2nd International Conference on Energy and Environment:
bringing together Engineering and Economics
Guimarães, Portugal
18-19 June, 2015

OVERLOOKED IMPACTS OF POWER GENERATION: THE LIFE CYCLE SIDE OF THE STORY

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KEYWORDS
Energy modelling optimisation, Climate change mitigation, Brazil.

ABSTRACT

This work seeks to evaluate the implications of a life cycle assessment of greenhouse gas (LCA-GHG) emissions in the optimisation of the power generation mix of Brazil through 2050, under baseline and low-carbon scenarios. Furthermore, this work assesses the impacts of enacting a tax on LCA-GHG emissions as a strategy to mitigate climate change. To this end, a model that integrates regional life cycle data with optimised energy scenarios was developed using the MESSAGE-Brazil integrated model.

Following a baseline trend, the power sector in Brazil would increasingly rely on conventional coal technologies. GHG emissions in 2050 are expected to increase 15-fold. When enacting a tax on direct-carbon emissions, advanced coal and onshore wind technologies become competitive, GHG emissions peak at 2025 and decrease afterwards, reaching an emission level 40% lower in 2050 than that of 2010. However, if impacts were evaluated through the entire life cycle of power supply systems, LCA-GHG emissions increase to a level 50% higher in 2050 than 2010 emissions under the same tax. This is due to loads associated with the construction of plant infrastructures and extraction and processing of fossil fuel resources. Thus, this study suggests that taxes might not be as effective in tackling GHG emissions as predicted in past studies if they are only applied to direct emissions.

INTRODUCTION

Brazil boasts one of the World's largest shares of renewable energies in the power generation portfolio, accounting for more than 78% share coming from non-fossil resources (EPE 2014a). Nonetheless, this relatively environmentally friendly profile is currently shifting to another direction. Brazil's economic growth has ramped up energy consumption, which is projected to increase by some 50% in the next decades. Following a business-as-usual scenario, a considerable portion of the new baseload power in Brazil will be supplied by fossil fuels, and, to some extent, by advanced renewable energy systems such as wind and PV-solar power (Lucena et al. 2015).

A major challenge in developing the expansion of the power generation system is how to define an optimal one that guarantees energy security of supply and complies with climate change mitigation objectives, without undermining economic development and social inclusiveness. In order to expand the power generation system several factors should, therefore, be taken into consideration, including minimisation of total generation costs and reduction of GHG emissions.

In the literature, few studies have aimed at forecasting the Brazilian generation mix considering these factors (Borba et al. 2012; Nogueira et al. 2014; Lucena et al. 2015). While relevant to the field, these studies, with a few exceptions (Dale et al. 2013), only account for the direct GHG emissions of power systems, which clearly benefit renewable energies, as they have minimal direct emissions (Portugal Pereira et al. 2013). Nonetheless, the life cycle assessment of GHG emissions (LCA-GHG) should not be neglected, as renewable energies require energy intensive materials and indirect consumption of fossil fuels in their material life cycle (Varun et al. 2009).

Aiming at filling this gap, this work seeks to evaluate the implications of LCA-GHG emissions in the optimisation of Brazil's power generation mix in a 2050 horizon, under baseline and low-carbon scenarios considering a range of costs and GHG constrains. Furthermore, this work assesses the impacts of enacting a tax on LCA-GHG emissions from the power sector as a market-based mechanism strategy to mitigate climate change. To this end, a robust model has been developed by integrating regional life cycle data of electricity generation systems in Brazil with optimised energy scenarios developed by using the MESSAGE-Brazil model v.1.3 (Lucena et al. 2015).

ANALYTICAL FRAMEWORK

To assess the optimisation of the power generation mix and the implications of taxing direct- and LCA-GHG emissions, the present research is organised in three methodological stages as shown in Figure 1, entailing (i) characterisation and parameterisation of energy systems, (ii) developing a database of LCA-GHG emissions, and (iii) model simulation of optimal electricity supply mixes accounting for direct- and LCA-GHG emissions. The following sections describe each of these stages in detail.

