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Abstract

Climate change (CC) has become a widespread global concern. Hence, governments have taken international commitments and begun to implement policies to reduce their national Green House Gases (GHG). Although the carbon tax appears as a generalized applied policy, structural socio-economic constraints of Latin American countries become this instrument costly and less effective than a tailor-made policy-mix. By developing a multi-sector recursive dynamic Computable General Equilibrium model which accounts for main structural characteristics of Latin American countries (inequality, unemployment, persistent macroeconomic deficits, etc.) and with a detailed modelling for GHG-intensive sectors (energy, agriculture and (de)forestry), we analyze the environmental, social and (macro- and sector) economic performance of a set of CC mitigation policies for these countries. We apply this analysis to Argentina whose results suggest that a policy-mix that combines the elimination of fossil fuels subsidies and a carbon tax on land-intensive sectors would be both, environmentally and socio-economic preferable than a generalized carbon tax which may be extremely damaging to the industrial sectors. CC policy recommendations also hold to other Latina American countries similar to Argentina.

Keywords: carbon tax, energy subsidies, deforestation, CGE model, Argentina.
JEL codes: C68, Q54, Q15, O54.

1. Introduction

During the last 30 years there has been growing concern regarding climate change (CC). Through the commitments undertaken under environmental international agreements, such as the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, the Paris Agreement and the UN Agenda 2030 for Sustainable Development, many countries have been embarked on different plans and policies that aim to mitigate the detrimental effects of Greenhouse Gas (GHG) emissions.

It is well-known that the responsibility of GHG emissions is not equally distributed across countries. For instance, while China and the United States of America (USA) accounted for more than half of the global GHG emissions, being in the two first position of the worldwide ranking of emitters, . Argentina is a relatively small emitter country being in the 24th position of the total GHG emissions ranking (365 MtCO2eq excluding Land Use Change and Forestry - LUCF - and 396 MtCO2eq including LUCF for 2019) according to the CAIT Climate Data Explorer (2021). Albeit the comparative responsibility of Argentina for the global GHG emissions is minor, its efforts towards the carbon neutrality are not cost-less.

Argentina's socio-economic costs linked to GHG mitigation could be even greater than for developed countries since the economy is under a persistent macroeconomic stress. Consequently, the issue that is particularly relevant for Argentina - and similar Latin American countries - is to design a climate change policy package (i.e., carbon tax, subsidies) that takes into account its structural problems and restrictions (i.e., poverty and inequality, unemployment and wage rigidity, high capital volatility, recurrent balance of payment crises, low value-added, low diversified exports, persistent fiscal deficits, deficient provision of public goods, tax evasion, chronic corruption, low stringency of law and weak policy enforcement) without failing to reduce GHG emissions Ramos and Chisari (2021).

Tackling the choice of CC policies as part of a wider sustainable development program also requires focusing on sectors' contribution to national GHG emissions in order to identify the sectors target and accounts for other impacts than environmental. In the particular case of Argentina, its last GHG emissions Inventory (Muzio et al.) highlights that more than a half of national GHG emissions are related to energy (53% of national GHG emissions) and land-intensive sectors (agriculture, cattle, forestry) are responsible of 37% of national GHG emissions mainly due to their impact on the land use change.

Thus, in order to address the challenge to evaluate and compare the environmental performance and the socio-economic impact of alternative CC policy scenarios to a country such as Argentina requires a model with a proper representation of structural issues as well as the behaviour in the main emitters sectors, i.e., energy and land-intensive sectors. Moreover, Creutzig et al. (2012) highlights that it is essential to model the trade-off between emission savings due to the substitution from fossil fuels to bioenergy and emission generation due to land use change in order to not overestimate environmental benefits. Moreover, Luderer et al. (2014) review the literature and shows that models do not limit the maximum share renewable energy penetration since this clean energies requires storage or back-up capacity. These concerns explicitly justify the modelling improvement for the renewable sources of energy and to the energy-land use sectors' interactions to reduce inherent structural uncertainties and contribute to a coherent analysis for CC policy and structural changes.

In this paper, we tackle this modelling challenge by developing a multi-sector recursive dynamic (2017-2030) Computable General Equilibrium (CGE) model calibrated to Argentina in 2017 with a proper representation of the energy sectors (fossil fuels, biofuels, power generation through different sources including renewable one), agriculture (crops culture and cattle) and the activity of (de)forestry that impact on the availability of productive land for the former land-intensive sectors. Moreover, this CGE model accounts for structural characteristics of Argentina (i.e., unemployment and wage rigidity, limited capital mobility across sector, income inequality). With this tool we seek a CC policy-mix for this country by comparing sector, macroeconomic, social and environmental impacts grounded in two policy changes: the reduction in energy (gas and thermal power generation) subsidies and the increase in the carbon tax rate, given the current tax structure and patterns of consumption and production in Argentina.

Argentina is an interesting case study to target energy and land use sectors. When it comes to the energy sector, the exploitation of shale gas and oil reservoir in Vaca Muerta (Argentinean Patagonia) has reverted its energetic deficit of Argentina but also reduced the incentives for the development of renewable energies Romero (2020). Moreover, even when fossil energy subsidies have shown a continuous reduction in the percentage of GDP (in US dollars) since 2015 (from 3.5% in 2014 to 1.3% in 2017) with a full elimination of petroleum and oil products subsidies since 2018 (Secretaría de Gobierno de Energía, 2019), subsidies on gas and electricity (all sources including the thermal one) persists. Furthermore, by the end of 2017 the Argentinean parliament has approved a tax on carbon content of fossil fuels products (10USD/tCO2eq.)[1] by partially replacing the existing oil tax (Gutman, 2018). Still, this amount of carbon tax and the scope of application remain insufficient to generate incentives to greener consumption and production behaviours.

