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Article

Energy policy implications of Ecuador’s NDC

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Abstract: In the third national communication submitted by Ecuador, the total greenhouse gases (GHG) emission was calculated at 80,627 $GgCO_{2\text{-eq}}$, considering the country’s commitment to the Framework on Climate Change. In 2018, Ecuador ratified its nationally determined contribution (NDC) to reduce its GHG emissions by 11.87% from the business-as-usual (BAU) scenario by 2025. The macroeconomic impacts of NDC implementation in the energy sector are discussed. A Computable Equilibrium Model applied to Ecuador (CGE_EC) is used by developing scenarios to analyze partial and entry implementation, as well as an alternative scenario. Shocks in exogenous variables are linked to NDC energy initiatives. So, the NDC’s feasibility depends on guaranteeing the consumption of hydropower supply, either through local exports or domestic demand. In the last case, the government’s Energy Efficiency Program (PEC) and electricity transport have important roles, but the high levels of investment required and poor social conditions would impair its implementation. NDC implementation implies a GDP increase and price index decrease due to electricity cost reductions in the productive sector. These conditions depend on demand-supply guarantees, and the opposite case entails negative impacts on the economy. The alternative scenario considers less dependence on the external market, achieving higher GDP, but with only partial fulfillment of the NDC goals.

Keywords: CGE model; Ecuadorian NDC; GHG reduction; energy policy; green growth

1. Introduction

The IPCC’s Sixth Assessment Report on the Physical Science Basis of Climate Change unequivocally states the relationship between climate change and anthropogenic greenhouse gas emissions (GHG). In 2018, in accordance with the 21st Conference of the Parties (COP21) agreements, Ecuador proposed its nationally determined contribution (NDC). The document contains a national climate action plan to reduce its GHG emissions, whose implementation can represent an opportunity to change the country’s productive structure and allow the development of an economy less reliant on fossil resources.

Despite the benefits that the potential NDC implementation would generate, there are doubts about its economic feasibility, due to the interactions between economic growth and energy consumption in Ecuador (Pinzón, 2017). In fact, during the 2008–2018 decade, there was significant growth in energy consumption per capita from 4.41 to 5.26 barrels of oil equivalent per inhabitant (MERNNER, 2021). This situation is explained by the rapid economic growth of middle-income households and the need to satisfy repressed demand (Castro et al., 2018).

This paper explores the economic implications of GHG mitigation policies by analyzing conventional macroeconomic indicators such as GDP variation, job creation, and price index changes. It also examines the economic sectors that would benefit or be impacted most by the implementation of NDCs. Furthermore, the paper investigates the conditions and factors, including resource availability, production factors, and price fluctuations that influence the feasibility of environmental policy implementation. Neglecting these economic-energy-environmental relationships could impede successful implementation.

This paper aims to assess whether Ecuador's productive structure aligns with the objectives established in the NDC, particularly in fostering an economy less reliant on fossil resources. By examining the economic implications of greenhouse gas (GHG) mitigation policies, key macroeconomic indicators such as GDP variation, job creation, and price index changes are analyzed. Consequently, the study defines three main objectives:

Objective 1: evaluate whether the productive economic structure is consistent with the NDC objectives.

Objective 2: analyze the implications of the main macroeconomic variables—unemployment rate, economic growth, and price index—in relation to NDC policies.

Objective 3: identify the main sectors that will be positively and negatively affected by the NDC implementation.

These objectives correspond to the following research questions: (i) Is the productive economic structure consistent with the objectives? (ii) What would be the implications on the main macroeconomic variables: unemployment rate, economic growth, and price index? (iii) What would be the main sectors positively and negatively affected? These questions are addressed by developing and applying a Computable General Equilibrium Model (CGE_EC) tailored to Ecuadorian conditions. This study provides a novel tool to quantify the implications of environmental policies in a primary-export economy dependent on non-renewable resources. The findings contribute to the broader debate on the costs and benefits of transitioning to a green economy in developing countries, highlighting the importance of considering the economic-energy-environmental relationships that could either facilitate or hinder successful NDC implementation.

The originality of this paper lies in the development of a macroeconomic model to quantify the implications of environmental policies, applied to a developing country with a primary-export economy, dependent on non-renewable resources. This paper introduces the first application of a Computable Equilibrium Model applied to Ecuadorian conditions (CGE_EC) to evaluate environmental policies, contributing to the debate on the cost to be "green". The paper starts by discussing the research problems and their role. Section 2 Systematic structuring presents the theatrical framework of the model, the importance of CGE models to evaluate mitigation policies (the state-of-the-art) and NDC action lines in the energy sector. Section 3 presents the methodological approach of CGE_EC. Section 4 presents the results and discusses the research questions proposed. Finally, the study's conclusions and policy implications are presented in section 5.

2. Systematic structuring and contextualization

This study adopts the theoretical framework proposed by Bukowski and Kowal (2010), in which a closed economy is structured, consisting of households, businesses, and the government. Households supply labor in the labor market, determine their consumption, and acquire bonds and shares. Businesses utilize capital, labor, and raw materials to produce both basic and final goods, generating a circular economic flow where households receive wages, dividends, and interest. Within this framework, the interaction between economic agents enables the government to manage taxes, ensuring a balance between production, consumption, and investment.

In this context, Deka et al. (2022) demonstrate that GDP growth is closely linked to energy use, particularly in developing and transitioning economies, where an increase in energy availability drives GDP growth and Jia et al. (2023) indicate that the transition to renewable energy can stimulate long-term economic growth by reducing dependence on fossil fuels.