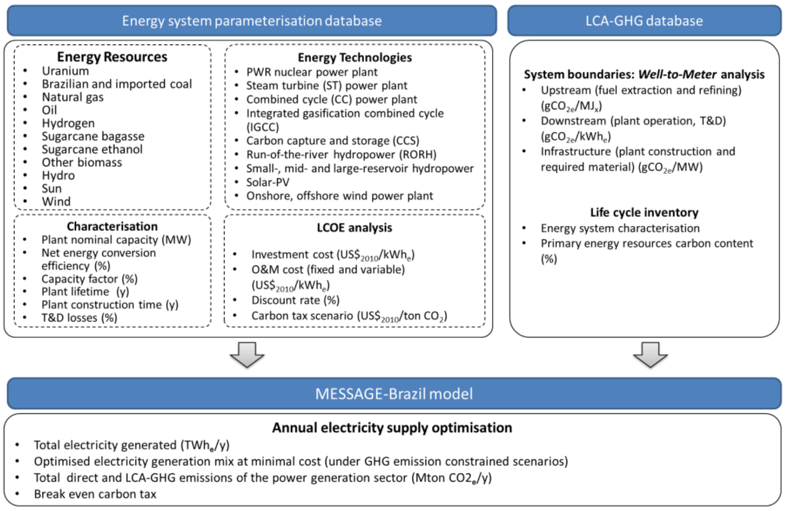


Figure 1: Analytical framework, data requirements and model outputs

Characterisation and parameterisation of energy systems

Table 1 displays technical parameters of power generation technologies considered in this study. Overall, it includes 12 primary and secondary energy sources, comprising uranium, fossil fuels (endogenous and imported coal, natural gas, and oil), renewables (hydropower, sugarcane bagasse, ethanol, forestry wastes, wind, and solar) and hydrogen. The technological chains encompass nuclear pressurized water reactor (PWR) plants, thermal power plants fired by oil, coal (pulverized – PC, fluidized-bed – FBC and integrated gasification combined cycle – IGCC) and natural gas (open and combined cycle), as well as renewable-based technologies, such as small mid and large-reservoir hydropower plants, thermal power plants burning sugarcane bagasse and other forestry wastes, onshore and offshore wind farms, solar-PV and concentrated solar power (CSP) facilities and decentralised Otto-engine generators powered with ethanol. Carbon capture and storage (CCS) technologies have also been taken into consideration in fossil fuel-based and biomass-based thermal power plants as feasible end-of-pipe mitigation strategies.

Table 1. Characteristics of electricity generation systems evaluated in this study

Period	System description	Nominal capacity (MW_e/yr)		Capacity factor (%)		Plant lifetime (yr)		Net energy efficiency (η_e)[(a)] (%)	
		2010	2050	2010	2050	2010	2050	2010	2050
Nuclear PWR	PWR with an enrichment of 3% and a burn-up of 28.5kgU_3O_8/GWh. Fuel is not recycled. Radioactive waste contained in drums and stored in a storage centre in Central Nuclear Almirante Álvaro Alberto	1000	1250	83	85	60	60	100	100
Coal-ST	Coal plant operating in pulverized –	750	750	50-85	50-85	40	40	29-40	17-35