Concerning the land-intensive sectors in Argentina, the bovine cattle activity remains the main methane gas emitter even when the cattle stocks have been quite stable since the last 10 years (Muzio et al.). Additionally, looking for more productive land the agriculture pushes on the native forest frontier (deforestation) (MAyDS, 2020). None of these agricultural sectors are directly taxed for the GHG they generate, but for their energy consumption (around 2% of overall GHG emissions of the sector). Since 2007 Argentina has approved a law to protect native forest against deforestation practices that was ultimately implemented in February 2009.[2] and the deforestation rate falls from 0,94% in 2007 to 0,34% in 2015.

The remaining of the paper is organized as follows. Section 2 presents the methodological approach in line with the related technical literature to address a differentiated CC policies based on carbon-intensity of sectors. Section 3 presents the CGE model's calibration data: the Social Accounting Matrix (SAM) of Argentina 2017, the associated GHG emissions by sources (production and consumption) and sectors and the assumptions for dynamic baseline parameters. Section 4 outlines a set of CC policy scenarios simulated so as to provide and discuss the most relevant results obtained. Finally, we conclude in section 5.

2. Methodological approach for CC policy in a CGE framework

2.1. Literature review

For CC mitigation evaluation, the modelling of both energy and land use within a CGE model framework has been addressed from multiple standpoints. Most of papers focus on evaluating a single carbon tax considering different amounts (Guo, 2014) and different sectors as targets (e.g., power generation or transport) (Cabalu et al., 2015). Others

[1] Law 27.430 from 29th December 2017. It was implemented in 2018. The conceptual modification in the oil to carbon tax on fossil fuels products has been taken into account in the baseline modelling in this paper.

[2] Law 26.331 of Environmental Protection of Native Forest in Argentina.

(Böhringer et al., 2003) evaluate the repercussions of joint implementation policies against GHG emissions , i.e. carbon policy packages, being more effective policy choices when combining innovation support, such as renewable energy subsidies/aids, with information provision leading to a greater effectiveness of a carbon tax (van den Bergh et al., 2021).

Thus, CGE modelling for CC policy evaluation should consider an appropriate representation and decomposition of the energy sectors and land demand, in order to capture the key trade-off between GHG emission reduction by supporting bioenergies and GHG emissions generation due to land use change. In particular, not every model captures the negative trade-offs between bioenergy exploitation and other natural resources (water, soil, biodiversity) and food security (food availability, nutrition, subsistence farming). Models used to simulate CC policies should account for these energy-land use interactions in order to capture all benefits but costs too (Creutzig et al., 2012).

One of the biggest concerns to evaluate any climate change mitigation policy is how to properly integrate the energy sector into a CGE model to target the pollutant activity. Burniaux (2002) uses an extension of the GTAP model called GTAP-E, by including energy substitution; carbon emissions from combustion of fossil fuels and mechanisms to trade emissions internationally. From a technical standpoint, he creates a energy-capital composite within the value added of the economy. Furthermore, energy is subdivided into electrical and non-electrical on a second nesting stage. Likewise, Guo (2014) uses a very similar approach. More recently, Langarita et al. (2019) goes one step further by adopting not only a capital-energy composite in the value added (combined with labour through a Cobb-Douglas production function) but also by splitting, on a second nesting stage, the activities of the electric sector (i.e, generation, transmission, distribution and commercialization of electricity related activities). In regards to the incorporation of energy into the demand side of a CGE model, there is a concensus to consider a consumption composite that combines energy consumption and non-energy goods though an low elasticity of substitution (0.5).

When it comes to land modelling, there is an array of works that use different modelling techniques in order to reflect changes in land use by different activities due to the implementation of GHG mitigation policies. Timilsina and Mevel (2012) studied the large scale impact of biofuels on land use change, food security and the overall economy. In order to do so, they adopted a model that introduces the land factor into the value added composite. On a second nesting stage, the authors relate through constant elasticities of transformation forest, pasture and crop. Additionally, crops is later subdivided in order to properly portray different land uses. In this way, a detailed structure of the land factor is achieved. On a similar vein, Timilsina et al. (2012) go one step further and combine this land modelling structure with the energy modelling structure adopted by Burniaux (2002). Both Timilsina and Mevel (2012) and Timilsina et al. (2012) develop global CGE model that cover a wide variety of sectors and countries including Argentina. On the other hand, Taheripour and Tyner (2013) introduce a slightly different structure when it comes to land modelling. In their work, they argue that they were able to improve the original GTAP model based on empirical evidence from the United States. As a consequence, they present a newer version of the model known as GTAP-BIO. Like Timilsina and Mevel (2012) and Timilsina et al. (2012) they introduce the land factor in the Value added composite. However, on a second nesting stage they combine forest with a pasture/crop composite through reestimated constant elasticities of transformation based on new collected data. Most recently, Carvalho et al. (2017) also used a CGE model to project the economic losses and land-use changes resulting from a policy to control deforestation and the rise in land productivity in Brazil. Specifically, a dynamic bottom up CGE model with 30 Amazon regions is used. Substitution takes place between capital, labor and land in the composition of the primary factors through CES functions. However, the land factor is allocated solely on the agricultural sectors. Land is modelled separately for each region, keeping the total area fixed and divided into 4 types: cropland; pasture; planted forest and natural forest. It is important to point out that, in all the models previously mentioned, demand for land respond to changes in land remuneration for each sector.

