as the maximum mitigation potential would be achieved. The World Bank Brazil Low Carbon Study (World Bank, 2010a) is employed in the present study with respect to technical aspects of maximum mitigation potential technologies in manufacturing sectors, which include CO_2 mitigation potential, technological penetration specificities (e.g. changes in fuel uses, implementation time, useful life span) and investment costs and cycles, by technology, and by manufacturing sector, on an annual basis. The World Bank study (ibid.), its supplementary report (World Bank, 2010b) and the associated PhD thesis (Henriques Jr, 2010), provide a paradigm for research on mitigation technologies and measures in Brazilian manufacturing sectors, as they are used to this day as key references in quantitative macroeconomic assessments of climate policies in the country (La Rovere et al., 2016; Rathmann (org.), 2017). The approach of the World Bank study provides realistic low carbon technological trajectories for Brazilian manufacturing sectors. If a GFR is implemented, these are the technologies that are readily available in the market for businesses to deploy at scale by 2030. In addition, because an integrated and coherent approach was used, technological trajectories can be analysed both separately for each technology, and jointly when more technologies are simultaneously implemented by manufacturing sectors. As future studies reveal new technologies that can become commercially available at scale in the market in the coming years, it is possible that the maximum mitigation potential increases alongside progress made in technological development.

It is noteworthy that the electrification of Brazil's manufacturing sectors was not included in the present study nor in other major research projects on mitigation in Brazil (La Rovere et al., 2016; World Bank, 2010a), despite Brazil's electricity sector being deemed low carbon (ibid.). One possible reason is that the additional increase in future electricity demand from industrial electrification could result in an increase of CO_2 emissions if it is addressed by an increase in the share of fossil fuels in power generation. There are uncertainties regarding the extent to which additional future electricity can be supplied while maintaining Brazil's overwhelming share of renewables in the energy mix (Santos et al., 2013). The Brazilian Mines and Energy Ministry estimates that virtually the entire large hydropower plant generation potential will be exhausted by 2030 in response to growing demand for electricity (MME & EPE, 2007; World Bank, 2010a). Manufacturing sectors are the main consumers of electricity with a 40.9% share in total electricity consumption in Brazil in 2012 (EPE, 2017). A shift from fossil fuel use to electricity use by these sectors could create significant pressure to increase carbon-intensive electricity production. For instance, the electrification of the Brazilian vehicle fleet has a projected net adverse impact on total emissions, because it is more-than-compensated by an increase in the emissions of the energy sector (Rathmann (org.), 2017). A similar negative effect on emissions could result from manufacturing sector electrification.

GFR scenarios are built to target each type of green investment (i.e. for each block of technologies) both separately and jointly (see Table 2). In each scenario, the level of tax exemptions and concessional finance provided vary according to the investment costs and cycle of mitigation technology being targeted by the green stimulus. For example, in the EE scenario the amount of tax that is exempted from payment and the volume of public funding provided are specifically designed to induce investments in energy efficiency. In each scenario, the level of incentive that is introduced is designed to induce additional investments in relation to the reference scenario that are at least equivalent to the estimated investment costs over the timeframe of investment (i.e. the investment cycle) of the technology in question (see Modelling).

Scenarios EE, MR, NG, RN, SB and CO are each separately built to simulate the introduction of "mini" GFRs targeted at specific green investments (i.e. investments in energy efficiency, materials recycling and savings, a shift to natural gas and renewable energy, sustainable biomass and cogeneration technologies). These scenarios aim at testing the impact of "mini" fiscal reforms targeted at each type of green investment separately.

Scenarios representing GFR that target different types of green investments jointly are also considered. Scenarios are incrementally built such that each of them progressively induces the uptake of one more block of technologies, as follows:

- EE+MR: GFR designed to induce investments in energy efficiency and materials recycling and savings technologies;
- EE+MR+NG: GFR targeted at investments in energy efficiency, materials recycling and savings and a shift to natural gas technologies;
- EE+MR+NG+RN: green stimulus focused on investments in energy efficiency, materials recycling and savings, a shift to natural gas and renewable energy technologies;

- EE+MR+NG+RN+SB: GFR spurs investments in energy efficiency, materials recycling and savings, a shift to natural gas and renewable energy and a shift to sustainable biomass technologies;
- EE+MR+NG+RN+SB+CO: green stimulus targets investments in energy efficiency, materials recycling and savings, a shift to natural gas and renewable energy, a shift to sustainable biomass and cogeneration technologies.

Regarding the rest of the world, it is assumed that no additional action to address climate change is taken in other countries, similar to the reference scenario, based on the IEA World Energy Outlook 2014 Current Policies Scenario**Error! Bookmark not defined.**. These scenarios explore GFR as a national development strategy that is not conditional on countries taking further actions to mitigate climate change.

I.II. MODELLING

E3ME. The scenarios described in the previous sections are modelled in E3ME, a macroeconometric, non-equilibrium, hybrid simulation model of the global energy-environment-economy (E3) systems. It is a quantitative tool that provides estimates of impacts on these three systems. E3ME 6.0, which is used in the current study, is the latest of a succession of models built since the 1960s (Barker et al., 2004). E3ME is theoretically grounded on "New Economics", which refers to a demand-led academic approach explicitly focused on institutional behaviour (e.g. there can be oligopolistic competition and varying returns to scale across industries and over time), expectations, as described above (i.e. imperfect foresight) and uncertainty (Barker, 2008; Barker et al., 2012; Barker & Scrieciu, 2010). New Economics is by construction a pluralist approach (Scrieciu, 2011), which seeks to integrate different disciplines (e.g. climate science, engineering, history and ethics) and different academic traditions within the Economics discipline, namely Post Keynesian, Evolutionary and Institutional Economics (Barker, 2008; Barker et al., 2012; Barker & Scrieciu, 2010; Scrieciu, Barker, et al., 2013). The modelling approach of E3ME is empirically grounded, allowing to reproduce real-world behaviour in E3 systems that emerge from less restrictive assumptions regarding economic dynamics. Because of that E3ME is particularly well-suited for assessments involving developing countries, as it allows analysing aspects in E3 systems that are important for economic development in these countries. One example is external constraints for long-term economic growth, which has been the main barrier to Brazil's sustained economic growth (Gramkow and Gordon, 2011, 2015; Jayme Jr, 2003; Nassif et al., 2015). E3ME can provide insights into expected impacts on the balance-of-payments position. Another example is insufficient levels of aggregate demand (i.e. disequilibrium between demand and supply), which implies that the economy does not necessarily operate at full-capacity and resources are not fully-employed. Moreover, as a demand-driven approach, E3ME allows for fiscal policy to have a role not only on the environmental system (e.g. by reducing GHG emissions via the implementation of carbon taxes), but also on the economy, by using public spending and taxation to boost aggregate demand. Hence the theoretical and empirical foundations of E3ME present scientific grounding for hypotheses relating to net gains of climate change mitigation in both economic and environmental terms, in contrast to standard equilibrium models (Mercure et al., 2016; Scrieciu et al., 2013b).

The treatment of money and the financial sector is also an aspect whereby E3ME differs from standard equilibrium models owing to different theoretical foundations. Although there is an explicit treatment for nominal variables (wages, costs and prices) and for carbon pricing in E3ME, the core of the model is built on real economy dynamics. Money supply is implicitly made endogenous in the model, since financial institutions (e.g. banks) can create money through new loans (up to the levels allowed by past regulations that are embodied in the model's econometric parameters) to address new investments (Pollitt & Mercure, 2018). As a result, there is no full crowding out of investments in E3ME, which is consistent with its New Economics theoretical foundation. In standard equilibrium models, in contrast, money supply is exogenous and there is full crowding out of investments, because new investments must be financed either by increased savings that reduce consumption or by reducing investment elsewhere. Notwithstanding, the different ways through which green investments can be financed in E3 models is insufficiently explored, and so far there are scarce models that present explicit treatment of money and financial sector (Anger & Barker, 2015; European Commission, 2016; Mercure et al., 2016; Pollitt & Mercure, 2018).

The dominance of E3 models based on the NCE tradition has been associated with a deeper problem in the economics discipline: that it offers little space for pluralism and alternative academic traditions to coexist (Scrieciu et al., 2013b; Spash & Ryan, 2012). It should be noted that NCE tradition itself presents theoretical variations and developments, but these occur around core concepts and assumptions that essentially do not change, such as optimising behaviour, perfect rationality and equilibrium assumptions (Courvisanos et al., 2016; Scrieciu et al., 2013b). There are diverse equilibrium models in terms of model structure, content and assumptions relating to energy, the environment and economics. This is partly explained by the complex nature of the problems being addressed by these models and the lack of consensus in the economics discipline (Haynes et al., 2011). The insufficiencies of methodological monism and the benefits of using a variety of approaches are becoming increasingly recognised in the discipline (Courvisanos et al., 2016; Davis, 2014; Dow, 2004; Garnett Jr., 2006).

E3ME reports year-by-year outcomes by employing the method of co-integration and error correction, which produces short-term dynamic outcomes moving towards a long-term relationship. The structure of E3ME is based on the standard national accounting framework, with further linkages to energy demand balances and environmental emissions. E3ME 6.0 covers 53 global regions, including Brazil explicitly. There is a detailed sectoral disaggregation in each world region, with 43 sectors for non-European regions (see E3ME manual for details; Cambridge Econometrics, 2014).

E3ME is comprised of three modules, whereby economic activity and general price levels are provided by the economy module. This information is passed onto the energy module, which then determines levels and prices of energy consumption. These are then used in the environment module to generate emissions levels and also feed back into the economy module.

In E3ME the economy is demand-driven so that supply is adjusted (subject to some constraints) to meet demand levels, but not necessarily at maximum representing energy, environment and economic systems. Supply constraints in E3ME include the availability of labour, an implicit measure of capacity (i.e. an estimate of normal output) such that any increase in demand beyond capacity increases prices and import substitution thereby forcing economic activity down and econometric parameters derived from historical data that incorporate constraints, such as past regulations that limit debt and finance available to expand investment. The levels of demand determine output, which determine employment levels allowing for varying returns to scale across industries and over time. The energy module in E3ME is eminently top-down with a bottom-up sub-model of the electricity supply sector. Thus, E3ME is considered a hybrid model as it incorporates elements from both top-down and bottom-up modelling approaches. This module is solved for each energy user (22 users in total), each energy carrier (12 fuel types in total) and each region in physical terms (see E3ME manual for details; Cambridge Econometrics, 2014). Energy demand, which allows for fuel substitution, is influenced by economic activity, energy prices and technology. Feedbacks from the energy module to the economy are made via input-output industry interactions, household energy balances and prices. The environment module in E3ME is represented by air pollution generated from end-use of different fuels and from primary use of fuels in the energy industries themselves, particularly electricity generation. It includes 14 pollutants, including GHGs and other pollutants (see E3ME manual for details; Cambridge Econometrics, 2014).