According to Hanna et al. (2024), decarburization policies and investments in renewable energy not only create jobs but also affect the quality and skills required in the labor market. Thus, evaluating job creation in the context of the NDCs allows for a better understanding of the additional social and economic benefits that these policies can offer, beyond emission reductions. Energy price fluctuations resulting from the implementation of climate policies have significant effects on inflation and purchasing power, impacting both consumers and producers (Hajdukovic, 2021). Therefore, including price index variation in the analysis of the NDC allows for an assessment of how energy policies might influence macroeconomic stability.

To assess the economic impacts of environmental policy implementation on different local actors. A Computable General Equilibrium (CGE) model was selected due to its strengths and scalability, making it an appropriate tool for the analysis conducted in this study (Ortega et al., 2023). The benefits of using CGE models lie in the perfect equilibrium of realistic data derived from social accounting matrices and the response from economic actors after the climate policy implementation, in consequence.

A systematic review by Babatunde et al. (2017) found a total of 301 scientific reports applying CGE models to assess climate change mitigation policies. The review found that the application of CGE models is crucial for addressing climate change mitigation at various levels, with most research focusing on carbon tax, emission trading, and renewable energy, but there is a trend of using more static than dynamic model. Various approaches have been employed to assess the economic implications of NDC implementation across different geographical scales.

In global scale, den Elzen et al. (2019) projected GHG emissions for G20 economies under current climate policies aligned with their NDC targets, revealing that six G20 countries are on track to meet their unconditional NDC targets with current policies, while eight others require further action. Tolliver et al. (2020) analyzed macroeconomic and institutional factors influencing the growth of the green bond market, finding that the robustness of NDCs has the most significant positive impact on green bond issuance volumes. Siriwardana and Nong (2021) used the GTAP-E model to assess the economic and environmental impacts of NDC targets in major emitting regions, discovering that China and India have lower emission abatement costs and significant potential to generate carbon credits. When integrated into an international carbon market, this potential significantly reduces global carbon prices and economic costs, benefiting regions such as the US, EU, and Australia. Collectively, these contributions underscore that NDCs have substantial economic implications across various geographical scales and that achieving climate goals depends on both robust domestic policies and effective international market mechanisms.

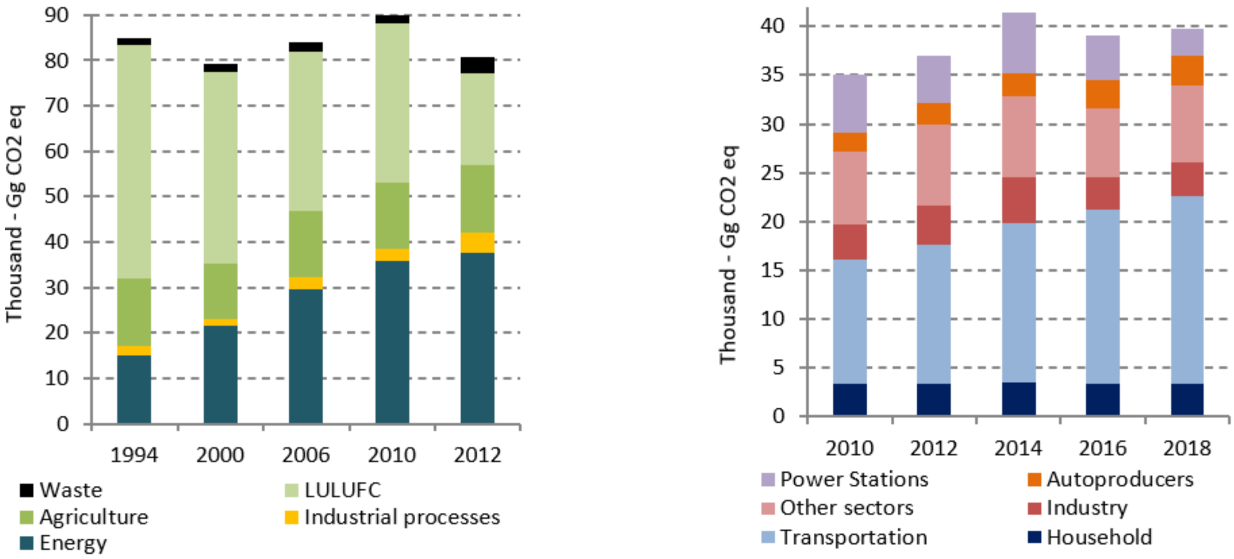
At the local scale, Chunark et al. (2017) assessed the economic impacts of renewable energy adoption in Thailand, finding that while Thailand's INDC can be achieved with current renewable energy targets, the GDP loss ranges from 0.2% to 3.1%, depending on the stringency of the GHG reduction target. Dai et al. (2018) analyzed the economic impacts of achieving China's INDCs, concluding that emissions trading is an economically efficient method to meet emission reduction targets. Vishwanathan et al. (2023) employed a CGE model to evaluate the socio-technical, financial, and macroeconomic implications of India's energy sector transformation, highlighting that to meet NDC targets, India must restructure its coal-based power and industrial sectors. Timilsina et al. (2024) evaluated the economic impact of China's NDC goal to reduce emission intensity by 65% below 2005 levels by 2030, using a CGE model to simulate policy instruments.

In the region, Brazil's potential to meet its NDC targets was assessed by Bastidas and McIsaac (2019), who projected GDP growth by analyzing the necessary adjustments in domestic demand based on the country's industrial structure. Amigo et al. (2021) evaluated Chile's NDC targets, concluding that the commitment to emissions reductions does not sufficiently incentivize a shift to greener technologies. According to Sousa et al. (2020), Colombia's emissions trading system could achieve its NDC mitigation targets cost-effectively; however, its implementation would result in a 0.8 percentage point reduction in the annual GDP growth rate. Across the region, all previous studies indicate that achieving NDC targets requires significant economic adjustments, which have varying impacts on economic growth and the effectiveness of incentives for greener technologies.