	PC, fluidized-bed – FBC and integrated gasification combined cycle – IGCC. With and without CCS end-pipe facility.								
Natural gas-OC and CC	NG open- (OC) and combined-cycle (CC) power plant. With and without CCS facility.	1350	1350	29-85	29-85	40	40	35-50	35-55
HFO-ST	HFO-ST power plant with SCR and FGD. With and without CCS facility.	450	450	54	54	40	40	30-33	30-33
Diesel-ST	Diesel-ST power plant with SCR and FGD. With and without CCS end-pipe facility.	450	450	20	20	40	40	30-35	30-35
Hydrogen	Fluidized-bed gasifier powered by natural gas or wood chips. Without CCS.	450	450	29-54	54-85	30	30	43-48	43-50
Hydropower	Small-, mid- and large-hydro power plants.	30-300	30-300	42-57	54-58	40	40	100	100
Biomass co-generation	Combined heat and power plant using sugarcane bagasse or wood chips as feedstock; includes fuel storage.	10	10	14-35	35-60	30	30	30	30
Ethanol	Stationary Otto engine generator burning ethanol in decentralised systems	1	1	20	20	15	15	44	44
Wind (Onshore and offshore)	Wind turbines in a mid-size park includes cables, transformers.	4	4	39-40	33-40	20	20	100	100
Solar-PV	Decentralised rooftop type PV with aluminium frame and rack. The PV cells use solar-grade (SOG) polycrystalline silicon.	0.003	0.003	30	30	35	35	100	100
Concentrated solar power	CSP plants with wet-cooled parabolic troughs operating in stand-alone conditions and with 12% biomass/NG auxiliary fuel	50	50	30-60	30-60	35	35	100	100

(a) In this study, net energy efficiency of non-combustible energy sources, except for biomass, is defined as the percentage of fossil fuel input energy that is retrieved as electricity output. Therefore, Hydropower, windpower, solar-PV, CSP and nuclear energy systems present a virtual net energy efficiency of 100%.

Database of LCA-GHG emissions

In this study, the database of LCA-GHG emissions has been developed by applying an attributional life cycle assessment (ALCA)[1], following the ISO 14040-44 guidelines (ISO 2006). The selected functional unit is the electricity supplied to end-users to fulfill their yearly demand in TWh. Total GHG emissions have been calculated as the sum of the power generation life cycle sub-systems, including both upstream (extraction of fuels and raw materials, fuel processing and transportation) and downstream processes (operation of power plants and transmission and distribution to the national grid up to end-users). The material life cycle, the so-called "Cradle-to-Gate" cycle, has also been taken into account, comprising the construction of the thermal power plant infrastructure and the manufacture of material requirements for the construction of renewable power generation facilities, namely hydro dams, windmills, solar-PV panels and CSP parabolic troughs.
Although the Brazilian national electric system is represented in the model by three regional divisions, namely North, Northeast and Central-South-Southeast, the LCA database does not take into account regional specificities of these sub-systems. It rather includes national averages of transmission and distribution losses, conversion efficiency of processes and technical characteristics of plants, as described in Table 1.
The LCA-GHG was developed by simulating input and output streams that describe power generation processes with SimaPro 8.0.1® model architecture (Goedkoop et al. 2014). SimaPro is an LCA software that allows users to customise inventory libraries of all stages of the life cycle

[1] In literature, LCA is classified in two different types: attributional and consequential. The Attributional LCA evaluates the average impacts of a system without assessing the implications beyond its system boundary. In the context of power generation systems, this approach is followed when assessing impacts of average power grid mixes. The Consequential LCA, on the other hand, describes the effects of changes introduced by a new system external to LCA boundaries. This approach is followed when assessing, for instance, the generation of marginal power.

(used materials, fuel extraction, processing and delivery). Data was collected from EcoInvent database (Pré Consultants 2013), governmental agencies, namely the Brazilian Energy Research Company (EPE 2014b) and the National Regulatory Electricity Agency (ANEEL 2011) and relevant literature (Coltro et al. 2003; Macedo et al. 2008; San Miguel & Corona 2014; Corona & San Miguel 2015).