Interactions between the three modules are solved by using the IDIOM software. IDIOM provides forecasts by solving a system of stochastic equations (estimated by employing co-integration and ECM) and accounting identities. The flows of goods between sectors in the economy are provided by input-output technical coefficients. However, crucially, input-output coefficients are endogenous in the sense that IDIOM allows for a variety of non-linear relationships to determine final demand components, such as income flows, relative prices, fiscal policy and shocks in the rest of the world. E3ME builds on multiple official and international data sources. Economic data is mainly obtained from Eurostat, OECD (STAN – Structural Analysis Database), European Commission (AMECO), the IMF and the United Nations (Comtrade). A single source for energy data is used: the OECD (IEA). Emissions data sources include Eurostat and EDGAR. Official national sources are sought when international sources are exhausted. Further details on E3ME can be found in its manual (Cambridge Econometrics, 2014).

Employment of E3ME in the present analysis is based on several factors. As a hybrid model, in E3ME the two-way causation linkages between E3 systems are developed so that it is capable of detailing top-down macroeconomic interactions, such as feedbacks and spillovers. The two-way causation between E3 systems represents an advantage of E3ME over other E3 models that ignore the interaction completely or only assume a one-way linkage (Barker and Scrieciu, 2010).

Compared to other E3 models, E3ME is a highly detailed and disaggregated model in terms of industries, energy carriers, regions, fuel users etc (Barker et al., 2006; Edenhofer et al., 2010, 2006; Pollitt et al., 2010; van Vuuren et al., 2009). This allows E3ME to represent complex scenarios, such as those that are differentiated according to sector, technology and country; and assess detailed (short- and long-term) impacts. For example, the global coverage with regional disaggregation allows one to capture the impacts of policies being implemented in one country (e.g. Brazil) on the country itself and on other countries. Although there are several advantages in employing E3ME in the context of the present research, there are also limitations, which apply to most E3 models (see Limitations).

Modelling of scenarios. Here we describe how the scenarios described above were modelled in E3ME. The changes made to E3ME to run the reference scenario concerned introducing business-as-usual policies, following the IEA World Energy Outlook 2014 Current Policies Scenario (IEA, 2014). Green policies and measures simulated in the baseline included projections of the EU ETS and the South Korean ETS, which also presents projections for carbon prices and prices of fossil fuels (see Table II) used in the simulations. In E3ME 6.0, process emissions are only projected for EU countries. These were added for Brazil by calculating Brazil's process CO_2 emissions coefficients using data from the 3rd Brazilian Inventory of GHG Emissions (Brazil, 2016). The rest of the data was kept as they are by default.

Modelling of GFR scenarios comprised a process of five main steps – see Figure II. Firstly, it was necessary to determine the costs of green investments for each scenario, which was used as a reference to establish the level of tax exemptions and provision of concessional finance. Green investment cost assumptions were based on estimates provided by the World Bank Brazil Low Carbon Study (Henriques Jr, 2010; World Bank, 2010a, 2010b). An extensive treatment of the estimations presented by the study was carried out to obtain investment cost assumptions for each scenario, year-by-year and sector-by-sector, which involved annualizing green investment cost estimates, adjusting estimates for endogenous GDP growth and converting estimates to E3ME classifications.

The second step refers to the introduction of tax exemptions. Tax exemptions for green investments were modelled as reductions on indirect taxes on capital goods. It was assumed that suppliers of capital goods fully passed the reduction of tax costs on to consumers of capital goods (i.e. manufacturing sectors) via reduction of investment prices. Owing to reduced investment prices, additional investments compared to the reference scenario are induced – provided that the price elasticity of investment expenditure is not null. In each scenario, the level of the tax exemption was set, sector-by-sector and year-by-year, to a level that induced additional investments in relation to the reference scenario that at least matched the investment costs of the green technology in question, by using the method of trial-and-error. An initial guessed level of tax exemptions (e.g. 5%) was simulated. For those sectors in which additional investments exceeded the cost of the green investment(s) in question, in the next simulation the level of exemptions was reduced. For the sectors that presented smaller additional investments compared to the cost of green investment(s), additional tax exemptions (up to 11.3%) were introduced for these sectors. This process was repeated successively until the resulting additional investments at least matched the required investments in the green technology under consideration.

The third step concerns the provision of concessional finance in the form of grants (i.e. non-reimbursable finance). Grants were provided as risk-reducing capital, i.e. as an initial capital provision in the early years of the investment cycle to help industries overcome costs and risks involved in kick-starting the transition to low carbon technologies, such as financial risks of high upfront (capital) costs and risks related to technological learning. Grants were also supplied to industries when tax exemptions at maximum level (i.e. 11.3%) were not enough to induce sufficient investments to reach the investment costs of green technologies. In both cases (i.e. as initial capital provision and as capital boost to further incentivise green investments), grants were provided at a volume equivalent to the green investment gap, year-by-year, in the corresponding sector for each scenario. The green investment gap is the difference between the cost of the investment in the green technology and the induced additional investments compared to the reference scenario owing to tax exemptions. Grants for green investments were modelled as exogenous investments, by assuming that all public funding supplied by the government is demanded by industries. This assumption was based on the fact that demand for grants for innovation projects was eight times the available supply from 2006 to 2008 by Brazilian manufacturing sectors, which indicates that an increased provision of public grants for the uptake of green technologies is likely to find demand (IBGE, 2010; IEDI, 2010).

The GFRs described in steps two and three reduce government's primary balance. The fourth step concerned the introduction of a carbon tax that prevents a net reduction of government primary budget balance (i.e. a net increase in budget deficit or a decrease of budget surplus). E3ME presents a built-in mechanism for the introduction of carbon taxes. The level of the carbon tax was defined by trial-and-error, i.e. by simulating the net impact of different tax rates on the government's budget. The carbon tax was set to the lowest possible tax rate such that, at any point in time over the forecast period (2018-2030), the negative fiscal impact of tax exemptions and public funding was at least compensated by revenues obtained from taxing carbon. As a result, the GFR does not create negative primary budget impact on any of the years covered in the analysis. The lowest possible carbon tax rate was used to avoid creating an unnecessary additional tax burden on Brazil's economy. As the carbon tax rate is fixed over time, in some of the years over the forecast period the net impact of the GFR on the government's primary balance may be positive. It was assumed that a net positive impact of GFRs on the government's budget was used by the government to reduce budget deficit (and was not recycled back to the economy).

Steps one to four were followed to design GFRs targeted to induce investments in specific mitigation technologies in each scenario. The fifth and final step concerns introducing technological changes that result from green investments in each scenario, which includes changes to energy consumption, shifts between fuels, changes in input-output coefficients and reductions to process CO_2 emissions. Put differently, the fifth step concerned introducing to the simulations the impacts that the induced green investments brought about in terms of technological change, following technological specifications in reference documents (Henriques Jr, 2010; World Bank, 2010a, 2010b). The changes made to each scenario are specific to the corresponding technology targeted by GFRs.

For each technology, an implementation period was assumed, which refers to the time industries take to fully transition to the new technology (ibid.). After industries shift to, and learn how to use, the new technology over the implementation period, the full mitigation potential can be obtained. The implementation period varies according to technology, but it is the same across sectors (Table III). It was assumed that technological change progresses linearly over the implementation period, starting from 0% in year one and achieving 100% from the first year following the implementation period. For example, in the case of steam recovery systems, whose implementation period is five years, industries adopting this technology achieve 0%, 20%, 40%, 60%, 80% and 100% of the energy savings potential in 2018, 2019, 2020, 2021, 2022 and 2023, respectively.

Energy efficiency technologies. Energy efficiency technologies enable using less energy in the production of goods, while maintaining their quality (Henriques Jr, 2010; World Bank, 2010a, 2010b). These technologies reduce consumption of fossil fuels and the extent of the reduction varies according to industry (fuel users; ibid.). The energy savings potential (in percentage terms) that can be achieved by fuel user and by technology used in the modelling can be seen in Table IV. The potential energy savings estimations were based on a detailed analysis of the technologies currently in use by each manufacturing sector in Brazil and of available best practices (nationally and internationally) that could be adopted to reduce fossil fuel consumption (ibid.). Energy efficiency technologies were modelled by reducing the use of the relevant fuels by the corresponding energy savings potential by fuel user.

Materials savings and recycling technologies. The materials savings and recycling technologies considered in this study concern the substitution of virgin inputs with recycled inputs and improvements in the production process that result in energy savings and in reduced CO_2 emissions. In the iron and steel industries, use of recycled scrap steel increases by 14% (Henriques Jr, 2010; World Bank, 2010a, 2010b). This was modelled by changing input-output coefficients such that these industries used 14% more recycled steel and reduced the equivalent amount from virgin steel per unit of output. In the aluminium industries, use of recycled aluminium increases by 27% (ibid.). Similarly, this was simulated by changing input-output coefficients to increase the use of recycled aluminium by 27% and reduce the corresponding input use from virgin alumina per unit of output. Analogous shifts in input-output coefficients were introduced in pulp and paper and glass industries, in which the use of recycled inputs increased, respectively, by 22% (re-used paper chips substituting for virgin pulp) and 75% (recycled glass substituting for virgin glass; ibid.). By skipping the energy-intensive stage of transforming pig iron into steel by employing recycled steel in the production process, iron & steel and ferro-alloys industry reduces its fossil fuel consumption by 2.9% (ibid.). When recycling is separately implemented (i.e. in scenario MR), the full 2.9% potential can be achieved. However, when recycling is implemented after considering the impacts of energy efficiency technologies (e.g. in scenario EE+MR), the energy savings joint potential of this technology is 1.9%, on average, as energy efficiency technologies reduce the potential quantity of energy that can be saved by recycling technologies. Likewise, using recycled aluminium as an input in aluminium industries avoids the consumption of virgin alumina, which involves an energy-intensive production process. As a result, non-ferrous metals industry reduces its use of heavy fuel oil by 3.4% (ibid.), when recycling technology is separately implemented. Notwithstanding, if it is implemented after the potential energy savings from energy efficiency technologies are addressed, the potential savings from recycling become 3.2%. Similarly, recycling in pulp and paper and glass industries also produces energy savings, which are larger if separately implemented in relation to scenarios that consider joint implementation of green technologies. In addition, ceramics and cement industries adopt materials savings technologies. By increasing the uptake of chemical additives in the production process of cement, these industries reduce the clinker-cement ratio by 5% (from 81-82%, which is Brazil's average, to 77-78%, which is the world average; ibid.). In modelling terms, the increased use of chemical additives was simulated by increasing the input-output coefficient such that cement industries consume 5% more chemical additives per unit of output. Reduced clinker requirements in the production of cement reduce energy consumption from fossil fuels by 4%, as the production of clinker is energy-intensive. Moreover, this technology reduces process CO_2 emissions associated with cement production by 5%. Ceramics industries adopt technologies that reduce production losses, by improving drying and firing processes to avoid, for example, losses owing to cracked and burned ceramics. Reduced losses in ceramics industries lead to a decrease of between 1% and 4% in the use of fossil fuels – when used separately. The energy savings potential of joint implementation, similarly to recycling technologies, was obtained by deducting the impact of energy efficiency from the potential of separate implementation. Similar to energy efficiency technologies, energy savings were modelled as reductions in the consumption of the corresponding fuel and fuel user (see Table V). The joint savings potential that can be obtained after deducting the impact of energy efficiency technologies is smaller in relation to separate uptake of materials savings and recycling technologies, because energy savings potential from materials savings and recycling are applied to a reduced energy consumption base (owing to energy efficiency technologies). In other words, the savings potential is not additive. In scenario EE+MR, there are energy savings owing to both energy efficiency and materials savings and recycling technologies. In this scenario, the joint potential savings from materials savings and recycling are added to energy efficiency potential savings.