Finally, the discussion regarding top-down and bottom-up modelling approaches is also a relevant debate in the previously cited papers. In particular, Langarita et al. (2019) considers its model as hybrid in the sense that is able to capture the detailed microeconomic structure of the energy sector without relegating a view of the economy as a whole. Similarly, Guo (2014) follow this kind of approach since they are able to study the repercussions of various carbon emissions scenarios over the main macroeconomic variables. Notwithstanding, their model is also capable of capturing the changes in the energy sector.

2.2. CGE model

We assume a small open economy, that takes international prices of commodities as given and interacts with the rest of the world (RoW) through trade. This small economy is composed of different institutions: firms, households (differentiated by their income distribution) and the government. All of them together, are able to determine the level of GHG emissions at a national level with their production, consumption and policies.

On the supply side, each representative firm produces a single good under constant returns to scale and sells them in markets that operate under perfect competition conditions. Firms production functions combine, in fixed proportions, non-energy inputs and a package composed of value added and energy inputs. Energy consumption and value added are combined in a CES function with average elasticity per sector of 0.34 (Antoszewski, 2019). In turn, non-energy inputs are combined in fixed proportions, the factors that make up the value added are combined through a Cobb-Douglas function, and the composite of energy inputs takes on a particular shape described further. The productive factors considered are capital (sunk and mobile across sectors), labour (mobile across sectors) and land (specific to agriculture and forestry activities). All productive factors except labour are assumed to be fully occupied. Unemployment is due to real wage rigidities.

On the demand side, firms demand (domestic and imported) goods and services (as imperfect substitutes) as inputs (intermediate consumption). Additionally, households, the government and the RoW demand them for final uses. Like firms that maximize profits, households, the government and the agent of the RoW satisfy their preferences given their budget constraints. Agents' income come from the remuneration of their production factors and from inter-agents' transfers (i.e., social transfers, remittances, loans through the assets market) and tax collection for government.

In equilibrium, all markets - goods, services and factors - clear under perfect competition and all agents solve their optimization problems under restrictions. Labour market is closed under a rule of constant real wages according to the consumer price index.[3]

Such as in Chisari et al. (2010), the equilibrium of the economy is solved in a recursive way for medium to long run periods of time. Given the capital to GDP ratio that characterizes

[3] Note that labour market closure is flexible in the model allowing for a minimum nominal wage rule or a full employment hypothesis.

the economy in the base year, the economy growth is driven by a capital accumulation mechanism (investment is saving-driven) assuming a capital depreciation rate, (total and active) population growth and the yearly Total Factor Productivity (TFP) improvement.

2.2.1. Energy modelling

The structure and composition of the energy supply is decisive to identify GHG emissions. For this reason, a detailed structure of the energy composition has been developed. First, between electrical and non-electrical, and then, between fossil or non-fossil energy origin, according to their primary sources of power generation. Figure 1 presents the scheme of the energy structure assumed in this model, where the elasticity of substitution between electricity and non-electricity is positive but relatively low (0.25). Electricity can be generated indistinctly (infinite elasticity of substitution) from different technologies: thermal, nuclear and hydro or from non-conventional renewable sources. However, the generated energy needs to be delivered. For this reason, electrical power generation and distribution are combined in fixed proportions. Regarding non-electric energy, it is composed of coal and other non-solid fossil resources (substitution of 0.5). We assume that crude oil, gas and fuels are substitutes (elasticity of substitution of 0.9 between them). In turn, fuels are composed of oil, gasoil and other fuels (elasticity of substitution of 0.15 between them). At the same time, oil and gasoil are the product of combining, in fixed proportions, refined fuels with biofuels (biodiesel or ethanol, as appropriate) according to the cut-off established by law. The elasticities of substitution considered at each level of the energy tree were taken from Böhringer et al. (2003) and the advice of experts in the Argentinean energy sector.

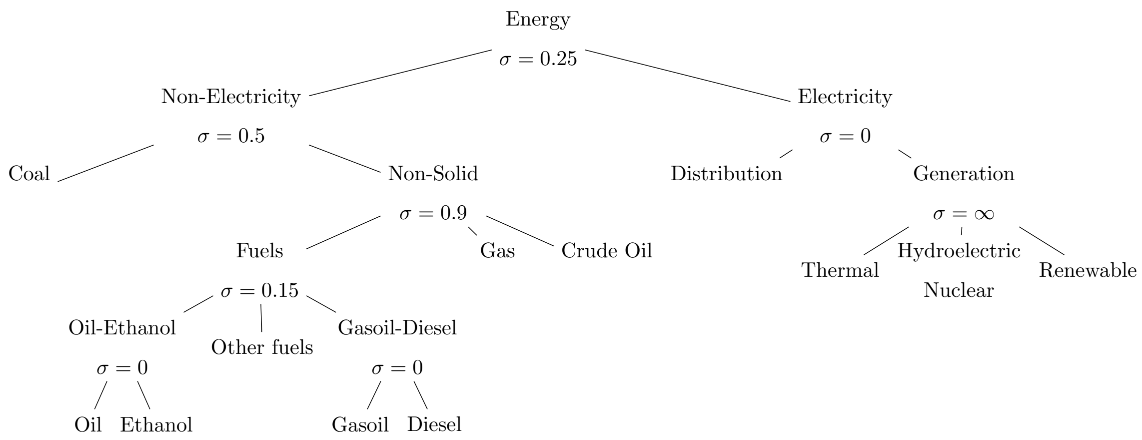

Figure 1: Nesting of the energy package demanded by the firms.