Table 2 summarises the carbon dioxide equivalent (CO_{2eq}) emissions[2] of power supply systems projected in a 2050 horizon, expressed in gCO_{2eq}/kWh, of power generation technologies during their full life cycle, including upstream, infrastructure and downstream stages. Fossil fuel thermal power plants are the main drivers of environmental loads, ranging between 89 and 1,329 gCO_{2eq} per kWh_e of power supplied to end-users. Although plants equipped with CCS facilities reduce impacts significantly, leading to a reduction up to 80-90% of end-of-pipe CO_2 emissions, this technology results in an "energy penalty", as it requires additional consumption of fuel and consequently emits supplementary upstream GHG emissions (Castelo Branco et al. 2013). Thus, while downstream processes of conventional thermal plants contribute to 87-96% of total environmental burdens, in the case of CCS thermal power plants downstream processes account for roughly 45% of total emissions, being the upstream processes more impactful.

Nuclear power has lower GHG emissions than fossil fuel technologies, as downstream impacts are nearly null because the fuel enrichment process and nuclear fission reactions do not release direct air pollutants to the atmosphere. Thus, GHG emissions are essentially related to upstream processes, during uranium extraction, and energy consumed in the enriched uranium production. However, if radiation exposure and human health impacts were accounted in this analysis, nuclear technology would present elevated impacts. Also, this study does not analyse plant decommission procedures and the treatment of nuclear residues, which exceed human time scales and would increase the overall GHG emissions significantly.

In terms of renewable energy sources, impacts vary between 4.4 and 135 gCO_{2e}/kWh, mainly from material life cycle of plant infrastructure. Thermal power plants fired with biomass contribute to the highest GHG emissions among renewable technologies. Nonetheless, their emissions are lower than those of fossil fuel chains. Biomass emissions derive from upstream processes during farming, processing and collection of feedstock. Solar-PV and CSP also contribute to GHG emissions due to the energy-intensive materials required to build and assemble renewable facilities. In the case of hybrid CSP units supplemented with biomass or natural gas, burdens also result from fuel combustion during plant operation. Onshore and offshore windmills, on the other hand, are the most attractive technologies, followed by hydropower plants. Nonetheless, large reservoirs and flooding of organic matter in tropical environments may emit considerable amounts of methane, whose global warming potential (GWP) is 34 greater than carbon dioxide (IPCC 2014), from vegetation that decays under anaerobic conditions and from the water passing the turbines and spillway (Rosa et al. 2004; IEA 2012). As methane concentration varies widely with type of vegetation, time and external variables, such as temperature, inflow rate, wind, water depth and oxygen content (Liden 2013), there is no consensus on the GHG emission factor quantification. Furthermore, part of methane emissions might come from upstream flows, such as industrial effluents and sewage discharge. Thus, methane emissions are very uncertain. For this reason, direct impacts of hydropower plants were not considered in this study. This issue is, however, relevant and should be evaluated in detail in future studies.

[2] Carbon dioxide equivalent emissions (CO_{2eq}) are calculated by the following expression: $CO_{2eq} = CO_2 + 34 \cdot CH_4 + 298 \cdot N_2O$, according to the GWP factors suggested by IPCC in its 5[th] assessment report (Myhre et al. 2013).

Table 2. Carbon dioxide equivalent emissions of electricity generation systems (gCO_{2eq}/kWh) in 2050