Natural gas. This technology concerns a shift in energy uses from fossil fuels (coal, coke, crude oil and heavy fuel oil) to natural gas (Henriques Jr, 2010; World Bank, 2010a, 2010b). They are considered mitigation technologies in the sense that their CO_2 emissions coefficient is smaller (by 38.4% in the case of coal) in relation to other fossil fuels (ibid.). A shift to natural gas does not involve a change in the total quantity of fuels that is consumed, but rather it refers to a change in the allocation between fuels. Table VI shows the potential shift by fuel user. The proportional potential for implementation of this technology separately or jointly with other mitigation technologies is undistinguished in terms of its modelling, because the percentage of fossil fuels that is displaced by natural gas is not modified by the introduction of the two technology blocks described previously. However, the final quantity of fuels that is displaced can differ, as the percentage is applied to different quantities of energy consumption. When the technology is implemented separately, as there are no energy savings from energy efficiency and materials savings and recycling, the amount of natural gas that displaces fossil fuels is larger than when it is jointly implemented. A shift to natural gas technologies was modelled in E3ME by shifting fuel uses between fuels by fuel user.

Renewables: biomass and solar-thermal technologies. These technologies refer to shifting fossil fuel use by renewable energy (Henriques Jr, 2010; World Bank, 2010a, 2010b). Two types of renewable energy are considered: (i) biomass from firewood and charcoal; and (ii) solar-thermal, which consists of complementary water heating systems. In iron and steel industries, charcoal use increases by 35% and replaces the corresponding use of coke and coking coal (ibid.). This shift does not represent a direct impact on CO_2 emissions, because the emissions coefficients for charcoal, coke and coking coal are the same (ibid.). However, the entirety of the additional charcoal is assumed to be obtained from wood from new planted forests, which avoids CO_2 emissions from deforestation. This indirect mitigation impact is captured by the technology block described next, i.e. sustainable biomass (SB). In the food and drink and pulp and paper industries, 10% of fuel oil use is replaced by firewood. The 10% figure was designed to complement the 90% figure of fuel oil substitution by natural gas (described previously; ibid.). Similar to natural gas technologies, a shift to biomass does not impact the total quantity of fuels that is consumed, but it changes the allocation between uses of fuels by fuel user. In terms of modelling, a shift to biomass technologies was introduced by shifting fuel uses between fuels. Akin to natural gas technologies, the potential for displacing fuel oil by firewood is the same for separate and joint implementation of this technology, because it is defined in relative (percentage) terms. The additional firewood is obtained from new planted forests. In addition, chemicals and food and drink industries adopt solar energy to substitute for fossil fuel energy used for thermal (heating) purposes. These industries use 50% of their fuel oil and natural gas consumption for heating purposes (ibid.). By adopting solar energy, they can reduce consumption of these fuels by 15%, thereby achieving a reduction of 7.5% in total use of fuel oil and natural gas if implemented separately. The joint potential reduction refers to deducting the impact of the previously described technology blocks on the separate potential. For food and drink industries, for example, substituting fuel oil by solar can only occur separately. As with scenarios that consider this technology jointly implemented with other green technologies (i.e. EE+MR+NG+RN, EE+MR+NG+RN+SB and EE+MR+NG+RN+SB+CO), fuel oil would have been completely substituted by natural gas and biomass. For these industries, the joint potential reduction in use of natural gas is smaller compared to the potential of separate implementation, because other technologies reduce the amount of energy that is available for substitution by solar-thermal technologies. The adoption of solar-thermal technologies was modelled by reducing the consumption of fuel oil and natural gas that is avoided by these technologies. Table VII summarizes references for the modelling of technological changes owing to adoption of renewable energy technologies in E3ME.

Sustainable biomass. This technology concerns phasing-out unsustainable firewood and charcoal (i.e. obtained via deforestation of native forests) and introducing sustainable firewood and charcoal (i.e. from wood produced from planted forests) instead (Henriques Jr, 2010; World Bank, 2010a, 2010b). Introducing sustainable firewood and charcoal does not present a technological impact on manufacturing sectors themselves, as the technology is implemented in the forestry sector that provides the wood from which firewood and charcoal are obtained. Manufacturing sectors consume the same amount of biomass as they would in the absence of this technology. The difference is that the biomass used is now more sustainable. Shifting to sustainable firewood and charcoal has a significant mitigation potential because planted forests avoid CO_2 emissions owing to deforestation of native forests (ibid.). By using sustainable biomass, manufacturing sectors contribute to mitigation and to conservation of biodiversity through preserving native forests. An integral shift to sustainable biomass is assumed, such that all firewood and charcoal used by manufacturing sectors become renewable. The shift thus includes firewood and charcoal ordinarily consumed (in scenario SB, which considers the separate adoption of this technology) and additional biomass introduced as described previously (in scenarios that consider the technology being jointly implemented with other mitigation technologies, EE+MR+NG+RN+SB and EE+MR+NG+RN+SB+CO). Trees are planted in 2018 and harvested seven years later, which is why CO_2 emissions start declining only from 2025 in scenarios that include SB. The adoption of sustainable firewood and charcoal thus starts in 2025. Land use, land use change and forestry emissions are not currently modelled in E3ME 6.0. The avoided CO_2 emissions (from avoided deforestation) were exogenously subtracted from total CO_2 emissions obtained from simulation results in scenarios that include this technology. The estimates provided by reference documents (ibid.) were used to calculate the avoided emissions (see Table VIII).

Cogeneration technologies. Cogeneration technologies refer to the combined production of thermal and electric energy in the same system (Henriques Jr, 2010; World Bank, 2010a, 2010b). Food and drink industries adopt cogeneration from residual biomass by producing electricity from sugarcane bagasse that is a by-product in the production process. Iron and steel industries adopt cogeneration technology from heat recovery in gas furnaces (i.e. outstanding heat resulting from steam production is used to generate electricity – the Rankine cycle). Pulp and paper industries adopt cogeneration from biomass by using by-product black-liquor to generate electricity. The electricity that is produced from cogeneration technologies is for own-use and represents reduced consumption of electricity centrally produced. In other words, cogeneration technologies enable industries to use less electricity from the grid, by producing electricity for their own use. As a result, CO_2 emissions are avoided by reducing centrally produced (grid) electricity and assuming that co-generated electricity's associated emissions are negligible (ibid.). Cogeneration technologies were modelled by reducing the consumption of electricity that is no longer obtained from the grid, but which is now being produced and consumed by industries themselves. The same potential reduction in grid electricity consumption could be obtained for both separate implementation of cogeneration technologies and joint implementation with other green technologies, because cogeneration does not depend on, or impact, fossil fuel use that is the focus of other mitigation technologies. In other words, the electricity production capacity from cogeneration technologies that is installed by industries is the same in scenarios that address these technologies. Reference values shown in Table IX were used in the modelling.

As each GFR scenario was designed to drive specific green investments, technological change was modelled according to the block(s) of technologies that are targeted by each scenario. The technological change that corresponds to each scenario was modelled by introducing separate technological impact in scenarios EE, MR, NG, RN, SB and CO; and joint implementation impact of green technologies in scenarios EE+MR, EE+MR+NG, EE+MR+NG+RN, EE+MR+NG+RN+SB and EE+MR+NG+RN+SB+CO. The introduction of technological change to scenarios was the fifth and final step in the modelling of GFR scenarios in Brazil.

In summary, modelling of scenarios involved these five steps: (i) estimating investment costs of green technologies in detail for each scenario; (ii) setting tax exemptions to levels that at least matched the costs of the green technologies in question (up to a maximum viable reduction of 11.3%); (iii) supplying public funding in the form of grants as initial capital provision to support early stages of technological transition and as capital boost to induce further green investments; (iv) introducing a carbon tax to avoid negative impact on government's primary budget; and (v) assigning technological change that corresponds to induced investments from the GFR.

Limitations. The data sources, methodology and modelling techniques employed were carefully selected to make the analysis as robust as possible. Notwithstanding, as with any quantitative assessments that involve human and physical systems and their interactions, there are limitations. First, the results obtained rely on the availability and quality of the data. The use of multiple databases in E3ME, as in any large-scale model, may contain imprecisions despite extensive data processing to ensure these are consistent with each other, economic theory and econometric practice. Second, any study that involves making projections of the future involves uncertainties. Owing to its intrinsically unpredictable nature, it is not possible to perfectly represent uncertainties in modelling. Uncertainties regarding key linkages from climate change damage and ecological limits to the economy also prevented accounting for these in the modelling exercise. Third, the treatment of elasticities in the model is based on adaptive expectations, i.e. based on learning and information about the past. Although elasticities may change in the future, this approach is reasonable in the presence of uncertainties, which are virtually always present in analysis of long timeframes (Evans and Ramey, 2006). We also highlight that the treatment of money and financial markets is not explicitly developed in E3ME, but it is (implicitly) consistent with Post Keynesian theory that rejects crowding out of investments (Pollitt and Mercure, 2018). Notwithstanding, the different ways through which green investments can be financed in E3 models is insufficiently explored, and so far, there are scarce models that present explicit treatment of money and financial sector (Anger & Barker, 2015; European Commission, 2016; Mercure et al., 2016; Pollitt & Mercure, 2018).

II. Supplementary Discussions

II.I. The fiscal reforms that can induce low carbon investments

In each scenario, green fiscal stimulus (i.e. tax exemptions and concessional finance) are introduced to induce additional investments in relation to the reference scenario that at least match the investment costs of green technologies, as stated in Supplementary Methods. Considering green technologies implemented separately, energy efficiency technologies present the highest absolute total investment cost (EUR_{2005} 23,986 million) and materials savings and recycling exhibit the lowest cost (EUR_{2005} 336 million) accumulated over 2018 to 2030 (see Table X). With respect to joint implementation, investment costs increase as industries progressively implement additional mitigation technologies. Joint implementation of all mitigation technologies requires investments of EUR_{2005} 35,959 million.