The characterization of the energy final demand is also necessary to properly account for the energy consumption source of GHG emissions. For the households' consumption choice between energy and the rest of final goods it was assumed a relatively low elasticity of substitution (0.5) (Rutherford et al., 1997; Langarita et al., 2019). This is because, although energy is an essential service in homes, the proportion consumed is not fixed, and can be substituted by other goods when the latter allow for greater energy savings. At the energy branch level, unitary elasticity of substitution is considered between the different energy goods. This same elasticity is also taken for the goods that make up the non-energy package. The scheme of the utility function can be seen in the figure 2.

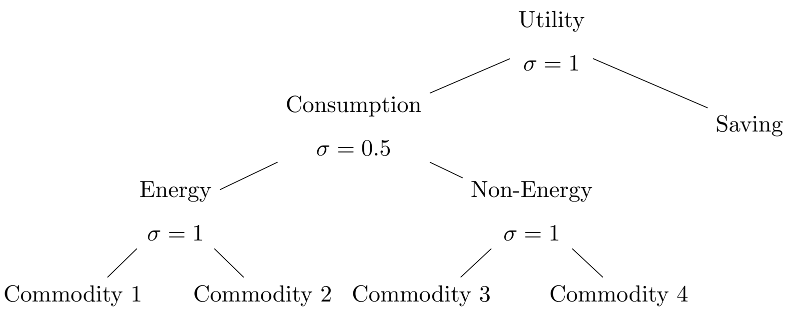

Figure 2: Nesting of the Utility function.

2.2.2. Land use and deforestation modelling

Agriculture and forestry land use is also essential to account for GHG emission, and particularly, for the pressure that these activities generate on the deforestation of native forests, which are a source of carbon capture.

Land is a specific factor of agriculture, livestock and forestry activities, but it is assumed mobile between them. Thus, it is assumed that land supply is transformed as shown in Figure 3. A low elasticity of transformation (0.1) is considered between forestry and agricultural uses. Later, a higher elasticity of transformation (0.2) is assumed between livestock (pasture) and agriculture (crops).This approach follows Taheripour and Tyner (2013) modelling specifications.

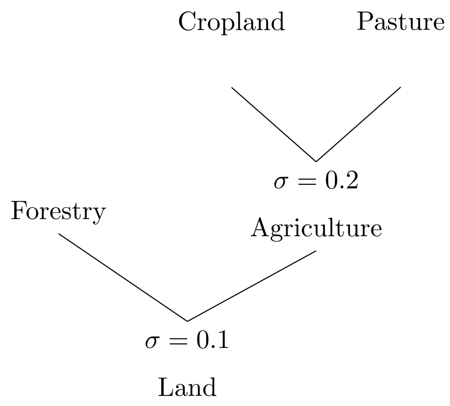

Figure 3: Land allocation.

The land stock is not fixed. It grows according to the level of activity of the deforestation sector, while reducing the stock of native forests and therefore the ability to capture carbon from the atmosphere.

The dynamics of the productive land stock is presented in equations 1 and 2. Its growth rate (equation 1) is yearly adjusted to the change in the deforestation sector's output (Q_t^{DEF}), and also, considering a land factor productivity rate $\rho_t = z^{t-1}$, where $z < 1$ meaning a decrease in land productivity, which holds if no heavy investments in soil fertility restoration is assumed (Jayne et al., 2014).[4] This land stock dynamic allows for greater realism according to historical projections.

$$\omega_t = \rho_t \frac{Q_t^{DEF}}{Q_{t-1}^{DEF}} \omega_{t-1} \tag{1}$$

Finally, the productive land supply ($\bar{T}$) increases yearly according to Equation 2.

$$\bar{T}_t = (1 + \omega_t) \bar{T}_{t-1} \tag{2}$$

2.2.3. GHG emissions

GHG emissions at a national level are computed taking into account those GHG emissions generated by energy (intermediate and final) consumption behaviour and production processes depending of each sector's carbon intensity. The net impact in GHG emissions results of inter-sectoral GHG transactions.

[4]The z value assumed is 0.995.

Equations 3 and 4 allows computing the GHG emissions related to energy consumption as inputs and final consumption, respectively.

$$GHG_j^{ICE} = \sum_i f_{i,j}^{ICE}.Q_{i,j}^d \tag{3}$$

$$GHG_h^{RCE} = \sum_i f_{i,h}^{RCE}.Q_{i,h}^d \tag{4}$$

$Q_{i,j}^d$ and $Q_{i,h}^d$ refer to the demand of product i by sector j and by household h, respectively. $f_{i,j}^{ICE}$ and $f_{i,h}^{RCE}$ are the GHG emissions factors' related to intermediate consumption and final consumption of product i, resp. Note that those factors are positive only if i is an energetic product.

Equation 5 computes GHG emissions related to the production process of each sector j measured by the j's value added and according to the GHG emission factor of the j's technology (f_j^{PRO}).

$$GHG_j^{PRO} = f_j^{PRO}.VA_j \tag{5}$$

All GHG emission factors are assumed fixed all over time; thus, changes in GHG emissions would come mainly from changes in the energy consumption composition (fossil or "green") and from the production pattern of the country.