	Upstream	Downstream	Infrastructure	Total
Nuclear PWR power plant	41.42	0.00	1.77	43.19
Brazilian coal thermal power plant	144.54	1183.41	1.42	1329.38
Brazilian coal thermal power plant with CCS	249.22	204.04	1.42	454.68
Imported coal thermal power plant	111.48	902.40	0.84	1014.71
Imported coal thermal power plant with CCS	126.68	102.55	0.84	230.06
Natural gas combined cycle thermal power plant NG	21.81	476.96	0.05	498.82
Natural gas combined cycle thermal power plant NG with CCS	27.89	61.01	0.05	88.96
Natural gas open cycle thermal power plant NG	34.27	749.50	0.05	783.82
Heavy fuel oil thermal power plant	123.93	949.36	2.37	1075.65
Heavy fuel oil thermal power plant with CCS	137.63	105.43	2.37	245.43
Diesel thermal fuel power plant	155.39	1011.14	6.40	1172.93
Diesel fuel thermal power plant with CCS	186.47	121.34	6.40	314.21
Hydrogen gasifier power with NG	93.26	0.00	0.05	93.31
Hydrogen gasifier power with wood chips	51.57	0.00	0.08	51.65
Hydropower plant (<30MW)	0.00	0.00	12.94	12.94
Hydropower plant (30-300MW)	0.00	0.00	12.85	12.85
Hydropower plant (>300MW)	0.00	0.00	15.90	15.90
Sugarcane bagasse thermal power plant (open cycle)	21.53	2.64	2.03	26.19
Wood chip thermal power plant (open cycle)	63.73	2.64	1.18	67.55
Ethanol power	128.18	0.79	6.40	135.37
Solar-PV	0.00	0.00	26.87	26.87
Wind – onshore	0.00	0.00	4.37	4.37
Wind – offshore	0.00	0.00	4.76	4.76
CSP stand-alone unit	0.00	0.00	30.57	30.57
Hybrid Wood chip CSP plant (12% fuel)	7.39	1.60	33.63	42.61
Hybrid NG CSP plant (12% fuel)	4.77	104.27	33.01	142.05

Scenario modelling

Power supply portfolio scenarios for Brazil in a 2050 horizon have been developed in the Model for Energy Supply System Alternatives and their General Environmental Impact tailored to a Brazilian context (hereafter referred to as MESSAGE-Brazil v.1.3), as described in (Lucena et al. 2010; Borba et al. 2012; Malagueta et al. 2014; Nogueira et al. 2014). The MESSAGE-Brazil v.1.3 model is an integrated energy system model that estimates the least costly expansion strategy for the Brazilian energy supply system to meet a certain exogenous demand, under specified constrains, namely energy resource availability, industrial installation capacity of each technology, investment costs, and political, social and environmental constraints. To this end, the model minimises the total cost of the entire energy system, considering different primary fossil and renewable energy sources and the interaction of conversion technologies to produce the required energy services to end-use sectors (industrial, energy, transport, residential, agricultural and waste). In this work, however, the model is strictly focused on the power supply sector, divided in three sub-regions to characterise the country's national inter-connected grid.

A baseline and two low-carbon scenarios have been designed. The baseline scenario reflects the current state of affairs of the Brazilian power supply sector and energy policy, assuming a lax attitude towards mitigation of climate change. In this case, the power sector expansion prioritises least-cost technologies without considering environmental externalities. Thus, under this scenario, no carbon restrictions have been introduced in the model and the optimised power supply portfolio foresees an increasing share of fossil fuel technologies to fulfil the demand in a 2050 horizon.

The low-carbon scenarios evaluate the implications of introducing a carbon tax that rises to US$100 per tonne of CO_{2eq} in 2050 applied to (i) direct-GHG emissions from combustion of fossil fuels in downstream processes (scenario 'C100'), and (ii) LCA-GHG emissions from the entire life cycle of power supply chain, including upstream, downstream and material "Cradle-to-Gate" life cycles (scenario 'L100'). Table 3 synthesises the progression of the applied carbon tax over time until a 2050 horizon.

Table 3. Carbon tax progression in the baseline and low-carbon policy scenarios (US$2010/tC)

Scenario	2010	2015	2020	2025	2030	2035	2040	2045	2050
Baseline	0	0	0	0	0	0	0	0	0
Low-carbon (C100 and L100)	0	0	25	35	55	75	85	95	100