Investment requirements differ with respect to industrial sectors and to technology. Whereas the basic metals sector, which includes iron and steel, is responsible for the majority of investment costs in energy efficiency and materials savings and recycling (with 64.9% and 70.9% of total investment costs, respectively), most (89%) of the investment costs in renewable energy is due to the chemicals sector (see Table XI). The majority (80.4%) of the investment costs in cogeneration are held by the food and drink sector. The concentration of investments in these sectors is due to their increased potential to implement these technologies relative to other sectors. In the case of cogeneration technologies, for instance, the food and drink sector has the largest potential to adopt these technologies owing to a massive supply of residual biomass (mainly sugarcane bagasse) used to produce electricity in this sector (Henriques Jr, 2010; World Bank, 2010a, 2010b). Likewise, chemicals industries have relatively more potential to uptake solar-thermal technologies, because of relatively more intense use of heated water in mild temperatures in production processes, such as pre-heating and drying (ibid.). Thus, industries that present a larger potential for implementation compared to other industries require relatively larger volume of investments in each technology. With regard to natural gas technologies, most (94.9%) of the investment cost is led by gas supply industries. These technologies require relatively small investments by manufacturing industries (in equipment for conversion and adaptation to natural gas), such that the bulk of the investment cost rests on natural gas transport and distribution (ibid.). The forestry sector is responsible for the entirety of investments costs in a shift to sustainable biomass, as in this case the investments are made in growing additional planted forests that supply sustainable firewood and charcoal used by manufacturing sectors.

The level of tax exemptions and the amount of concessional finance that can induce the necessary level of green investments varies between GFR scenarios. For every tax exemption level, the corresponding amendment that can lead to an equivalent reduction in tax cost on investment might include green investment drawback, IPI tax exemption on green investments and immediate recovery of ICMS and PIS/COFINS taxes on green investments (see Table I). This discussion brings more realism to the present analysis, by showing how the levels of tax exemptions simulated under different scenarios can be achieved in practice in Brazil.

II.II. Macroeconomic impacts of GFRs

GDP. The projected impact of GFRs on the economy is positive for all scenarios relative to the baseline, except for scenario MR in which the impact is neutral. In the presence of green stimulus, Brazil's real GDP in 2030 is larger than the baseline GDP by 0.42% in scenarios EE, EE+MR and EE+MR+NG+RN+SB+CO; 0.40% in scenario EE+MR+NG+RN+SB; 0.36% in scenario EE+MR+NG+RN; 0.33% in scenario EE+MR+NG; 0.17% in scenario RN; 0.06% in scenario NG; 0.04% in scenario SB; and 0.02% in scenario CO (see Table XII).

Investments. GDP growth is driven mainly by faster-growing investments relative to the baseline. GFR reduce distortive taxes on investments and provide grants for low carbon investments, which increase industries' investment levels. As a component of GDP, investments increase GDP owing to direct impact of additional investments in green technologies and also because of macroeconomic feedbacks and interactions that produce indirect and induced impacts that further increase GDP and investment levels in E3ME. The scenarios that simulate the introduction of more green stimulus for low carbon investments, such as larger tax exemptions and significant volumes of public financing, present larger increases in real investment levels (see Table XIII). The largest increase is observed in scenario EE+MR+NG+RN+SB+CO, which simulates the most comprehensive GFR. In 2030, relative to the reference scenario, investment levels increase by 1.16% in scenario EE+MR+NG+RN+SB+CO; 1.09% in scenario EE+MR+NG+RN+SB; 0.92% in scenario EE+MR+NG+RN; 0.87% in scenario EE+MR+NG; and 0.47% in scenarios EE+MR and EE. In other scenarios, which simulate GFRs targeted at separate implementation of technologies that require relatively less fiscal incentives (i.e. NG, RN, SB and CO), projections show an increase of between 0.08% and 0.18% in investment levels in 2030 compared to the baseline. Scenario MR presents an increase in investments (of up to 0.08% relative to the reference scenario) until 2023, after which insignificant impact (less than 0.01%) is projected. This scenario simulated temporary tax exemptions (of up to 5% until 2022) and relatively small volumes of grants (in 2018) to three sectors only. Since the fiscal incentives are concentrated exclusively over the first five years of the technological transition in this scenario, its macroeconomic impacts are only significant in those years. Scenario MR shows that provisional fiscal incentives do not present a permanent impact on investments levels. This result indicates that if the green fiscal reform is aimed at sustaining increased investments over a longer period of time, it must not be temporary in nature.

Trade balance. Another driver of GDP growth is an increasingly positive impact on the balance of trade produced by GFRs. Trade balance, defined as the difference between exports and imports, is, like investments, a component of GDP. As the trade balance is improved by GFRs, it presents similar macroeconomic interactions and feedback effects as investments (and other components of GDP) do in terms of direct, indirect and induced increases in economic output. GFRs improve trade balance for two main reasons. Firstly, these reforms induce the uptake of technologies that reduce consumption of fossil fuels, either because mitigation technologies save energy (e.g. energy efficiency technologies) or because they substitute fossil fuels by other energy carriers (e.g. renewable energy). As Brazil is a net importer of fossil fuels, the reduction in the consumption of these fuels reduces imports, thereby improving trade balance. The largest reductions in fossil fuel imports occur in scenarios EE+MR and EE (11.9% and 11.8% reduction, respectively, compared to the baseline in 2030), which are the scenarios in which all fossil fuel use is reduced owing to energy savings. Other scenarios that include a shift to natural gas, jointly with energy efficiency and materials savings and recycling technologies (i.e.

EE+MR+NG, EE+MR+NG+RN, EE+MR+NG+RN+SB and EE+MR+NG+RN+SB+CO) result in a reduction in fossil fuel imports ranging from 2.6% to 2.8% relative to the reference scenario in 2030, partly because imports of natural gas are included in the estimates of fossil fuel imports. The exceptions are scenarios SB and CO, which present an increase of 0.02% in total imports in the same year. These sectors do not directly address fossil fuel consumption; in which cases heated economic activity (owing to fiscal incentives for green technologies) result in increased total imports in response to growing demand. The second reason why GFRs help improve trade balance is that they help increase exports. Export projections show that GFRs not only increase total volume of exported products but also relieve external restrictions on long-term economic growth as they enhance the technological content of exports (see Table XV). By promoting investments in modern green technologies, GFRs are helping Brazil build competitiveness based on effective modernization of the productive structure. As a result, exports become relatively less dependent on primary and natural-resource intensive products as more technologically sophisticated products become competitive. Exports enhance trade balance in quantitative terms (as absolute export volume increases) and in qualitative terms (as exports become more diversified and relatively more driven by technologically-intensive manufacture). The improvement of trade balance is pivotal for Brazil's long-term economic growth, as it reduces vulnerability to external constraints to economic development.

Wages, personal disposable income. GFRs result in a positive impact on wages and personal disposable income in real terms (see Figure 4 and Figure III). In both cases, the magnitude of the impact is larger in scenarios that simulate more fiscal incentives for green investments, especially scenarios in which joint implementation of mitigation technologies is being targeted. Wages and personal disposable income increase by up to 0.5% and 0.3%, respectively (in scenario EE+MR+NG+RN+SB+CO) in 2030 relative to the baseline. The increase in these variables is engendered by growing labour productivity. As the Brazilian economy becomes more capital-intensive, labour productivity expands as more output can be obtained by each worker. Increased productivity leads to increased revenues per worker, which pushes wages and personal disposable income up. These variables show the relevant socioeconomic gains of green fiscal reforms, concerning an increased amount of money available for households to spend and save after income taxes have been accounted for.

Jobs. The impact of GFR scenarios on employment is positive in the first instance but becomes negative later on (see Figure 5). As investments expand, they drive expansion of economic activities, which leads to net job creation relative to the baseline owing to macroeconomic interactions and feedbacks. Most jobs are created in 2022 in scenario EE+MR+NG+RN+SB+CO, which represents an increase of 0.1% (or 117 thousand net jobs created) in comparison to the baseline. However, as investments continue to expand, ever increasing capital stocks start substituting for labour. Net job losses start to occur from 2026 in most scenarios. It is underlined that the magnitude of the impact is small, i.e. it represents up to 0.1% of employment levels in the reference scenario. Notwithstanding, substitution of labour by capital could be avoided. GFRs were designed to reduce the cost of capital, but they could be amended to include fiscal incentives that reduce labour costs in industries that adopt green technologies. GFRs present a positive fiscal impact on government's budget over most of the period of analysis. These resources could be used to reduce tax costs on labour, such as social security contributions, instead of reducing the budget deficit. Studies show that countries that recycle carbon tax revenues back to the economy by reducing distorting labour taxes have achieved net job creation (Withana et al., 2013). This possibility can be explored by future studies in the context of Brazil.

II.III. Energy and environmental impacts of GFRs

Fossil fuel use. Projections show that the introduction of mitigation technologies in GFR scenarios produces significant changes to Brazil's energy and CO_2 emissions profiles. Consumption of fossil fuels is reduced in all scenarios (see Table XVII), except in scenario SB that does not address fossil fuel-related CO_2 emissions (this scenario focuses instead on reducing emissions by avoiding deforestation). In the context of technologies implemented separately, energy efficiency technologies result in the largest reduction in fossil fuel consumption (of 7.0% in 2030) relative to the baseline. As more mitigation technologies are jointly implemented, the projected reduction in fossil fuel use is increased. The largest projected reductions thus occur in scenario EE+MR+NG+RN+SB+CO, in which the GFR tackles all mitigation technologies jointly. In this scenario, fossil fuel use is reduced by up to 8.5% (in 2030) relative to the baseline.

Reduced fossil fuel consumption is due to the direct impact of the uptake of mitigation technologies spurred by green fiscal reforms; and to indirect and induced macroeconomic effects that can further reduce demand for fossil fuels, not only in manufacturing sectors but throughout the economy. Reduced fossil fuel use by sectors other than manufacturing (e.g. electricity and transport) can be attributed to indirect and induced macroeconomic effects that reduce demand for these fuels. Electricity demand can be reduced as an indirect effect of mitigation technologies that save energy. As manufacturing sectors adopt technologies such as energy efficiency or materials savings and recycling, they demand less fossil fuels. Fossil fuel industries respond by reducing output, thereby reducing their own energy demand, which includes electricity. This indirect macroeconomic impact of energy savings also applies to transport sectors. As less fossil fuels are demanded, less transport throughout the economic value chain of fossil fuels is required. In addition to these indirect effects of the uptake of green technologies on fossil fuel consumption, induced energy demand reduction can occur owing to endogenous technological change in E3ME, which is based on accumulated gross investment enhanced by R&D expenditures. As economic sectors grow and accumulate capital, there can be technical progress translated into further energy savings, owing to learning-by-doing, economies of scale and spillover effects (Barker et al., 2005). Furthermore, the introduction of the carbon tax can induce additional reductions in use of fossil fuels, as it increases their costs relative to less carbon intensive fuels. We highlight that not all macroeconomic interactions and feedbacks produce energy savings in E3ME. For instance, energy efficiency increases real income by reducing the real price of fossil fuels in response to reduced fossil fuel use, such that demand can increase (if it is not at saturation levels; Scrieciu et al., 2013a). Simulation results, having accounted for these complex and non-linear relations between energy and economic systems, show that GFRs reduce fossil fuel consumption in net terms (i.e. compared to the baseline).