In the specific case of Ecuador, there are no studies using the CGE model to assess GHG mitigation policies, although there are CGE applications to assess taxes and trade policies (Aguiar et al., 2012; Cicowiez and Sánchez, 2010; Jácome and Cicowiez, 2012; Montenegro and Ramirez-Alvarez, 2022). In consequence, the importance of evaluating the implications of the NDC in economies highly dependent on primary resources, such as Ecuador, is evident. In 2024, the Ecuadorian GDP was US $122 billion in nominal terms. To understand the potential NDC implications on the Ecuadorian economy, it is necessary to describe the main characteristics: Primary export country and dollarized economy. The "oil boom" produced a structural change in the Ecuadorian economy that lasts until today (Correa, 2004), In fact, oil exports account for 30% of the country's exports, a total of US $9 billion/year on average (BCE, 2024). The country's economy has a high vulnerability to external factors, such as crude oil price fluctuation.

This situation is aggravated by an unfavorable oil horizon, where the country's policymakers must consider ambitious policies focused on reducing the dependence on oil exports and expansion of renewable energy sources over the next decade (Castro Verdezoto et al., 2019; Espinoza et al., 2019). A shift to hydroelectricity is often mentioned as an opportunity to achieve both GHG reduction and productive transition (Hurtado et al., 2023). The implementation of NDC initiatives in the energy sector is an opportunity to reduce imports of oil derivatives and to develop new productive areas based on renewable energy sources (Benito et al., 2023; Benito et al., 2024; Pérez-Gelves et al., 2024).

According to the Third National Greenhouses Gas Inventory, the total GHG emissions from Ecuador were 80,627 $GgCO_{2\text{-eq}}$ in 2012. The energy category is the major contributor to national emissions with 46%, followed by LULUCF (land use, land-use change, and forestry), with a share of 25% of net emissions.



(a) **(b)**

Figure 1. Ecuador’s emissions by **(a)** IPCC categories; **(b)** energy category.

Source: Own calculations based on MAE (2017).

There has been no significant variation in the total yearly emissions (which have remained in the range of 80,000 $GgCO_{2\text{-eq}}$), but emissions linked to LULUCF have been decreasing. (**Figure 1a**). The latest GHG emission report presents the net issues in the LULUCF category by considering the GHG absorptions in forests and grasslands. It implies a decrease in net GHG emissions due to land use of 60.18% since 1994. In the energy category, transportation is the main emitter of GHGs (**Figure 1b**), in consequence the governmental policies focus on changing the energy mix and diversifying its production. This paper highlights three main NDC actions: new hydropower plants; more efficient thermos-power plants; and greater household energy efficiency.

The Ecuadorian NDC establishes the action lines and initiatives considering two categories: efforts dependent only on national actions (unconditional) and efforts dependent on international collaborations (conditioned). The analysis focuses exclusively on NDC initiatives within the unconditional category because the initiatives in the conditional category are not currently being implemented and are still subject to feasibility analysis.

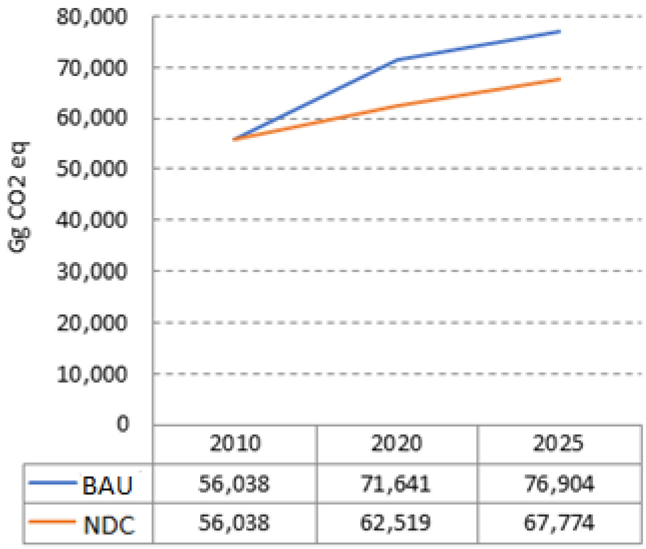


Figure 2. NDC's GHG emissions projections.

Source: MAE (2019).

The NDC initiatives proposed would reduce GHG emissions by 11.87% in relation to the BAU conditions for 2025 (**Figure 2**). Since the GHG emissions in the energy category had a share of 63.90%, the NDCs have a strong focus on reducing the emissions in this sector. The Ecuadorian NDC established the following action lines for the energy sector: Renewable energy sources based on hydropower potential and unconventional renewable sources (**Table 1**). A change in consumer behavior would be a great challenge considering the rapid economic growth of middle-income households.

Table 1. Action lines established in the unconditional category.

Initiatives	Description
Hydropower development (Hydro)	Hydropower generation
Optimization of power generation and energy efficiency (OGE and EE)	Flare reduction Use of associated gas for LPG production and power generation
Non-conventional renewable energy (NCRE)	Wind and solar energy expansion Landfill biogas development
Efficient public transport (Transport)	Quito Subway line and Cuenca tramway
Efficient cooking program (PEC program)	Replace the use of LPG stoves with induction stoves for cooking

Source: MAE (2019).

The first initiative consists of the construction of 8 hydroelectric power plants to increase the installed capacity by 2828 MW until 2025. Hydroelectric power will then displace thermoelectric plants based on diesel and fuel oil, leaving only the gas-fired plants in operation. The OGE and EE project produces electricity using the gas associated with oil extraction, mainly in Amazonia. This electricity will supply demand in the Amazon region, for oil extraction, water pumping, and isolated communities, aiming to eliminate gas flaring.