RESULTS AND DISCUSSION

The power supply portfolio is shown in Figure 2. Results suggest a two-fold increase in demand in a 2050 horizon, thanks to improved quality of life and rising consumption patterns of the Brazilian population. Thus, following a baseline trend, the power demand rises from 540 TWh in 2010 to 1,022TWh in 2050. This finding goes in line with previous scenarios developed by (IEA 2013; Nogueira et al. 2014; Lucena et al. 2015). To fulfil this demand in the short-term, the power supply expansion is based on an increasing capacity of hydropower, primarily by implementing new mid-reservoir dams. Thus, in 2020, the share of hydropower grows by 34% from 402 TWh in 2010 to 539 TWh. In the same period, legacy natural gas thermal power plants are projected to shut down in the end of their operational lifetime. From 2020 onwards, the hydropower expansion is limited due to technical, social and environmental constrains. Thus, in the long-term, the expansion of the sector relies on increasing capacity of conventional thermal power plants. Between 2020 and 2050, coal-based power ramps up from 10 TWh in 2010 to 372 TWh. Currently, fossil fuel thermal power plants are only used during peak periods to optimise the use of hydropower plants. However, in the long view, the increasing capacity of fossil fuel thermal power plants is projected to be used as baseload power.

Regarding renewable energy sources, the baseline scenario exhibits an ascending curve of wind onshore and distributed solar-PV technologies. Nonetheless, without aggressive governmental incentives, these technologies still play a minor role in the generation portfolio, accounting for 7% of the total supply, equivalent to 67 TWh.

Nuclear power is also a minor actor in the power supply portfolio. The implementation of new reactors is involved in a large controversy about possible accidents and risks toward the environment and local communities, nuclear waste storage and treatment, plant decommission high capital and operating costs. Thus, under a baseline trend, the expansion capacity is restricted to current reactors operating in 2050 or projects already approved and under construction[3], i.e., Angra #2 (1.35 GW) and Angra#3 (1.44 GW), which will supply 20.2 TWh yearly in 2050.

In a scenario where a tax on carbon emissions from the power sector is enacted (Scenario ‘C100’), the expansion of power supply sector would rely on advanced coal thermal power technologies with higher conversion efficiency and lower GHG emissions than conventional coal technologies and also CCS facilities. Thus, from 2030 onwards, scenario ‘C100’ reveals a growing expansion of IGCC plants in replacement of conventional technologies. In 2050, this scenario shows a share of 22% of IGCC units, nearly half equipped with CCS units. Expansion is also based on an increasing capacity of wind onshore farms, which contribute to 11% of total generation. Distributed solar-PV increases its share, ensuring 3% of total generation. Nuclear power expands up to 7.7 GW, equivalent to 58 TWh, 4% of total share.

When applying a tax on the LCA-GHG emissions (scenario ‘L100’), the share of energy systems in the power supply sector portfolio does not change significantly. This is due to a structural limitation of optimisation modelling. MESSAGE-Brazil v.1.3 is an integrated energy model that finds optimised mixes for the energy system as a whole, rather than evaluating sectorial optimal solutions. For this reason, the mix under direct- and LCA-GHG emissions does not change significantly. Nonetheless, under LCA-GHG emissions, minor deviations were observed. The share of biomass thermal power plants and CCS facilities declines, while the share of wind onshore and CSP rises. This is due to environmental burdens from biomass processing and coal extraction upstream

[3] Currently there are two NPP operating in Brazil, in Rio de Janeiro State: Angra#1 has operated since 1985 and its decommission is predicted to 2045; Angra#2 started operating in 2001 and will be operating during the timeframe of this study analysis. A third reactor, Angra#3, is currently under construction, predicted to full operate in 2018.

processes and the construction of wind farm infrastructure, which increase significantly overall LCA-GHG emissions.