CO_2 emissions. All GFR scenarios present net reductions in CO_2 emissions relative to the baseline (see Table XVIII). In the context of separately implemented technologies, the largest reduction in CO_2 emissions projections are found in scenarios EE and SB. In these scenarios, accumulated CO_2 emissions over 2018 to 2030 are reduced by, respectively, 3.6% and 3.3% relative to the baseline. In scenario EE, the high reductions compared to other technologies are due to the fact that energy efficiency technologies are broadly disseminated across all manufacturing sectors and present larger energy savings potentials. In scenario SB, comparatively high CO_2 reduction projections illustrate that halting deforestation of native forests can be a major driver of mitigation efforts in Brazil. Emissions abatement starts in 2025, after the seven-year period it takes between plant and harvest of forests, as manufacturing sectors start using sustainable biomass (i.e. charcoal and firewood) only then. Projections demonstrate that despite presenting a relatively late mitigation effect, uptake of sustainable biomass exhibits a significant impact on CO_2 emissions. Notwithstanding, scenario SB does not reduce Brazil's fossil fuel dependence, which can lead to carbon lock-in that increases mitigation costs in the long-term. Reductions in CO_2 emissions relative to the baseline are more substantial when more mitigation technologies are targeted by GFRs, especially in the scenario that simulates the most comprehensive green fiscal reform, EE+MR+NG+RN+SB+CO. In 2030, relative to 2018 under BAU, it is projected that the growth rate of CO_2 emissions in the reference scenario is virtually three times the growth rate in scenario EE+MR+NG+RN+SB+CO.

III. Supplementary Figures

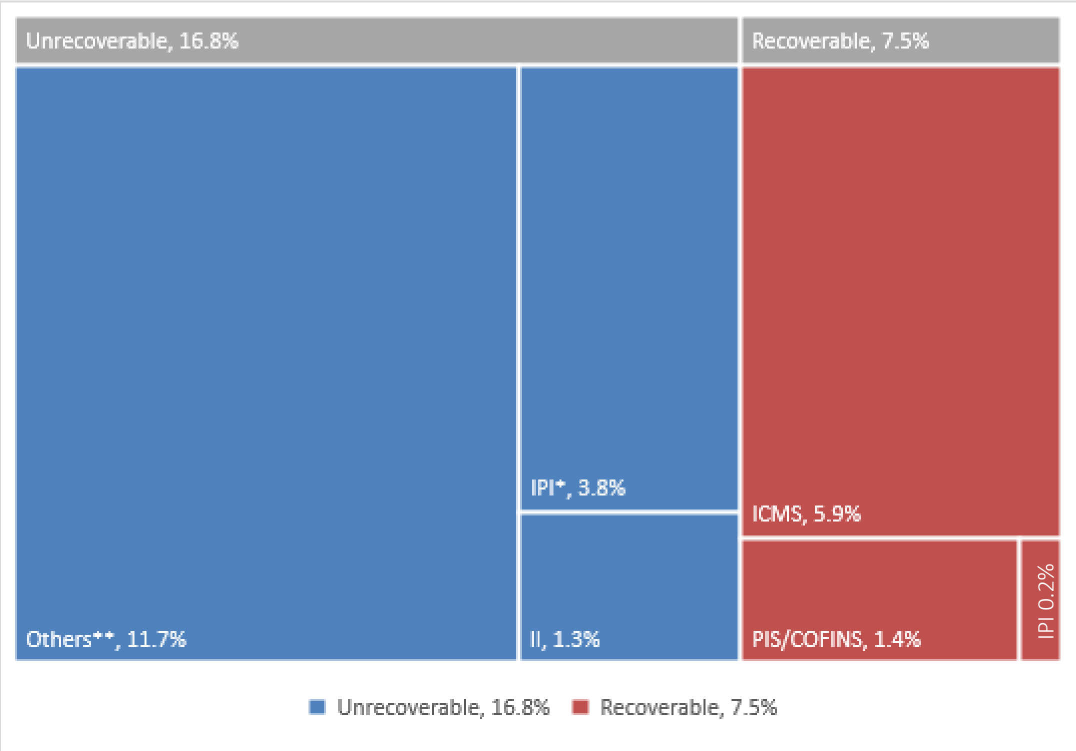

Figure I. The tax burden on investments in Brazil (% of investments)

Source: Based on FIESP (2010). Notes: (1) IPI* is IPI on investment. (2) Others** include income tax, social charges, property tax and other minor taxes.

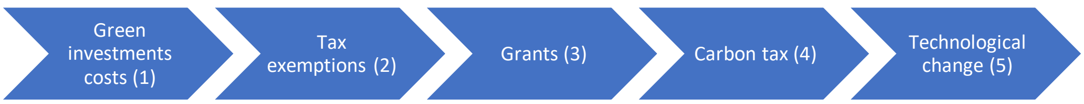

Figure II. Steps in modelling GFR scenarios

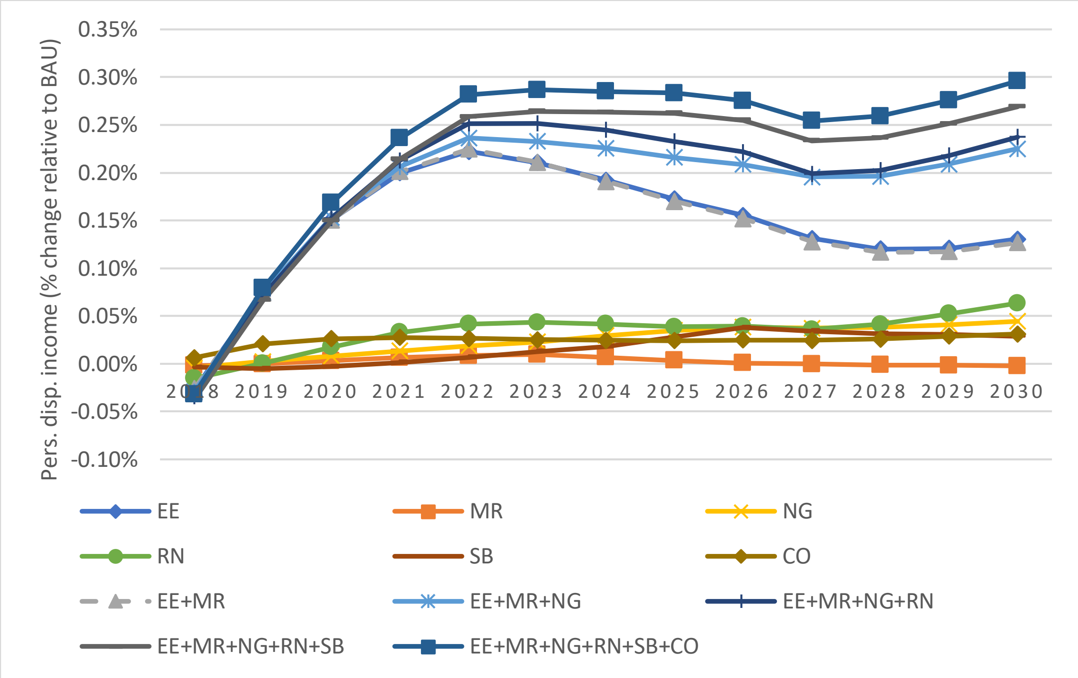

Figure III. Personal disposable income in green fiscal reform scenarios, % change relative to the baseline (2018-2030)

IV. SUPPLEMENTARY TABLES

Table I. Summary of tax structure and proposed tax exemptions to green investments

	Intermediary consumption of capital goods sector	Capital goods added value
IPI	0.2% (B1)	3.8% (A)
II	0.9%	0.4%
Others	6.1%	5.6%
ICMS	0.7% (B2)	5.2% (C1)
PIS/COFINS	0.4% (B3)	1.0% (C2)
Total	8.2%	16.1%
Exemption of capital goods from IPI (A): 3.84% Investment Drawback: (B1 + B2 + B3): 1.23% Immediate recovery of ICMS and PIS/COFINS (C1 + C2): 6.22% Total exemptions (A + B1 + B2 + B3 + C1 + C2): 11.29%		

Source: Based on FIESP (2010)**Error! Bookmark not defined.**.

Table II. Fossil fuel prices assumptions

Year	Brent crude oil*	Natural gas**	Steam coal***	Year	Brent crude oil*	Natural gas**	Steam coal***
2005	52	6	45	2018	131	12	122
2006	62	8	47	2019	137	13	126
2007	69	8	62	2020	143	14	130
2008	93	12	121	2021	149	14	134
2009	59	8	68	2022	155	15	138
2010	76	7	94	2023	161	15	142
2011	105	8	97	2024	167	16	146
2012	106	9	100	2025	173	16	150
2013	109	9	104	2026	179	17	155
2014	112	10	107	2027	185	18	159
2015	115	11	111	2028	192	18	164
2016	120	11	115	2029	198	19	168
2017	126	12	118	2030	205	20	173

Source: Based on IEA (2014). Notes: *Prices in USD/barrel; **Prices in USD/MBtu; and ***Prices in USD/tonne.

Table III. Implementation period by technology (in years)

Technology		Implementation period
Energy efficiency	Combustion optimization	5
	Heat recovery systems	5
	Steam recovery systems	5
	Furnace heat recovery systems	10
	New industrial processes	5
	Other measures	5
Materials savings and recycling		5
Shift to natural gas		5
Renewable energy	Biomass	0+7*
	Solar	5
Sustainable biomass		0+7*
Cogeneration		5

Source: Based on Henriques Jr (2010). Note: *After seven years (time it takes between plant and harvest of trees), full implementation occurs.

Table IV. Energy savings potential from energy efficiency technologies (%)

Fuel users	Enginee-ring etc. and Other industries	Paper & pulp and wood & printing	Textiles, clothing and foot-wear	Food, drink and tobacco	Ore-extrac-tion (non-energy)	Non-metallic mine-rals	Chemi-cals and phar-maceu-ticals	Non-ferrous metals	Iron & steel and ferro-alloys	Energy own use & transfor-mation
Total	16.0	17.2	16.0	10.6	21.3	24.9	22.1	7.9	34.2	18.8
Combustion optimization	2.0	2.5	2.0	2.0	3.0	2.3	3.0	2.0	2.9	0.1
Heat recovery systems	0.0	0.0	3.0	2.0	0.0	0.0	3.0	0.0	0.0	14.1
Steam recovery systems	5.0	5.5	5.0	2.0	0.0	1.1	3.0	0.0	0.0	0.3
Furnace heat recovery systems	5.0	2.4	0.0	3.0	18.3	14.7	6.0	5.9	7.0	0.3
New industrial processes	4.0	6.8	4.0	1.6	0.0	6.8	7.2	0.0	23.4	0.2
Other measures	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	1.0	3.8

Source: Adapted from World Bank (2010a), World Bank (2010b) and Henriques Jr (2010).