Currently, non-conventional renewable sources have marginal participation in the Ecuadorian energy mix, i.e., 21 and 26 MW for wind and solar, respectively. Estimates based on technical reports have projected there is potential for developing 884 and 911 MW of wind and solar energy, respectively (MERNNER, 2018). In the transportation sector, the NDC contemplates two local projects: the expansion of the tramway in Cuenca and the construction of a subway in Quito. Both projects seek to improve urban mobility and traffic flow while reducing the GHG emissions related to transportation in urban buses.

The fourth initiative refers to the Energy Efficiency Program (PEC). Its main goal is to replace the use of LPG for cooking and water heating with electricity. One of the main action lines under this initiative is replacing LPG stoves with induction stoves in 1.5 million households and installation of electric shower heads in 750,000 homes.

3. Materials and method

The CGE_EC model include the economic relationships such as market, prices, and trade. The implementation of the NDC action lines is interpreted as variations or shocks in the productive sectors, which are the inputs for the CGE_EC.

In the CGE_EC model, the behavior of consumers and firms is defined by a Linear Expenditure System and Constant Elasticity of Substitution, respectively. The relationship between intermediate sectors is represented by a Leontief function, indicating no sensitivity to relative price variations between sectors (**Figure 3**). To determine the interaction of the domestic economy with external economies, the CGE_EC model employs a Constant Elasticity of Transformation function and an Armington function.

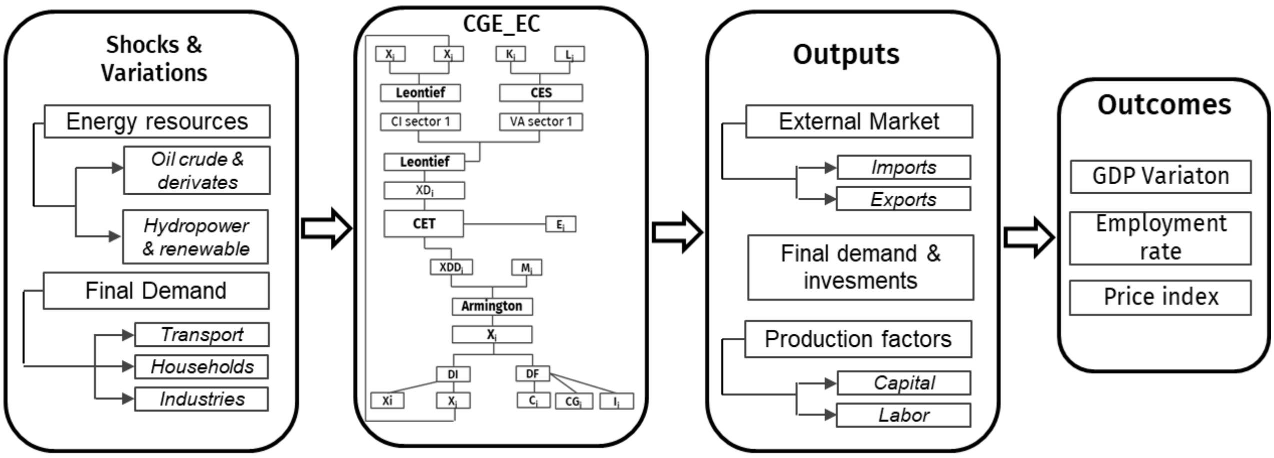


Figure 3. Schematic framework of this study.

Consequently, as an output from the model due to the shock, the implications for wealth generation, the external market, the production of goods and services, and other interactions among economic actors are derived from the analysis. This leads to the implications for the main macroeconomic variables: GDP variation, employment rate, and price index. Also, the study proposes scenarios using a gradual approach to carry out a broad evaluation for decision-makers, enabling prioritization of initiatives in the face of budgetary constraints.

The CGE_EC was built using the model structures proposed by Machado et al. (2020) and Machado et al. (2021), considering Ecuadorian economic conditions, the Central Bank of Ecuador serves as the primary reference for official information, including historical macroeconomic reports. To maintain consistency with the NDC conditions, the model uses the social accounting matrix for 2010 (SCM). This matrix classifies the Ecuadorian economy into 25 sectors. To execute and make it operational, the model was structured with the General Equilibrium Modelling Package (GEMPACK). In it, consumer behavior is defined as a linear expenditure system function that considers the minimum levels of subsistence per sector, linked to budgetary constraints.

The production of goods and services is defined in a constant elasticity of substitution function, by implying minimization of costs of two production factors—capital and labor—to determine the flows in the productive sector. The model considers an input-output structure, assuming there is no sensitivity to the relative price variation. The total economic production for each sector is represented by all intermediate and all final consumption factors. The basic premise is a fixed demand/production ratio among sectors.

Additionally, there are two functions considered to determine the interaction between domestic and external economies. First, the Constant Elasticity of Transformation function is used to define a local production target, considering that the local production goes either for internal consumption or exportation. The second function considered is the Armington function. It is used to define the value of goods and services that are imported. The CGE_EC model consists of 1112 variables—nine exogenous variables and 1103 endogenous variables—constrained by 1103 equations. In the following section, we explore the NDC action lines in the energy sector to define the exogenous variables and their shocks.

The NDC action lines in the energy sector, regarding export, import, supply, and domestic production of the energy sectors, are defined beforehand. So, two subsectors were created: Oil products and Electricity (closure selection). As a result, a set of variables become exogenous for the CGE_EC: Oil products import; Oil products production; Oil products supply; Electricity import; Electricity production; Electricity supply; and Electricity consumption, so the variations and behavior of the actors due to the NDC's energy initiatives are CGE_EC outputs.