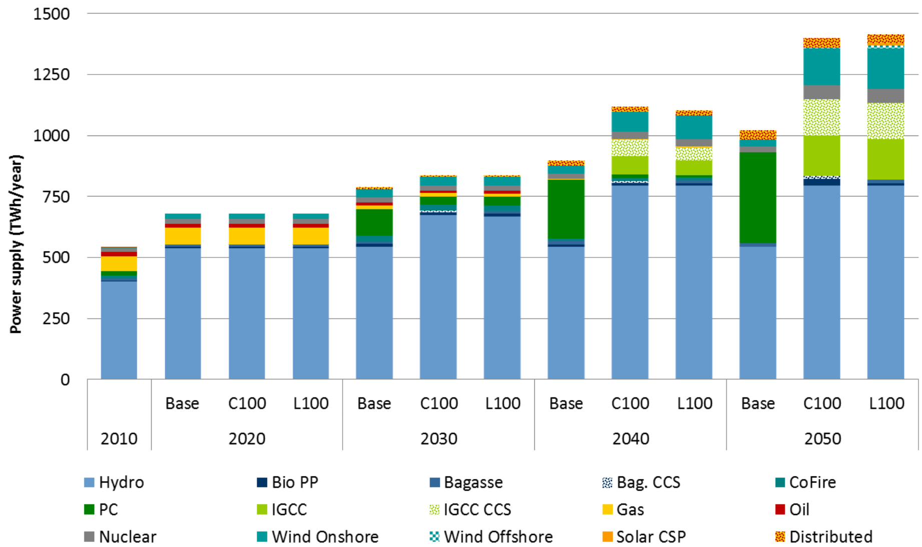
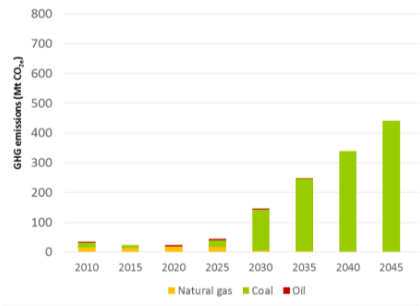
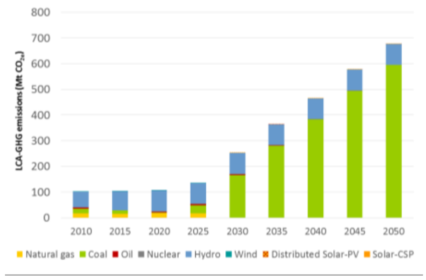


Figure 2. Portfolio of the power supply sector in the baseline and low-carbon scenarios

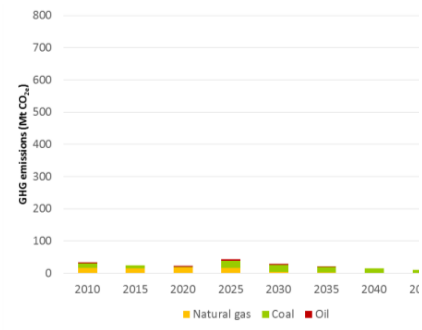
Figure 3 displays the total amount of GHG emitted by the power supply sector from 2010 until 2050. If the Brazilian government does not adopt strategies to tackle climate change, a reference trajectory (see Figure 3.a) suggests a steadily rise of GHG emissions from under 35 $MtCO_{2eq}$ in 2010 to 530 $MtCO_{2eq}$ in 2050. In the short-term and until 2025, natural gas is a major driver of emissions. However, 2025 onwards, coal is the main emitter, as natural gas thermal power plants are replaced by conventional coal technologies. As mentioned earlier, conventional coal technologies are responsible for large amounts of carbon dioxide emissions due to coal high carbon content and low conversion efficiency of conventional steam turbines.
As expected, when evaluating baseline GHG emissions with a life cycle perspective (Figure 3.b), emissions are increased by nearly 30%, corresponding to impacts from upstream and infrastructure processes. Thus, conventional coal thermal power plants and hydropower are main drivers to GHG emissions, contributing to 88% and 22% of LCA-GHG emissions in the baseline scenario, respectively. Other renewables and nuclear power play a minor role, as they have a lower penetration in the energy mix.
Applying a tax on direct-GHG emissions of the power sector yields significant GHG emissions savings (Figure 3.c). When a carbon tax is imposed, GHG emissions peak around 2025 and then show a descendent curve. Thus, in 2025, GHG emissions reach 44 $MtCO_{2eq}$, nearly 27% higher than 2010 levels and then decrease to 40% of 2010 level (13 $MtCO_{2eq}$) in 2050. This sharp decline is related to: (i) the substitution of natural gas and conventional coal thermal power plants by advanced coal technologies equipped with CCS, which presents high conversion efficiency and low emission factor, and (ii) increasing share of wind onshore and distributed solar-PV technologies that have null direct GHG emissions.
When a tax is applied to the entire life cycle of the power supply systems (scenario 'L100') (Figure 3.d), the GHG emissions trend changes dramatically. While impacts are still lower than in the baseline trend, the LCA-GHG emissions do not phase out, as observed in scenario 'C100'. Emissions rather follow a sharp increase until 2025 and onwards stabilise at 151 $MtCO_{2eq}$ in 2050. This is mainly due to impacts associated with dams' infrastructure. Although impacts related to the operation of hydropower plants were not accounted for in this study, the construction of dams consumes a great amount of materials and fossil fuel resources, which results in 117 $MtCO_{2eq}$ emissions, equivalent to 77% of total LCA-GHG emissions. Coal technologies contribute to nearly 20% of total emissions, mainly due to upstream processes of extraction and processing of coal.