Table V. Energy savings potential from materials savings and recycling technologies (%)

Fuel users	Engineering etc. and Other industr.	Paper & pulp and wood & printing		Textiles, clothing and footwear	Food, drink and tobacco	Ore-extraction (non-energy)	Non-metallic minerals			Chemicals and pharmaceuticals	Non-ferrous metals	Iron & steel and ferro-alloys	Energy own use & transformation
Fuels	N/A	Natural gas	Heavy fuel oil	N/A	N/A	N/A	Other coal (including coke, coking coal etc.); crude oil; middle distillates	Hard coal; other gas (including furnace gas etc.)	Heavy fuel oil; natural gas	N/A	Heavy fuel oil	Hard coal; other coal (including coke, coking coal etc.); crude oil; heavy fuel oil; middle distillates; other gas (e.g. blast furnace gas); natural gas	N/A
Separate	N/A	6.9	8.6	N/A	N/A	N/A	3.2	2.3	3.3	N/A	3.4	2.9	N/A
Joint (2018-2030 average)	N/A	5.6	7.0	N/A	N/A	N/A	2.4	1.8	2.6	N/A	3.2	1.9	N/A

Source: Adapted from World Bank (2010a), World Bank (2010b) and Henriques Jr (2010).

Table VI. Potential shift between fossil fuels and natural gas (%)

Fuel users	Displaced fuels	% that is displaced
Energy own use & transformation	Hard coal; other coal (coke, coking coal etc.)	-6.0
	Heavy fuel oil	-6.0
Iron & steel and ferro-alloys	Heavy fuel oil	-100.0
Non-ferrous metals	Heavy fuel oil	-100.0
Chemicals and pharmaceuticals	Hard coal	-80.2
	Other coal (coke, coking coal etc.)	-100.0
	Heavy fuel oil	-90.1
Non-metallic mineral	Hard coal; other coal (coke, coking coal etc.)	-51.0
	Heavy fuel oil	-94.0
Ore-extraction (non-energy)	Other coal (coke, coking coal etc.)	-100.0
	Heavy fuel oil	-50.0
Food, drink and tobacco	Hard coal; other coal (coke, coking coal etc.)	-100.0
	Heavy fuel oil	-90.0
Textiles, clothing and footwear	Heavy fuel oil	-100.0
Paper & pulp and wood & printing	Hard coal	-100.0
	Other coal (coke, coking coal etc.)	-48.0
	Heavy fuel oil	-94.8
Engineering etc. and Other industries	Hard coal, other coal (coke, coking coal etc.), heavy fuel oil	-100.0

Source: Adapted from World Bank (2010a), World Bank (2010b) and Henriques Jr (2010).

Table VII. Potential shift between fossil fuels and renewable energy (%)

Fuel users	Engine-ering etc. and Other indus-tries	Paper & pulp and wood & printing	Textiles, clothing and foot-wear	Food, drink and tobacco		Ore-extrac-tion (non-energy)	Non-metallic minerals	Chemicals and pharma-ceuticals	Non-ferrous metals	Iron & steel and ferro-alloys	Energy own use & transfor-mation
Displaced fuels	N/A	Heavy fuel oil	N/A	Heavy fuel oil; natural gas	Heavy fuel oil	N/A	N/A	Heavy fuel oil; natural gas	N/A	Other coal (coke and coking coal)	N/A
% that is displaced	N/A	-5.2	N/A	Separate: -7.5 Joint: 0.0 (fuel oil) and -5.7 (natural gas)	-10.0	N/A	N/A	Separate: -7.4 Joint: -0.6 (fuel oil) and -5.6 (natural gas)	N/A	0.0	N/A
Fuel that is included	N/A	Biomass (firewood)	N/A	N/A (solar-thermal own use)	Biomass (fire-wood)	N/A	N/A	N/A (solar-thermal own use)	N/A	Other coal (char-coal)	N/A

Source: Adapted from World Bank (2010a), World Bank (2010b) and Henriques Jr (2010).

Table VIII. Avoided emissions from adoption of sustainable biomass, thousands of tonnes of carbon (2018-2030)

Fuel users	Separate	Joint
Energy own use & transformation*	N/A	N/A
Iron & steel and ferro-alloys	40,902	38,710
Non-ferrous metals	50	48
Chemicals and pharmaceuticals	68	8
Non-metallic minerals	16,045	18,667
Ore-extraction (non-energy)*	N/A	N/A
Food, drink and tobacco	10,330	6,368
Textiles, clothing and footwear	747	16
Paper & pulp and wood & printing	0	376
Engineering etc. and Other industries	5,854	2,481
Total	73,996	66,675

Source: Adapted from World Bank (2010a), World Bank (2010b) and Henriques Jr (2010). Note: *These sectors do not use firewood and charcoal.

Table IX. Reduced grid electricity use owing to cogeneration technologies, thousand toe (2018-2030)

Fuel users	Reduction in electricity consumed from grid
Energy own use & transformation	N/A
Iron & steel and ferro-alloys	422
Non-ferrous metals	N/A
Chemicals and pharmaceuticals	N/A
Non-metallic minerals	N/A
Ore-extraction (non-energy)	N/A
Food, drink and tobacco	8,485
Textiles, clothing and footwear	N/A
Paper & pulp and wood & printing	1,733
Engineering etc. and Other industries	N/A

Source: Adapted from World Bank (2010a), World Bank (2010b) and Henriques Jr (2010).

Table X. Investment costs by scenario, EUR_{2005} million (2018-2030)

Scenarios	EE	MR	NG	RN	SB	CO	EE+MR	EE+MR+NG	EE+MR+NG+RN	EE+MR+NG+RN+SB	EE+MR+NG+RN+SB+CO
2018	1,665	59	134	337	798	76	1,729	1,864	1,989	2,832	2,913
2019	1,791	63	136	352	816	78	1,859	1,996	2,127	2,988	3,071
2020	1,911	68	139	368	834	81	1,983	2,120	2,257	3,138	3,224
2021	2,002	71	141	382	853	84	2,075	2,211	2,354	3,254	3,343
2022	2,092	75	144	397	879	87	2,166	2,299	2,448	3,377	3,468
2023	1,693	0	147	0	906	91	1,694	1,825	1,827	2,783	2,876
2024	1,768	0	149	0	934	94	1,766	1,887	1,889	2,875	2,971
2025	1,856	0	152	0	139	97	1,853	1,968	1,969	2,121	2,220
2026	1,955	0	155	0	149	101	1,952	2,064	2,063	2,225	2,329
2027	2,060	0	158	0	160	105	2,058	2,170	2,169	2,343	2,451
2028	1,642	0	162	511	172	109	1,641	1,772	1,957	2,141	2,254
2029	1,729	0	165	532	177	113	1,728	1,864	2,057	2,244	2,363
2030	1,820	0	169	552	182	117	1,820	1,960	2,160	2,352	2,476
Total	23,986	336	1,952	3,431	7,000	1,232	24,324	26,000	27,265	34,673	35,959

Table XI. Industrial share of investment costs by scenario, % (2018-2030)

Sectors/Scenarios	EE	MR	NG	RN	SB	CO	EE+MR	EE+MR+NG	EE+MR+NG+RN	EE+MR+NG+RN+SB	EE+MR+NG+RN+SB+CO
Other mining	4.9%	0.0%	1.4%	0.0%	0.0%	0.0%	4.8%	4.4%	4.2%	3.3%	3.2%
Food, drink and tobacco	1.4%	0.0%	0.3%	11.0%	0.0%	80.4%	1.3%	1.3%	1.7%	1.4%	4.1%
Textiles, clothing and leather	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.3%	0.3%	0.2%	0.2%
Wood and paper	1.3%	12.5%	0.3%	0.0%	0.0%	9.1%	1.5%	1.4%	1.3%	1.0%	1.3%
Manufactured fuels	5.6%	0.0%	0.0%	0.0%	0.0%	0.0%	5.5%	5.2%	5.0%	3.9%	3.8%
Chemicals	7.6%	0.0%	1.5%	89.0%	0.0%	0.0%	7.5%	6.8%	10.7%	8.4%	8.1%
Non-metallic mineral products	11.9%	16.6%	0.2%	0.0%	0.0%	0.0%	11.9%	11.3%	10.8%	8.5%	8.2%
Basic metals	64.9%	70.9%	0.9%	0.0%	0.0%	10.5%	65.0%	60.3%	57.6%	45.3%	44.3%
Other*	2.2%	0.0%	0.4%	0.0%	0.0%	0.0%	2.2%	2.1%	2.0%	1.6%	1.5%
Gas supply	0.0%	0.0%	94.9%	0.0%	0.0%	0.0%	0.0%	6.9%	6.6%	5.2%	5.0%
Forestry	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	21.3%	20.5%

Note: *Other includes E3ME sectors 3, 8, 10, 12, 15, 16, 17, 18, 19, 20 and 21.

Table XII. GDP in green fiscal reform scenarios, % change relative to BAU (2018-2030)

Scenarios	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EE	0.07%	0.17%	0.26%	0.31%	0.34%	0.35%	0.36%	0.37%	0.39%	0.40%	0.40%	0.42%	0.43%
MR	0.00%	0.01%	0.01%	0.01%	0.01%	0.02%	0.01%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%
NG	0.01%	0.02%	0.03%	0.04%	0.05%	0.05%	0.05%	0.05%	0.05%	0.05%	0.05%	0.06%	0.06%
RN	0.00%	0.02%	0.04%	0.06%	0.07%	0.08%	0.09%	0.10%	0.11%	0.13%	0.15%	0.16%	0.17%
SB	-0.01%	-0.01%	0.00%	0.01%	0.02%	0.03%	0.04%	0.07%	0.07%	0.07%	0.06%	0.05%	0.04%
CO	0.01%	0.03%	0.03%	0.03%	0.03%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%
EE+MR	0.07%	0.17%	0.26%	0.31%	0.34%	0.35%	0.36%	0.37%	0.39%	0.40%	0.40%	0.42%	0.43%
EE+MR+NG	0.07%	0.18%	0.28%	0.32%	0.33%	0.30%	0.28%	0.27%	0.27%	0.28%	0.29%	0.31%	0.33%
EE+MR+NG+ RN	0.07%	0.18%	0.28%	0.33%	0.35%	0.33%	0.31%	0.30%	0.30%	0.31%	0.32%	0.34%	0.36%
EE+MR+NG+ RN+SB	0.06%	0.18%	0.28%	0.34%	0.37%	0.36%	0.35%	0.37%	0.38%	0.38%	0.38%	0.39%	0.40%
EE+MR+NG+ RN+SB+CO	0.07%	0.19%	0.30%	0.37%	0.40%	0.38%	0.37%	0.39%	0.39%	0.40%	0.40%	0.41%	0.42%

Table XIII. Investments in green fiscal reform scenarios, % change relative to BAU (2018-2030)