Adding-up equations 3, 4 and 5 we get the total of GHG emissions at the country level. The GDP carbon intensity (Kuznets GHG emissions index) is also measured by dividing total GHG emissions by the GDP.

3. Data for the CGE model calibration

Calibration of the aforementioned CGE model requires consistent information between the structure of the economy (Argentina) in the base year (2017) and its associated GHG emissions. These information is thus presented here as well as the dynamic parameters assumptions.

3.1. Social Accounting Matrix to Argentina 2017 and associated GHG emissions

A Social Accounting Matrix (SAM) consistently integrates the economic flows of an economy in a particular year. Although the construction of these matrix is valuable by itself, it also constitutes the basis to calibrate walrasian models, particularly CGE models.

Based on the Argentina 2017 SAM from Chisari et al. (2020),[5] the Argentina GHG emission inventory[6] (**?**) and public information about agriculture-forestry, energy and transport sectors,[7] a new SAM with an appropriate sector desegregation for CC purpose was developed.

Gross Output (GO), Value Added (VA), Subsidies (SUB) and GHG emissions (GHG) of most pertinent sectors in the SAM are presented in Table 1. Moreover, factors' intensity in sectors' VA is also shown.

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[5] Table A.1 in the Appendix provides a Macro SAM Argentina 2017.

[6] The GHG emissions inventory is available for 2014 and 2016. We have used the last one, provided by the Environment Ministry of Argentina - Climate change division.

[7] Land use information of agriculture-forestry activities was taken from the Land Usage Matrix estimated for Argentina. Detailed information about the Energy and Transport sectors was obtained from the National Energy Balance and the Supply and Use Tables of Argentina (2004), respectively.

Table 1: Economic and environmental characterization of sectors' supply - Argentina SAM 2017.

Sector	**GO**	**VA**	**VA Intensity**			**SUB**	**GHG**
			K	**L**	**T**		
Agriculture	4.3%	4.4%	8.1%	35.5%	56.4%	0.9%	12.4%
Cattle Raising	1.6%	2.1%	8.1%	35.0%	56.8%	0.0%	30.2%
Deforestation	0.0%	0.0%	8.1%	35.4%	56.5%	0.0%	5.4%
Silviculture	0.0%	0.0%	0.7%	94.1%	5.2%	0.0%	-6.9%
Oil, Gas and Coil Extraction	1.7%	2.7%	66.2%	33.8%	0.0%	14.5%	5.1%
Mining	0.6%	0.7%	88.8%	11.2%	0.0%	0.0%	0.2%
Fuels and Biofuels	2.4%	0.4%	88.0%	12.0%	0.0%	2.3%	3.0%
Thermal Power Generation	0.5%	0.7%	77.0%	23.0%	0.0%	34.3%	14.2%
Hydroelectric and Nuclear Generation	0.0%	0.2%	13.6%	86.4%	0.0%	6.1%	0.0%
Renewable Generation	0.0%	0.0%	85.0%	15.0%	0.0%	0.7%	0.0%
Distribution of Electricity	0.6%	0.3%	62.2%	37.8%	0.0%	0.0%	0.0%
Rail Transportation	0.1%	0.4%	90.8%	9.2%	0.0%	11.7%	0.0%
Road Transportation	2.5%	2.2%	29.5%	70.5%	0.0%	20.8%	13.5%
Rest of Transportation	2.7%	2.0%	27.1%	72.9%	0.0%	1.4%	1.4%
Rest of Good and Services	82.9%	83.7%	47.7%	52.3%	0.0%	7.3%	21.6%
Total	**18,214**	**7,956**	**3,632**	**4,034**	**290**	**217**	**337**

Source: own elaboration.

Note: Total row of GO, VA, (capital) K, (labour) L, (land) T and SUB are in billions Pesos (Argentinean currency) while GHG is in MtCO2eq. Sectors' information are in shares of the total values, except for K, L and T whose intensity is measured over the total sector's VA.

Sectors' detailed in Table 1 contributes to 20% of VA while they generates almost 80% of GHG emissions linked to the supply side. More precisely, main GHG contributions come from Agriculture and Cattle Raising (43%), Thermal Power Generation (14%) and Road Transportation (13.5%), due to both production processes and energy intermediate consumption. Moreover, Thermal Power Generation concentrates the greatest percentage of subsidies (34.3%) followed by Road transportation (20.8%) and Oil, Gas and Coil Extraction (14.5%), summing-up almost 70% of all production subsidies.

Table 2 provides an insight on GHG emissions associated with the Argentinean demand side. It evidences a direct relation between the final demand goods and services with (household's) GHG emissions. The consumption of manufactured goods is the main responsible of households' GHG emissions, followed by fuels burnt.

Table 2: Economic and environmental structure of demand. SAM Argentina 2017

Sector	Consumption			GHG
	Domestic	Imports	Total	Emissions
Agriculture	1.9%	1.0%	1.8%	0.0%
Cattle Raising	0.1%	0.2%	0.1%	0.0%
Deforestation	0.0%	0.0%	0.0%	0.0%
Forestry	0.0%	0.1%	0.0%	2.3%
Oil, Gas and Coil Extraction	0.0%	0.0%	0.0%	0.0%
Mining	0.0%	0.0%	0.0%	0.0%
Fuels and Biofuels	1.1%	0.0%	1.0%	12.0%
Thermal Power Generation	0.0%	0.0%	0.0%	0.0%
Hydroelectric and Nuclear Generation	0.0%	0.0%	0.0%	0.0%
Renewable Generation	0.0%	0.0%	0.0%	0.0%
Distribution of Electricity	1.1%	0.0%	1.0%	0.0%
Rail Transportation	0.4%	0.0%	0.4%	0.0%
Road Transportation	5.1%	0.0%	4.8%	0.0%
Rest of Transportation	1.7%	0.5%	1.6%	0.0%
Rest of Good and Services	88.7%	98.2%	89.3%	85.7%
Total	**6,492**	**453**	**6,944**	**27**

Source: own elaboration.