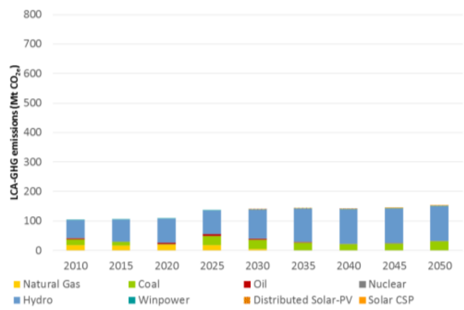


(a) Baseline (direct-GHG emissions)



(b) Baseline (LCA-GHG emissions)





(d) Scenario 'L100'

(c) Scenario 'C100'

Figure 3. GHG emissions of baseline and low-carbon scenarios in a 2050 timeframe

CONCLUDING REMARKS

An LCA-GHG analysis of the power supply sector in Brazil was implemented in the optimisation energy model MESSAGE-Brazil v.1.3 to evaluate the impacts of LCA-GHG emissions in the power supply portfolio and the effectiveness of a carbon tax scheme.

Following a baseline trend and in the absence of climate change policies, the power sector in Brazil would increasingly rely on conventional coal technologies with severe impacts on the environment and implications in terms of dependence on imported fossil fuel resources. When enacting a tax on direct-carbon emissions of the power sector (scenario 'C100'), advanced coal technologies, such as IGCC equipped with CCS facilities, and wind onshore technologies become competitive in the power supply portfolio. Thus, under the scenario 'C100', emissions peak at 2025 and afterwards decrease reaching in 2050 a level 40% lower than 2010 emissions.

However, if impacts were evaluated through the entire life cycle of power supply systems (scenario 'L100'), LCA-GHG emissions increase up to a level 50% higher than 2010 emissions. This is essentially due to impacts associated with infrastructure of hydropower, onshore wind farms, and extraction and processing of fossil fuel resources. Thus, this study suggests that carbon taxes might not be as effective in tackling total GHG emissions as predicted in past studies, if they are strictly applied to direct emissions. It stresses the need for analysing the power supply mitigation strategies from the holistic life cycle assessment point of view. Comparing a baseline trend with scenarios that constrain direct- and LCA-GHG emissions provide a solid basis for climate policy making in Brazil in the Post-Kyoto negotiations.

ACKNOWLEDGMENTS

This work was funded by the Brazilian research funding agencies CNPq and CAPES, under the Science Without Borders Programme, and the Marie Curie International Research Staff Exchange Scheme Fellowship within the 7th European Union Framework Programme, under the project NETEP- European Brazilian Network on Energy Planning (PIRSES-GA-2013-612263).
We also would like to thank to Pedro Rochedo for his assistance with the MESSAGE-Brazil v.1.3 model.

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