Scenarios	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EE	0.00%	0.40%	0.89%	1.31%	1.39%	1.32%	1.11%	0.91%	0.74%	0.62%	0.55%	0.48%	0.46%
MR	0.00%	0.02%	0.04%	0.06%	0.08%	0.08%	0.08%	0.05%	0.02%	0.01%	0.00%	-0.01%	-0.01%
NG	0.00%	0.04%	0.10%	0.13%	0.16%	0.17%	0.17%	0.17%	0.17%	0.16%	0.15%	0.15%	0.15%
RN	0.00%	0.01%	0.11%	0.23%	0.30%	0.32%	0.30%	0.27%	0.23%	0.20%	0.18%	0.18%	0.18%
SB	0.00%	-0.06%	-0.04%	0.02%	0.08%	0.14%	0.20%	0.24%	0.41%	0.42%	0.35%	0.28%	0.22%
CO	0.00%	0.07%	0.18%	0.15%	0.14%	0.12%	0.09%	0.08%	0.07%	0.06%	0.07%	0.07%	0.07%
EE+MR	0.00%	0.41%	0.90%	1.33%	1.42%	1.34%	1.11%	0.91%	0.74%	0.62%	0.55%	0.47%	0.45%
EE+MR+NG	0.00%	0.44%	0.96%	1.41%	1.51%	1.47%	1.28%	1.12%	1.01%	0.95%	0.92%	0.87%	0.86%
EE+MR+NG+ RN	0.00%	0.44%	0.97%	1.44%	1.61%	1.61%	1.42%	1.25%	1.11%	1.02%	0.99%	0.92%	0.91%
EE+MR+NG+ RN+SB	0.00%	0.38%	0.93%	1.46%	1.69%	1.76%	1.63%	1.50%	1.54%	1.46%	1.36%	1.22%	1.14%
EE+MR+NG+ RN+SB+CO	0.00%	0.43%	1.02%	1.57%	1.80%	1.85%	1.70%	1.56%	1.59%	1.51%	1.41%	1.27%	1.20%

Table XIV. Imports in green fiscal reform scenarios, % change relative to the baseline (2030)

	Other products	Fossil fuels	Total
EE	0.1%	-11.8%	-0.91%
MR	0.0%	-0.4%	-0.02%
NG	0.0%	-0.7%	-0.04%
RN	0.1%	-2.6%	-0.15%
SB	0.0%	0.1%	0.02%
CO	0.0%	0.1%	0.02%
EE+MR	0.1%	-11.9%	-0.91%
EE+MR+NG	0.1%	-2.6%	-0.11%
EE+MR+NG+RN	0.1%	-2.8%	-0.10%
EE+MR+NG+RN+SB	0.2%	-2.6%	-0.08%
EE+MR+NG+RN+SB+CO	0.2%	-2.7%	-0.08%

Table XV. Exports in green fiscal reform scenarios, % change relative to the baseline (2030)

Scenarios		EE	MR	NG	RN	SB	CO	EE+MR	EE+MR+NG	EE+MR+NG+RN	EE+MR+NG+RN+SB	EE+MR+NG+RN+SB+CO
Primary products		0.00%	0.00%	0.00%	0.00%	0.31%	0.00%	0.00%	0.01%	0.01%	0.36%	0.37%
Natural resource-intensive	Manufactured products	-0.49%	-0.02%	-0.03%	-0.21%	0.03%	0.08%	-0.51%	0.21%	0.20%	0.22%	0.28%
Low-technology		0.00%	0.00%	0.03%	-0.01%	-0.01%	-0.01%	0.00%	-0.01%	-0.01%	-0.02%	-0.03%
Medium-technology		0.46%	-0.01%	0.16%	1.21%	0.00%	0.02%	0.46%	0.57%	0.87%	0.87%	0.88%
High-technology		0.27%	0.00%	0.17%	0.03%	0.01%	0.01%	0.27%	0.30%	0.30%	0.32%	0.33%
Services		0.04%	0.00%	0.01%	0.01%	0.00%	0.00%	0.03%	0.06%	0.06%	0.07%	0.07%
Total		0.06%	-0.01%	0.06%	0.39%	0.02%	0.03%	0.05%	0.29%	0.39%	0.42%	0.44%

Table XVI. Trade balance in green fiscal reform scenarios, % change relative to BAU (2018-2030)

Scenarios	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EE	0.00%	-0.01%	0.10%	0.17%	0.34%	0.59%	0.91%	1.26%	1.60%	1.88%	2.09%	2.27%	2.41%
MR	0.00%	0.00%	-0.01%	-0.01%	-0.01%	-0.01%	0.00%	0.02%	0.03%	0.04%	0.04%	0.04%	0.04%
NG	0.00%	0.00%	0.02%	0.07%	0.11%	0.15%	0.14%	0.14%	0.14%	0.14%	0.13%	0.15%	0.18%
RN	0.00%	0.01%	0.01%	0.01%	0.04%	0.09%	0.17%	0.27%	0.42%	0.57%	0.73%	0.90%	1.00%
SB	0.00%	0.00%	0.00%	-0.01%	-0.02%	-0.02%	-0.03%	-0.04%	-0.04%	-0.03%	-0.03%	-0.01%	-0.01%
CO	0.00%	-0.01%	-0.03%	-0.02%	-0.01%	-0.01%	-0.01%	-0.01%	-0.01%	-0.02%	-0.02%	-0.02%	-0.01%
EE+MR	0.00%	0.01%	0.11%	0.17%	0.34%	0.59%	0.91%	1.26%	1.61%	1.89%	2.10%	2.28%	2.42%
EE+MR+NG	0.00%	0.00%	0.12%	0.15%	0.21%	0.24%	0.23%	0.20%	0.25%	0.32%	0.40%	0.54%	0.66%
EE+MR+NG+RN	0.00%	0.01%	0.13%	0.16%	0.22%	0.23%	0.23%	0.20%	0.28%	0.36%	0.50%	0.70%	0.82%
EE+MR+NG+RN+SB	0.00%	0.01%	0.12%	0.15%	0.20%	0.21%	0.19%	0.16%	0.25%	0.34%	0.47%	0.69%	0.81%
EE+MR+NG+RN+SB+CO	0.00%	0.01%	0.11%	0.14%	0.19%	0.21%	0.20%	0.17%	0.26%	0.36%	0.49%	0.71%	0.84%

Table XVII. Fossil fuels consumption in green fiscal reform scenarios, % relative to the baseline (2018-2030)

Scenarios	EE	MR	NG	RN	SB	CO	EE+MR	EE+MR+NG	EE+MR+NG+RN	EE+MR+NG+RN+SB	EE+MR+NG+RN+SB+CO
2018	-0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.8%	-0.8%	-0.8%	-0.7%	-0.8%
2019	-1.2%	-0.1%	-0.1%	-0.1%	0.0%	-0.1%	-1.3%	-1.4%	-1.4%	-1.3%	-1.4%
2020	-1.5%	-0.1%	-0.1%	-0.1%	0.1%	-0.1%	-1.6%	-1.8%	-1.8%	-1.8%	-1.8%
2021	-1.8%	-0.1%	-0.1%	-0.1%	0.1%	-0.2%	-1.9%	-2.2%	-2.3%	-2.2%	-2.3%
2022	-2.3%	-0.2%	-0.2%	-0.2%	0.1%	-0.2%	-2.4%	-2.7%	-2.8%	-2.7%	-2.8%
2023	-2.9%	-0.3%	-0.2%	-0.2%	0.1%	-0.2%	-3.0%	-3.2%	-3.3%	-3.2%	-3.3%
2024	-3.7%	-0.3%	-0.5%	-0.3%	0.1%	-0.2%	-3.8%	-4.0%	-4.2%	-4.1%	-4.1%
2025	-4.6%	-0.4%	-0.3%	-0.4%	0.1%	-0.2%	-4.8%	-4.8%	-5.1%	-5.0%	-5.1%
2026	-5.5%	-0.4%	-0.3%	-0.4%	0.1%	-0.2%	-5.7%	-5.8%	-6.7%	-6.7%	-6.7%
2027	-6.2%	-0.4%	-0.2%	-0.4%	0.1%	-0.1%	-6.4%	-6.6%	-7.3%	-7.3%	-7.4%
2028	-6.6%	-0.4%	-0.2%	-0.5%	0.1%	-0.1%	-6.8%	-7.1%	-8.0%	-7.9%	-8.0%
2029	-6.8%	-0.4%	-0.2%	-0.5%	0.0%	-0.1%	-7.1%	-7.4%	-8.3%	-8.2%	-8.3%
2030	-7.0%	-0.4%	-0.2%	-0.5%	0.0%	-0.1%	-7.2%	-7.6%	-8.4%	-8.4%	-8.5%
2018-2030	-4.0%	-0.3%	-0.2%	-0.3%	0.1%	-0.1%	-4.2%	-4.4%	-4.8%	-4.8%	-4.8%

Table XVIII. CO_2 emissions in green fiscal reform scenarios, % relative to the baseline (2018-2030)

Scenarios	EE	MR	NG	RN	SB	CO	EE+MR	EE+MR+NG	EE+MR+NG+RN	EE+MR+NG+RN+SB	EE+MR+NG+RN+SB+CO
2018	-1.2%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%
2019	-1.4%	-0.2%	-0.4%	-0.1%	0.0%	-0.1%	-1.7%	-2.2%	-2.2%	-2.2%	-2.2%
2020	-1.6%	-0.3%	-0.7%	-0.1%	0.1%	-0.1%	-1.9%	-2.8%	-2.8%	-2.8%	-2.8%
2021	-1.8%	-0.3%	-1.1%	-0.1%	0.1%	-0.1%	-2.2%	-3.4%	-3.5%	-3.4%	-3.4%
2022	-2.2%	-0.3%	-1.4%	-0.2%	0.1%	-0.1%	-2.6%	-4.1%	-4.2%	-4.1%	-4.2%
2023	-2.7%	-0.4%	-1.7%	-0.2%	0.1%	-0.1%	-3.0%	-4.8%	-4.9%	-4.8%	-4.9%
2024	-3.3%	-0.4%	-2.0%	-0.3%	0.1%	-0.1%	-3.7%	-5.2%	-5.3%	-5.2%	-5.3%
2025	-4.1%	-0.5%	-1.9%	-0.4%	-6.8%	-0.1%	-4.5%	-5.8%	-6.0%	-12.1%	-12.1%
2026	-4.8%	-0.5%	-1.8%	-0.4%	-6.8%	-0.1%	-5.2%	-6.4%	-7.1%	-13.2%	-13.3%
2027	-5.3%	-0.6%	-1.8%	-0.5%	-6.8%	-0.1%	-5.7%	-6.9%	-7.5%	-13.6%	-13.7%
2028	-5.6%	-0.6%	-1.7%	-0.5%	-6.8%	-0.1%	-6.0%	-7.1%	-7.8%	-13.9%	-14.0%
2029	-5.8%	-0.6%	-1.7%	-0.5%	-6.9%	-0.1%	-6.2%	-7.4%	-8.0%	-14.2%	-14.3%
2030	-5.9%	-0.6%	-1.6%	-0.5%	-7.0%	-0.1%	-6.3%	-7.5%	-8.1%	-14.4%	-14.5%
2018-2030	-3.6%	-0.4%	-1.4%	-0.3%	-3.3%	-0.1%	-4.0%	-5.1%	-5.4%	-8.4%	-8.5%

V. Supplementary References

Anger, A., Barker, T., 2015. The effects of the financial system and financial crises on global growth and the environment, in: Arestis, P., Sawyer, M. (Eds.), Finance and the Macroeconomics of Environmental Policy. Palgrave Macmillan, pp. 153–193.