Note: Consumption (domestic, imports and total) is measured in billions Pesos (Argentinean currency) while GHG (households' emissions) is measured in MtCO2eq. Sectors' information are in shares of the total values.

3.2. Baseline calibration data

To calibrate the parameters of the dynamic baseline (2017-2030) for the Argentinean economy, the model mainly considers the estimation of Fouré et al. (2013). The dynamic parameters are the capital depreciation rate (5.5% yearly), the capital to GDP ratio (2.43 for the base year), the TFP growth rate (1.5% yearly) and the total and active population growth rate (1.09% yearly).

Each period the capital and land stock is updated recursively according to the level of investment and deforestation of the previous period. In turn, the total and active population is updated following Fouré et al. (2013) (1.09% yearly).

Moreover, the model assumes an additional adjustment for the minimum real wage based on 2.5% of the GDP growth in each period. Dynamic baseline also introduces the carbon tax applied on the fossil fuels consumption since 2018 in Argentina (10 USD/tCO2eq).

4. Simulating Carbon Mitigation Policy in Argentina

4.1. Description of Carbon Mitigation Policy Scenarios

In order to analyse available carbon related policy instruments for Argentina, we have designed the following scenarios. The first scenario provides an inside for current discussion concerning a support for pollutant energies. Even when foosil fuel energies have been reduced and even eliminated in the case of naphtha and gasoil, subsidies remains for gas and electricity (thermal is one of the main sources of power generation in Argentina). So, this scenario seeks to continue with the process of progressive fossil fuel based energy subsidies in line with the Sustainable Development Goal of UN related to affordable and clean energies. The second scenarios simple looks at increase the current carbon tax in an additional amount in order to provide a real sign to the market and induce the replacement of "dirty" to "clean" energies. Scenario 2-b is similar to 2 in terms of the magnitude of the shock but only target the land-intensive sectors. In this case we want to tax the emissions generated not only through energy consultion in agriculture sectors but also those emissions related to the production process (cattle) and land use change. Finally, scenario 3 provide a suggestion of a CC policy-mix looking for an improvement in the environmental performance of isolated previsous instruments.

- **Lower Polluting Energy's Subsidies (Scenario 1)**: reduction to 25% (2020) of current amount of fossil fuels' and thermal power generation's subsidies.
- **Greater Carbon Tax (Scenario 2)**: increase in 13.68 USD/tCO2eq (2020) additional to the initial carbon tax. This additional amount is equivalent of the previous energy subsidies cut and it is applied allover sectors.
- **Greater Carbon tax only on Agriculture, Cattle and Silviculture sectors (Scenario 2-b)**: Unlike scenario 2, scenario 2-b focuses the increase in carbon taxation solely on land- intensive sectors. This is mainly due to the fact that they are significant contributors to the overall emission level.
- **Carbon mitigation policy-mix (Scenario 3)**: a combination of reduction of polluting energy subsidies like in (1) and an increase in carbon tax applied to land-intensive sectors in (2-b).

Even though we might see an increase in government revenue due to an increase (decrease) in taxation (subsidies), the composition of the government expenditure remains unvarying under all scenarios.

4.2. Baseline

The baseline scenario has been run from 2017 to 2030; however, for simplicity we present its results for two key years: the current one and the year we introduce the shocks in other scenarios (2020) and the target-year to reduce GHG emissions according to the UN 2030 Agenda (2030).[8] Tables 3 and 4 (the first two columns) present GHG emissions (total and sectors' percentage contributions) and the main macroeconomic indicators for the Argentinean economy in 2020 and 2030, respectively.

GDP increases during all the years (the COVID-19 pandemic was not considered in 2020) at the average growth rate of 1.27% per year. In line with GDP evolution, the unemployment rate falls but, due to strong scale effect, GHG emissions increase by reaching the level of 443 MtCO2eq in 2030 (even below of the first Argentina NDC target). However, the decrease in the Kuznets index by 2030 shows also the presence of some technique and composition effects, favouring a lower carbon intensity per unit of GDP. According to this baseline, welfare smoothly improves, at both social and private (households' deciles of income) levels.

The dynamic baseline also considers population growth which also increases food demand. Thus, the Agriculture and Forestry sectors significantly increase their production also increasing their shares in the overall GHG emissions by 2030 (Table 1). On a similar vein, these sectors also increase their land demand pushing over deforestation (table 4) between 2020 and 2030 (Kha deforested multiply by 5 in 10 years). On the contrary, our baseline projections predict a reduction in the GHG emissions of the Thermal electricity sector, since its level of activity also falls due to the allowed substitution between thermal electricity and renewable energies by model's construction.

4.3. Carbon mitigation policies: comparison of scenarios

Tables 4 and 5 present the results of all scenarios in comparison with the baseline. When it comes to scenario 1, the reduction of subsidies in the fossil fuel and thermal electric-

[8]The absolute target of GHG emissions committed by Argentina in its first National Determined Controbution (NDC) is 483 MtCO2eq but 2030; however, in December 2020 Argentina has presented its second NDC improving this commitment to 359 MtCO2eq by 2030, and in April 2021 during the Climate Summit Argentina even reduced that target to 349 MtCO2eq by 2030.