The NDC implementation implies high investments by the Ecuadorian government, as well as intensive use of production factors (capital and labor), so the factor capital supply is considered an exogenous variable. To determine the household welfare, which is measured by purchasing power, the remuneration of labor is the unit of account in the CGE_EC, so price variation of goods and services is referenced around it.

The NDC initiatives propose a reduction of 8200 $GgCO_{2\text{-eq}}$ (**Table 2**), the equivalent to 89.81% of the objective set, validating the role of reduction policies in the energy sector. To achieve it, a significant investment is required, the equivalent to 8.09% of nominal GDP in 2020. They also need to account for variations in energy production/consumption structure, resulting in energy savings due to reduction of fossil fuel consumption. To adapt these variations to CGE_EC's structure, an economic-energy ratio is defined both in monetary terms and energy units. This is determined according to the destination sector and its end-use. Consequently, the shock in the exogenous variables is determined.

Table 2. NDC initiatives' targets*.

Initiatives	GHG reduction ($GgCO_{2\text{-}eq}$)	Investment (million US $)	Energy Prod./Cons. (GWh)[1]	Energy savings (k BOE)[2]
Hydro	4606	4500	15,678	10,633
OGE and EE	937	1152	1272	1100
NCRE	250	594	451	849
Transport	67	1781	−72	432
PEC	2340	-	−5463	3885
Total	8200	8027	11,865	26,799

Source: Own calculations based on MAE (2019) and MERNNER (2018).
[1] To electricity use Gigawatt (GWh) as a unit of measurement.
[2] To fossil fuels use Barrel of Oil Equivalent (BOE) as a unit of measurement.
* Positive refers to production and negative refers to consumption.

Four scenarios were developed in the CGE_EC, gradually evaluating the initiatives: i) implementation of the supply initiatives only (S scenario); ii) implementation of both the supply and demand initiatives (S and D scenario); iii) implementation of all NDC initiatives (NDC scenario); and iv) an alternative scenario, which is aligned with the NDC initiatives with more measured levels of implementation.

The Supply scenario (S scenario) was evaluated from minimum to maximum addition, which represents all NDC supply initiatives. The maximum addition is equivalent to an 80% increase in monetary terms of base year electricity production. The supply-demand scenario (S and D) considers a gradual increase of electricity consumption, where the maximum consumption is equivalent to a 50% increase in monetary terms of the base. Like the supply scenario, this increase is satisfied by the growth in electricity production from 5% until 80%. Also, the S and S&D scenarios do not consider fuel import reductions and improved performance by more efficient power generation technologies.

The NDC scenario considers all the conditions previously presented along with the implications of reducing fossil fuel consumption, a necessary condition to guarantee GHG reduction. The alternative scenario proposes electricity production without surpluses and without high dependence on electrical exports, but assurance of economic growth, reduced unemployment, and lower prices.

4. Discussion

This section is divided into two subsections. The first is an evaluation of the technical-economic aspects related to the investments involved in NDC implementation as well as to the reduction of GHG emissions. The second part explores the macroeconomic consequences based on the scenarios proposed using the CGE_EC model.

4.1. Economic and environmental performance

The NDC expectations focus mainly on two initiatives: hydropower expansion on the supply side and the PEC program on the demand side. Both initiatives contribute to a reduction of 6942 $GgCO_{2\text{-eq}}$., equivalent to 76% of the overall reductions estimated for the NDC (**Figure 2**). Therefore, the contribution from the other initiatives contained in the NDC is marginal. The hydropower initiative aims to contribute the largest GHG reductions (56.17% of total reductions); it also requires the largest investment, representing for 56.06% of the total cost of NDC initiatives. Nevertheless, it has the best GHG reduction per level of investment, as the reduction of each Kg.CO2-eq entails an investment of US $0.98 (see **Table 3**). The hydropower expansion will increase electricity production by 76.91%, a value that would be 1.55 times more than in the present electricity consumption mix. Such increase will cause a significant surplus, which can be allocated to regional export, production diversification or energy-intensive industries.

Table 3. Performance of energy supply initiatives.

Initiatives	GHG reduction (US $/$GgCO_{2\text{-eq}}$)	Energy production (US $/kWh)	Energy savings (US $/BOE)	Payback[3] (years)
Hydro	0.98	0.29	423	4.75
OGE and EE	1.23	0.91	105	1.18
NCRE	2.37	1.32	699	7.85

[3] Estimated value considering oil product import prices.

The PEC program has a contribution of 28.54% of GHG reduction without significant investments. This is because costs of technological change fall mainly on consumers, with slight participation of the state when compared to previous projects. The PEC program implementation involves an increase of 5463 GWh in residential electricity consumption. This increase in domestic demand would consume 50% of the hydropower expansion surplus. Such increase is linked to the reduction of 3.8 million BOE, the equivalent to a 70.94% reduction in household consumption of LPG.

The OGE and EE program involves productive use to methane, which is currently flared, implying positive results due to less methane burning. So, each MW added by OGE and EE implies a reduction of 2890 $GgCO_{2\text{-eq}}$., while the hydropower initiative implies a reduction of 1670 $GgCO_{2\text{-eq}}$, since emissions from methane burning have a higher global warming potential than CO2 emissions. Nevertheless, OGE and EE energy savings are debatable, because they are significantly higher than expected in the hydropower expansion. Both initiatives seek to reduce the fossil fuel consumption for power generation in the same regulatory framework (market and prices).

Thus, according to **Table 3**, the OGE and EE program would have a return on investment of 1.18 years, which is an optimistic figure for this kind of project. It might be that estimates of the OGE and EE program are too large. Regarding the energy savings indicator, the OGE and EE program would be the most beneficial, with an investment of US $105 for each BOE saved, while NCRE initiatives are the less beneficial, with an investment of US $699/BOE.