Barker, T., 2008. The economics of avoiding dangerous climate change: an editorial essay on the Stern Review. Clim. Change 89, 173–194. https://doi.org/10.1007/s10584-008-9433-x

Barker, T., Anger, A., Chewpreecha, U., Pollitt, H., 2012. A new economics approach to modelling policies to achieve global 2020 targets for climate stabilisation. Int. Rev. Appl. Econ. 26, 205–221. https://doi.org/10.1080/02692171.2011.631901

Barker, T., Dada, W., Peterson, W., 2004. Software developments in the Cambridge Growth Project 1960-1976: The origins of software for space-time economics. J. Econ. Soc. Meas. 29, 173–182.

Barker, T., Pan, H., Köhler, J., Warren, R., Winne, S., 2005. Avoiding dangerous climate change by inducing technological progress: scenarios using a large-scale econometric model (No. 77), Tyndall Centre Working Paper. Tyndall Centre for Climate Change Research, Norwich.

Barker, T., Qureshi, M.S., Köhler, J., 2006. The costs of greenhouse gas mitigation with induced technological change: a meta-analysis of estimates in the literature (No. 89), Tyndall Centre Working Paper. Norwich.

Barker, T., Scrieciu, S., 2010. Modeling low climate stabilization with E3MG: towards a “New Economics” approach to simulating energy-environment-economy system dynamics. Energy J. 31, 137–164. https://doi.org/10.5547/ISSN0195-6574-EJ-Vol31-NoSI-6

Brazil, 2016. Third National Communication of Brazil to the United Nations Framework Convention on Climate Change – Volume III. Ministério da Ciência, Tecnologia e Inovação, Brasilia.

Brazil, 2015. Intended nationally determined contribution: towards achieving the objective of the UNFCCC. Federative Republic of Brazil, Brasilia.

Cambridge Econometrics, 2014. E3ME technical manual, version 6.0.

CNI, 2014. O custo tributário do investimento: as desvantagens do Brasil e as ações para mudar. CNI, Brasília.

Courvisanos, J., Doughney, J., & Millmow, A. (2016). Reclaiming pluralism in economics: essays in honour of John E. King. London and New York: Routledge.

Davis, J. (2014). Pluralism and anti-pluralism in economics: the atomistic individual and religious fundamentalism. Review of Political Economy, 26(4), 495–502. https://doi.org/10.1080/09538259.2014.950459

Dercon, S., 2012. Is green growth good for the poor? (No. 6231), Policy Research Working Paper. Washington, DC. https://doi.org/10.1093/wbro/lku007

Dow, S. (2004). Structured pluralism. Journal of Economic Methodology, 11(3), 275–290. https://doi.org/10.1080/1350178042000252965

Edenhofer, O., Knopf, B., Barker, T., Baumstark, L., Bellevrat, E., Chateau, B., Criqui, P., Isaac, M., Kitous, A., Kypreos, S., Leimbach, M., Lessmann, K., Magné, B., Scrieciu, S., Turton, H., van

Vuuren, D.P., 2010. The economics of low stabilization: model comparison of mitigation strategies and costs. Energy J. 31, 11–48. https://doi.org/10.5547/ISSN0195-6574-EJ-Vol31-NoSI-2

Edenhofer, O., Lessman, K., Kemfert, C., Grubb, M., Köhler, J., 2006. Induced technological change: exploring its implications for the economics of atmospheric stabilization. Synthesis report from the innovation modeling comparison project. Energy J. 27, 57–107. https://doi.org/10.5547/ISSN0195-6574-EJ-VolSI2006-NoSI1-3

EPE. (2017). 2017 Statistical Yearbook of Electricity. Rio de Janeiro: EPE.

European Commission. (2016). Impact assessment accompanying the document Proposal for a Directive of the European Parliament and of the Council amending Directive 2012/27/EU on Energy Efficiency. Brussels: European Commission.

Evans, G.W., Ramey, G., 2006. Adaptive expectations, underparameterization and the Lucas critique. J. Monet. Econ. 53, 249–264. https://doi.org/10.1016/j.jmoneco.2004.12.002

FIESP, 2010. Relatório FIESP sobre custos tributários do investimento. FIESP, São Paulo.

Garnett Jr., R. (2006). Paradigms and pluralism in heterodox economics. Review of Political Economy, 18(4), 521–546. https://doi.org/10.1080/09538250600915725

Gramkow, C., Gordon, J.L., 2011. As características estruturais da inserção externa brasileira e suas principais implicações – 2000/2010. Cad. do Desenvolv. 6, 93–118.

Gramkow, Gordon, J.L., 2015. Aspectos estruturais da economia brasileira: heterogeneidade estrutural e inserção externa de 1996 a 2009. Cad. do Desenvolv. 9, 35–61.

Haynes, P., Linder, S., & Sewell, M. (2011). Modelling energy-environment-economy interdependencies: a comparative analysis of ten E3 models. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.1839649

Henriques Jr, M.F., 2010. Potencial de redução de emissão de gases de efeito estufa pelo uso de energia no setor industrial brasileiro. PhD thesis. Federal University of Rio de Janeiro.

IBGE, 2010. Pesquisa de inovação tecnológica 2008.

IEA, 2014. World energy outlook 2014. IEA, Paris. https://doi.org/10.1787/weo-2014-en

IEDI, 2010. Incentivos para inovação: o que falta ao Brasil.

IPCC, 2014. Climate change 2014: mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Jayme Jr, F., 2003. Balance-of-payments-constrained economic growth in Brazil. Brazilian J. Polit. Econ. 23, 62–84.

Kaldor, N., 1966. The causes of the slow rate of growth of the United Kingdom economy. Cambridge University Press, Cambridge.

Kalecki, M., 1983. Crescimento e ciclo das economias capitalistas. Hucitec, São Paulo.

Keynes, J.M., 1936. General theory of employment, interest and money. Palgrave Macmillan, London.

Kosonen, K., 2012. Regressivity of environmental taxation: myth or reality?, in: Milne, J., Andersen, M. (Eds.), Handbook of Research on Environmental Taxation. Edward Elgar, Cheltenham.

La Rovere, E., Wills, W., Pereira Jr, A., Dubeux, C., Cunha, S., Oliveira, B., Moreira, M., Watanabe, S., Loureiro, S., Moreira, L., Grottera, C., Harfuch, L., Weiss, M., Santos, L., Carvalho, P., Kishinami, R., Zveibil, V., Santos, L., Kimura, W., Santos, T., Toni, A., Bachion, L., Lima, R., Zambianco, W., Nassar, A., Walter, M., Marcondes, S., Ely, R., Lefevre, J., Oliveira, L., Zicarelli, I., 2016. Implicações econômicas e sociais de cenários de mitigação de gases de efeito estufa no Brasil até 2030: projeto IES-Brasil.

Mercure, J.-F., Pollitt, H., Bassi, A., Viñuales, J., Edwards, N., 2016. Modelling complex systems of heterogeneous agents to better design sustainability transitions policy. Glob. Environ. Chang. 37, 102–115. https://doi.org/10.1016/j.gloenvcha.2016.02.003

MME, & EPE. (2007). Plano Nacional de Energia 2030: Projeções. Brasília: MME; EPE.

Nassif, A., Feijó, C., Araújo, E., 2015. Structural change and economic development: is Brazil catching up or falling behind? Cambridge J. Econ. 39, 1307–1332. https://doi.org/10.1093/cje/beu052

OECD, 2008. OECD glossary of statistical terms.

Parry, I., Pizer, W., 2007. Emissions trading versus CO2 taxes. Resources for the future, Washington.

Pollitt, H., Barker, A., Barton, J., Pirgmaier, E., Polzin, C., Lutter, S., Hinterberger, F., Stocker, A., 2010. A scoping study on the macroeconomic view of sustainability - Final report for the European Commission, DG Environment.

Pollitt, H., Mercure, J.-F., 2018. The role of money and the financial sector in energy-economy models used for assessing climate and energy policy. Clim. Policy 18, 184–197. https://doi.org/10.1080/14693062.2016.1277685

Rathmann, R. (org.), 2017. Modelagem integrada e impactos econômicos de opções setoriais de baixo carbono. Ministério da Ciência, Tecnologia, Inovação e Comunicação, Brasília.

Robb, G., Tyler, E., & Cloete, B. (2010). Carbon trading or carbon tax? Weighing up South Africa's mitigation options. In H. Winkler, A. Marquard, & M. Jooste (Eds.), Putting a price on carbon. Economic instruments to mitigate climate change in South Africa and other developing countries (pp. 196–213). Cape Town: Energy Research Centre, University of Cape Town. https://doi.org/10.3763/cpol.2010.0690

Santos, R., Rosa, L. P., Arouca, M., & Ribeiro, A. (2013). The importance of nuclear energy for the expansion of Brazil's electricity grid. Energy Policy, 60, 284–289. https://doi.org/10.1016/j.enpol.2013.05.020

Scrieciu, S., 2011. Towards new thinking in economics: Terry Barker on structural macroeconomics, climate change mitigation, the relevance of empirical evidence, and the need for a revised economics discipline. World Econ. 12, 115–144.

Scrieciu, S., Barker, T., Ackerman, F., 2013a. Pushing the boundaries of climate economics: critical issues to consider in climate policy analysis. Ecol. Econ. 85, 155–165. https://doi.org/10.1016/j.ecolecon.2011.10.016

Scrieciu, S., Rezai, A., Mechler, R., 2013b. On the economic foundations of green growth discourses: the case of climate change mitigation and macroeconomic dynamics in economic modeling. Wiley Interdiscip. Rev. Energy Environ. 2, 251–268. https://doi.org/10.1002/wene.57

Spash, C., & Ryan, A. (2012). Economic schools of thought on the environment: investigating unity and division. Cambridge Journal of Economics, 36(5), 1091–1121. https://doi.org/10.1093/cje/bes023

Stern, N., 2016. Current climate models are grossly misleading. Nature 530, 407–409.

van Vuuren, D.P., Hoogwijk, M., Barker, T., Riahi, K., Boeters, S., Chateau, J., Scrieciu, S., van Vliet, J., Masui, T., Blok, K., Blomen, E., Kram, T., 2009. Comparison of top-down and bottom-up estimates of sectoral and regional greenhouse gas emission reduction potentials. Energy Policy 37, 5125–5139. https://doi.org/10.1016/j.enpol.2009.07.024

Withana, S., ten Brink, P., Kretschmer, B., Mazza, L., Hjerp, P., Sauter, R., Malou, A., Illes, A., 2013. Evaluation of environmental tax reforms: international experiences - final report. Institute for European Environmental Policy, Brussels.

World Bank, 2017. Carbon tax guide: a handbook for policy makers. World Bank, Washington.

World Bank, 2010a. Brazil low-carbon: country case study. World Bank, Washington.

World Bank, 2010b. Estudo de baixo carbono para o Brasil. Emissões do setor da indústria. Tema O - relatório técnico.