Table 3: Argentina GHG emissions and sectoral contributions (Baseline, 2020 & 2030)

GHG emissions	**2020**	**2030**
Agricultural-Forestry	44.8%	46.0%
Silviculture	-6.3%	-6.4%
Fuels & other energy	14.8%	14.9%
Thermal electricity	12.7%	11.2%
H-N-R Electricity	0.0%	0.0%
Transport	13.8%	13.6%
Rest-Primary goods	0.2%	0.3%
Rest-Manufactures	12.5%	12.9%
Rest-Services	7.5%	7.5%
Total GHG emissions (MtCO2eq.)	**384**	**443**

Source: own elaboration.

Notes: Agriculture-Forestry does not include Silviculture.

H-N-R Electricity is Hydroelectric, Nuclear and Renewable electricity.

ity sector is able to generates the proper incentives to shift towards renewable energies. Specifically, we are able to see how Fuels and other energies as well as Thermal electricity reduce their Gross Output and Value Added while there is an increase in the same variables for the H-N-R Electricity sector (Table 5). As a consequence, this scenario is able to successfully reduce GHG emissions without having significant negative effects in the economy. Particularly, table 4 indicates a negative variation of 0.22 in the GDP of 2030 compared to the baseline for the same year. Additionally, deforested hectares tend to slightly decrease when compared with the baseline.

On the other hand, if we consider scenario 2 where an increase in carbon taxation is implemented, we can appreciate that there is a bigger detrimental effect in the macroeconomic variables without successfully reducing carbon emissions (see table 4). At the same time, table 5 indicates that an additional carbon tax to all sectors in the economy not only fails to diminish GHG emissions per sector but also does not generate the proper incentives to adopt cleaner energy sources. Nevertheless, unlike scenario 1, scenario 2 shows to be more useful when it comes to reducing deforestation due to the negative impact on land-intensive sectors. Along the same line, scenario 2-b draws similar though attenuated results. In particular, focusing the increase in carbon taxes solely in the land-intensive sectors would not have such harmful ramifications in the rest of the economy. However, scenario 2-b is less effective when it comes to reducing both, GHG emissions and deforestation.

Finally, under a CC policy-mix (scenario 3) that combines a subsidy reduction and an increase in carbon taxes on land-intensive sectors, we are not only able to perceive a substitution effect between fossil fuel and renewable energies but also a reduction in the amount of deforested land. Even though the cutback in the GDP of 2030 is larger than under scenario 1 (but smaller than scenario 2), so are the reductions in overall emissions. Additionally, the reduction in the carbon intensity of GDP (lower Kuznets index) is bigger than in the rest of the scenarios considered. Consequently, this means that a policy-mix that particularly punishes the carbon-intensive sectors, Energy (lower subsidies) and Agriculture (greater carbon tax), would allow Argentina to become a cleaner economy by 2030 without significant side effects in the economy.

Table 4: Macroeconomic, welfare and environmental results - Baseline & CC policy scenarios (2020 & 2030)

Indicators	**Baseline**		**Scenario 1**		**Scenario 2**		**Scenario 2-B**		**Scenario 3**	
	2020	2030	2020	2030	2020	2030	2020	2030	2020	2030
Macroeconomic										
GDP	6.04	24.03	-0.26	-0.22	-0.70	-0.50	-0.18	-0.07	-0.45	-0.29
Unemployment rate	6.22	5.04	0.45	0.32	1.00	0.61	0.28	0.14	0.74	0.47
Welfare										
1st Decile	4.13	16.76	-0.48	-0.46	-0.64	-0.52	-0.08	-0.01	-0.56	-0.47
5th Decile	5.63	22.64	-0.41	-0.38	-0.78	-0.60	-0.20	-0.10	-0.62	-0.48
10th Decile	5.06	20.02	-0.58	-0.54	-1.05	-0.92	-0.47	-0.42	-1.06	-0.96
Social welfare	5.09	20.47	-0.14	-0.09	-0.54	-0.37	-0.18	-0.09	-0.32	-0.18
GHG emissions										
GHG (MtCO2eq.)	383.72	443.20	-23.77	-25.19	-6.88	-7.02	-2.22	-2.17	-26.02	-27.46
Emission index	105.29	121.61	-6.52	-6.91	-1.89	-1.93	-0.61	-0.60	-7.14	-7.54
Kuznets index	99.30	98.05	-5.93	-5.41	-1.13	-1.16	-0.40	-0.42	-6.34	-5.86
Deforestation										
Deforested kha (*)	635.35	2113.82	-0.61	-5.86	-4.32	-42.79	-3.61	-36.27	-4.20	-41.82

Source: own elaboration.

Note: Baseline results are in levels and scenarios' in variations from the baseline. (*) Deforested thousand hectares (Kha) yearly accumulated.