The NCRE initiative is more costly than the hydro and OGE and EE initiatives. It would require an investment of US $2.37 per Kg.CO2-eq avoided, as well as higher energy production, of US $1.32 per kWh, and longer payback time. On demand side, the transport initiative implies an investment of US $26.58 for each Kg.CO2-eq reduced. Its implementation involves a 720% increase in electricity consumption in the transportation sector. The debate focused on electricity generation sources to supply this significant increase is crucial, since power generation based on traditional fuels implies counterproductive results.

The transport initiative has the lowest expected reduction in GHG emissions and the second-highest state investment requirement. This entails an investment ratio of 26.58 USD/Kg.CO2-eq avoided, a value that exceeds the limits in comparison with other initiatives (**Table 3**). This suggests that the reduction of GHG emissions is not the main goal of this initiative, but only a byproduct.

It is concluded that the mechanisms and initiatives defined by the NDC are consistent with its objectives. Remarkably, 89.91% of the GHG reduction is concentrated in the energy category, so the remaining 10.19% reduction is distributed in the other four categories (i.e., agriculture, LULUFC, industrial process, and waste sectors). So, there is a potential reduction not yet explored by the NDC in these four categories. There would also be a preferential bias towards the energy category due to the seizure of economic opportunities.

Aligned with the results obtained, the UNDP's Climate Promise initiative underscores Ecuador's NDC projection of an unconditional emissions reduction potential of 9% across various sectors, including energy. Furthermore, the initiative highlights the necessity of advanced models to deepen the understanding of the economic and environmental trade-offs associated with NDCs in Ecuador PNUD-MAAE (2020).

To evaluate the macroeconomic implications, the following sections describe and discuss the implications of NDC implementation using MPC_EC, exploring its gradual implementation through the scenarios proposed.

4.2. Supply scenario (S)

Assuming the local electric energy demand remains unaltered, the surplus electric generation would be allocated to export, with high external savings (**Figure 4a**). A gradual increase in capacity added to electricity production from 5% (minimum) to 80% (maximum) would increase exports by between US $68 and US $1121 million (see **Figure 4b**). For increases below 30%, the electricity export levels are marginal compared to the total export volume.

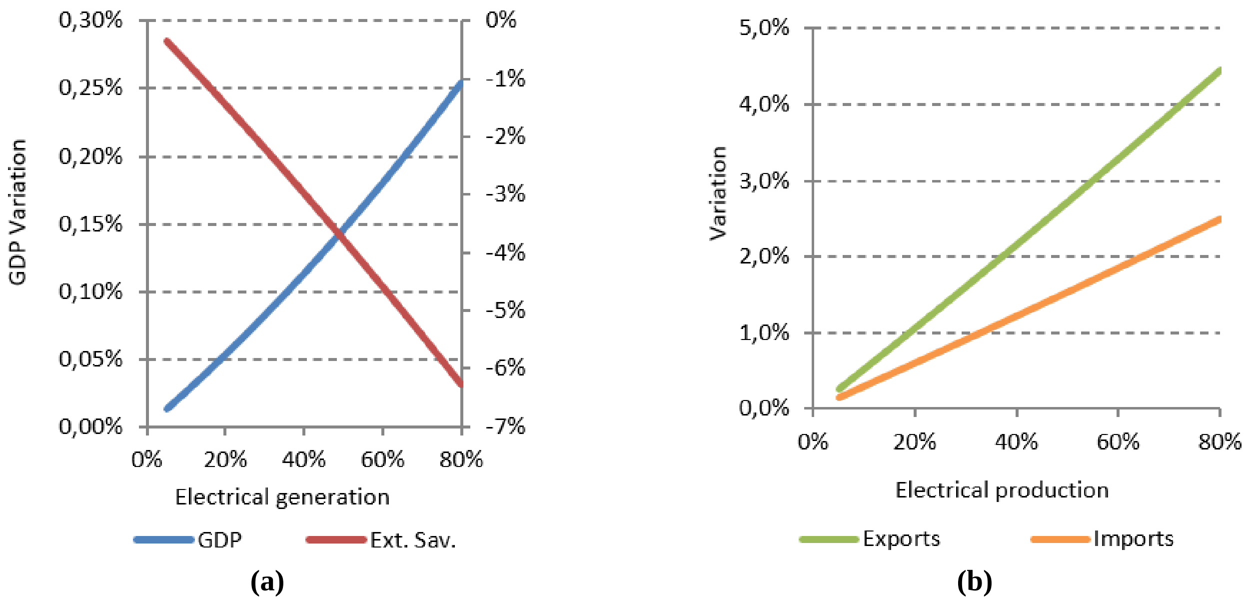


Figure 4. Supply scenario **(a)** GDP variation; **(b)** external market.

Despite the large increase in the electric energy exports, GDP would rise by only 0.25% (**Figure 4a**). Because of its maximum capacity added (3297 MW), there would be a significant reduction in the country's external savings, reaching a minimum of −6.27% when the electricity production expands by 80%. To avoid such a significant drop, national savings should simultaneously be increased, by the private and/or public sector. Also, the destination of the surplus is dubious due to technical aspects and market availability (**Figure 4b**). Electricity is a secondary source of energy since its storage and transport require the installation of extra facilities. While batteries only allow electricity to be stored in small quantities, other indirect methods, which involve transformation processes, allow the storage of large amounts. On the other hand, the transportation of electricity would entail the installation of costly infrastructure and transmission lines to serve external markets.

Considering the technical restrictions, the logical markets would be the border countries (Peru and Colombia). These countries currently do not have an electricity deficit, so their energy planning programs do not include significant energy import scenarios for the next 10 years (MINEM, 2014; UPME, 2022). The main contribution of the Supply scenario is the conclusion that the Ecuadorian economic-productive structure is not suitable for high levels of electricity production. The implementation of supply initiatives necessarily requires electricity consumption initiatives. This can be either intermediate or final consumption, which motivates the development of a scenario that combines electricity supply and demand initiatives.

4.3. Supply-demand scenario (S and D)

The supply-demand initiatives together would have a greater impact on economic growth in comparison with the supply scenario (S), i.e., national GDP would grow between 0.79% and 2.75%. The minimum growth corresponds to the minimum conditions for both demand and supply of electricity, whereas the maximum GDP growth is a consequence of an increase of 5535 GWh in electricity consumption, the equivalent to 57% of consumption in 2010 monetary terms. However, the growth of GDP is still marginal for all possible combinations between the growths of supply and demand (see **Figure 5a**).

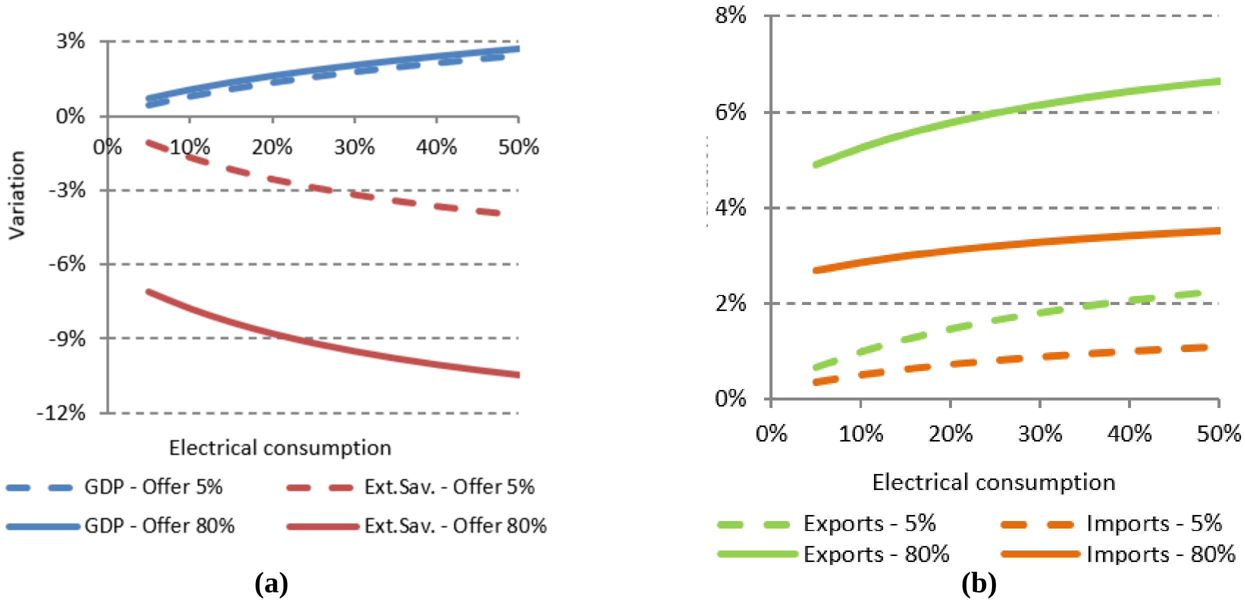


Figure 5. S and D scenario **(a)** GDP variation; **(b)** external market.

According to **Figure 5b**, the implementation of scenario S and D would cause an increase in total exports. The increases in installed capacity would be significantly higher than the added electricity consumption, resulting in a surplus of 11,865 GWh. If this amount is exported, provided that it is feasible, the total export income would rise by 6.64% (when compared to the base year of 2010). There would also be an improvement in the trade balance (reflected in **Figure 5a**), where the external savings would be reduced to 10.47% compared to the base year 2010.

The Supply and Supply-Demand scenarios both reflect the prominent role of final consumption in the Ecuadorian economy. In agreement with Ortega-Pacheco et al. (2021) our study suggests that public policies and the implementation of the NDC initiatives 1, 2 and 5 should not only be based on the increase of internal demand for electric energy per se, but should also evaluate alternatives for productive use of it.

4.4. NDC scenario (NDC)

The NDC scenario implies a GDP increase of US $3 billion, the equivalent of 4.43% of GDP in 2010. This GDP growth is higher than that estimated for the scenarios S and S and D. The implementation of the NDC scenario will also provoke a 1.01% reduction in the price index due to the decline in final electricity prices by 27.85% because of the electricity surplus. The opposite outcome is observed in Korea, where a slight contraction in real GDP is expected due to carbon pricing and mitigation policies (Kim et al., 2023). Similarly, in the Brazilian economy, a GDP contraction of up to 2% is anticipated in scenarios lacking complementary policies, but the inclusion of measures such as carbon pricing and the expansion of renewable energy can help mitigate these effects (Gurgel et al., 2019).

The final electricity price for consumers would be around US $0.05–0.06/kWh, implying a decrease of 33% in relation to current market prices. These competitive prices could allow the local industry to generate greater added value. To reinforce this argument, in this scenario the production cost of intermediate products would decrease between 0.5% and 1%. Nevertheless, there would be an increase in prices of public and financial services of 1.56% and 1.14%, respectively. Due to the lower cost of energy, the cost of the transportation sector would have a reduction of 2.77%, due to more efficient modality in the passenger transport and the use of electricity. In addition, the NDC scenario causes a 1.27% reduction in unemployment, a rate linked to an increase of 4.13% in the supply of the labor factor. According to **Figure 6**, increases in the demand of production factors (Capital and Labor) would be focused on the electricity sector. At the same time, there would be a reduction of these factors in the crude oil and oil products, a predictable result due to the shift in consumption and production from fossil sources in favor of less polluting sources. Additionally, the pulp and paper sector would also benefit from the energy transition, considering it is an energy-intensive industry, and competitive costs plus a significant supply of electricity would allow the use of more efficient machinery. It is therefore advisable to propose transition strategies to direct job losses in the oil extraction and derivatives production sectors to the new jobs generated in other productive sectors, such as agroindustry and technology.