5. Final remarks

The issue regarding climate change and GHG emissions has proven to be a top priority in the coming years for both, developed and developing nations. Argentina is no exception to such phenomena. However, unlike other developed nations, the question of what is the optimum CC policy mix for Argentina should not be taken lightly. Taking into account this framework and the specific characteristics of the Argentinean energy and land sectors, this papers aimed to determine the most performing CC policy-mix among a set of possible scenarios to tackle GHG emissions, but without bringing about harmful socio-

Table 5: GHG emissions, Gross Output and Value Added results by sector - CC policy scenarios (% change to the baseline - 2030)

	Scenario 1			**Scenario 2**			**Scenario 2-B**			**Scenario 3**		
	GHG	GO	VA	GHG	GO	VA	GHG	GO	VA	GHG	GO	VA
Agriculture-Forestry	-0.1	-0.1	-0.1	-1.1	-0.7	-0.7	-1.0	-0.5	-0.6	-1.1	-0.6	-0.7
Silviculture	0.2	-0.2	-0.2	1.9	-2.2	-2.0	0.3	-0.3	-0.3	0.5	-0.5	-0.5
Fuels & other energy	-10.6	-1.7	-1.5	-1.2	-0.7	0.1	0.1	0.1	0.3	-10.5	-1.6	-1.2
Thermal electricity	-31.2	-31.6	-26.8	-3.4	-2.9	-2.3	0.0	0.0	0.0	-31.5	-32.0	-27.1
H-N-R Electricity	0.0	17.7	17.3	0.0	2.2	2.1	0.0	0.9	0.8	0.0	18.4	17.9
Transport	-1.8	-0.5	-0.5	-2.5	-1.4	-1.4	-0.3	-0.1	0.0	-2.1	-0.7	-0.7
Rest-Primary goods	-1.7	-0.1	-0.1	-0.7	-0.3	-0.3	-0.5	-0.2	-0.2	-2.2	-0.4	-0.3
Rest-Manufactures	-2.0	-0.5	-0.4	-2.1	-2.8	-2.3	-0.3	-1.8	-1.6	-2.3	-2.3	-1.9
Rest-Services	-1.1	0.0	0.0	-0.6	0.1	0.2	0.0	0.2	0.3	-1.1	0.2	0.3

Source: own elaboration.

Notes: Agriculture-Forestry does not include Silviculture. H-N-R Electricity is Hydroelectric, Nuclear and Renewable electricity.

economic reverberations. As a consequence, a multi-sector dynamic recursive CGE model for Argentina was developed.

First contribution of this paper is the development of data and modelling of the Argentinean economy for a recent year (2017) and with an appropriate sectors' detail (energy, agriculture-forestry) and characterization (land use and deforestation). As a consequence, our methodological framework allows for a better understanding of the sources of GHG emissions to be tackle by different CC policy instruments.

Then, the results of the CC policy scenarios suggest that a mere increase in carbon taxation will fail to achieve the desired goals. On the contrary, a more sophisticated policy package that includes subsidy reductions in GHG emitting energies and an increase in the carbon tax for land-intensive sectors will bring more promising results in Argentina. As was previously stated, such policy will bring two positive effects. Firstly, the reduction in subsidies will motivate the use of renewable energy sources diminishing the level of emissions due to fossil fuels and thermal electricity. Secondly, an increase in the carbon tax on land-intensive sectors such as Agriculture-Forestry will propitiate a reduction in native forest deforestation. Altogether, this policy package appears as a viable option to mitigate GHG emissions with relatively low macroeconomic costs. For this reason, we encourage policy makers to embark on packages that are able to both, generate the proper and focused incentives and reduce the amount of deforested land.

Even though our approach is able to draw useful results for CC policy design, there are some limitations that need to be addressed. On the one hand, the parameters used, such as elasticities of substitution, were adopted from previous works and may not necessary reflect the reality of the Argentine sectors. Ideally, future works should advocate to estimating values better fitted for Argentina. On the other hand, an interesting alternative would be to integrate R&D within the modelling structure. In this way, we would be able to analyze how different policy packages motivate the development of new technologies (energy efficiency, land productivity) that ultimately contribute to a reduction in emissions.

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Appendix A. Macro SAM Argentina 2017

Table A.1: Macro SAM Argentina 2017

		Activities	Factors			Taxes	Households		Government	Investment		RoW	Total
			L	K	T		H01	H02		Priv.	Pub.		
Activities		6,937.4					2,389.0	4,102.6	1,880.5	1,203.3	504.3	1,196.8	**18,213.8**
Factors	**L**	4,033.9											**4,033.9**
	K	3,632.2											**3,632.2**
	T	290.1											**290.1**
Taxes	**ITNS**	1,317.6					42.1	72.7		19.8			**1,452.2**
	TL	678.7											**678.7**
	TK+TT	557.6											**557.6**
	IH						31.1	48.4					**79.5**
Households	**H01**		881.8	490.6					471.9				**1,844.4**
	H02		3,042.1	2,178.0	290.1				1,334.7				**6,844.8**
Government				828.7		2,768.0							**3,596.8**
Investment	**Priv.**						45.1	1,447.3					**1,492.4**
	Pub.								504.3				**504.3**
RoW		766.2	110.0	134.9			166.6	286.1		269.3			**1,733.1**
CB							-829.5	887.8	-594.6			536.4	**0**
Total		**18,213.8**	**4,033.9**	**3,632.2**	**290.1**	**2,768.0**	**1,844.4**	**6,844.8**	**3,596.8**	**1,492.4**	**504.3**	**1,733.1**	**0**

Source: Chisari et al. (2020) Notes: L (labour), K (capital, T (land), H01 (households of 1-5 deciles of income), H02 (households of 6-10 deciles of income), ITNS (indirect taxes on sectors), TL (labour taxes), TK (capital taxes), TT (land taxes), IH (direct taxes over households), CB (closure bond).