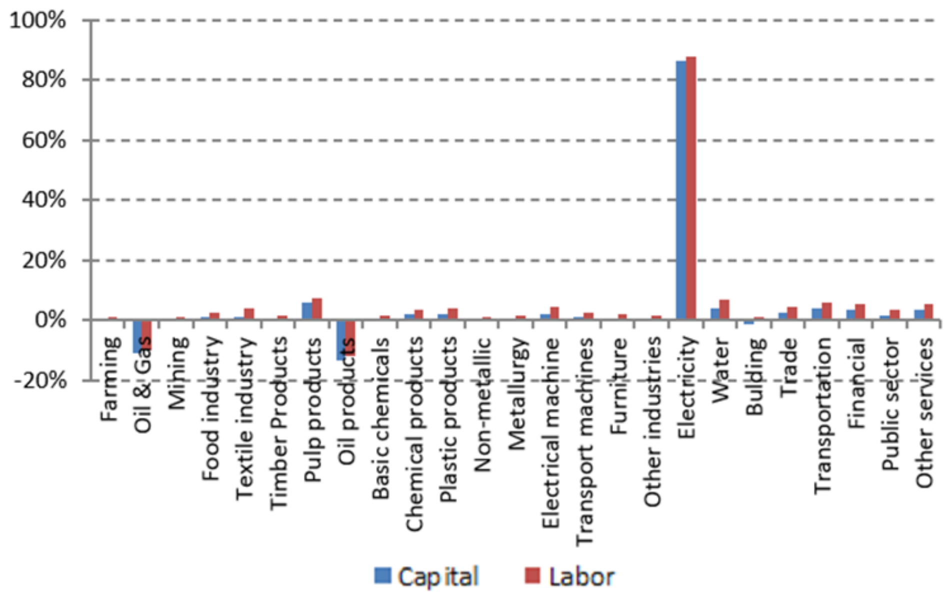


Figure 6. Demand for productions factor in NDC Scenario.

In the services sectors, the primary implication is the increase in capital and labor supply driven by investments required for the construction of electrical infrastructure (designs and services for execution), both public and private. The farming sector shows no significant variations in production factors (**Figure 6**), unlike in Brazil, where the agricultural sector could face production decreases due to mitigation policies. In Brazil, there is an estimated 2% reduction in the labor force resulting from the adoption of more efficient and less labor-intensive technologies (Gurgel et al., 2019).

Regarding the external sector, exports would increase by 17.42% compared to the base year 2010, mainly focused on the export of electricity. There would also be a reduction in exports of crude oil and its derivatives due to the reduction in consumption and production of hydrocarbons. This is a desired effect within the implementation of the NDC to guarantee the reduction of GHG emissions. Oil exports are the main source of income in the Ecuadorian economy, so a scheme is necessary that guarantees maintaining the same export levels. According to Kim et al. (2023), a similar condition would occur in the Korean case, with a more moderate reduction in exports of around 1.7%. South Korea could mitigate these effects through technological innovation and international cooperation, enabling some industrial sectors to remain competitive globally.

The imports of fuels and refinery supplies would decrease by 12% and 2.31% respectively, due reduction of fossil fuels consumption and lower requirements for solvents used in the process to improve the quality of oil derivatives. Sine total exports would increase more than imports, the trade balance would be improved, and the external savings reduced by 10% compared to 2010.

Similar to the S and S and D scenarios, in the NDC scenario the exports of electricity are necessary to guarantee appropriate growth of use of the surplus electricity generated. Exports in the electricity sector would be US $1717 million due to the availability of 6123 GWh, which is half of the availability in the S and D scenario. So, it would be necessary to find external markets to export surpluses or increase domestic consumption. The latter would imply an estimated decrease of electricity prices of 45.72%. Therefore, the productive sectors would need to more intensively electrical technologies, such as induction furnaces and electricity transport infrastructure, opening the possibility for rational use of electrical energy due to lower market prices.

4.5. Alternative scenario (Alt)

Undesirable macroeconomic conditions have been presented in the previous scenarios, such as decrease of external savings, production factor concentration in fewer sectors, and high investment with low GDP growth. The alternative scenario proposes an increase of 25% in the final electricity consumption, linked to a 15% increase in local electricity production. This means increasing production by 3,000 GWh. As a result of this scheme, we obtained a 5% reduction in fuel imports, the equivalent of US $170 million. The GHG reduction was estimated at 1000 $GgCO_{2\text{-eq}}$. a value equivalent to 12% of that planned in the NDC.

The alternative scenario considers a lower concentration of production factors in the electricity sector (**Figure 7**), implying a better distribution of capital and labor in different productive sectors. It entails better performance, including an increase in the labor factor for the oil products sector, an opposite situation concerning the NDC scenario. This characteristic is probably the product of the high levels of investment involved in certain initiatives of the NDC (**Table 3**). It reflects the reduction of GHG as a collateral result and not the main goal of the initiative, as is the case of the subway line in Quito and the tramway in Cuenca.

The alternative scenario estimates electric exports of US $700 million, a forecast result in the electric expansion planning. It implies an increase of 1.33% in the total exports. There would be an improvement in the trade balance and a reduction in foreign savings of 5% when compared to the base year. This scenario presents more appropriate macroeconomic results, but the GHG reduction goals in the NDC would not be fully met.

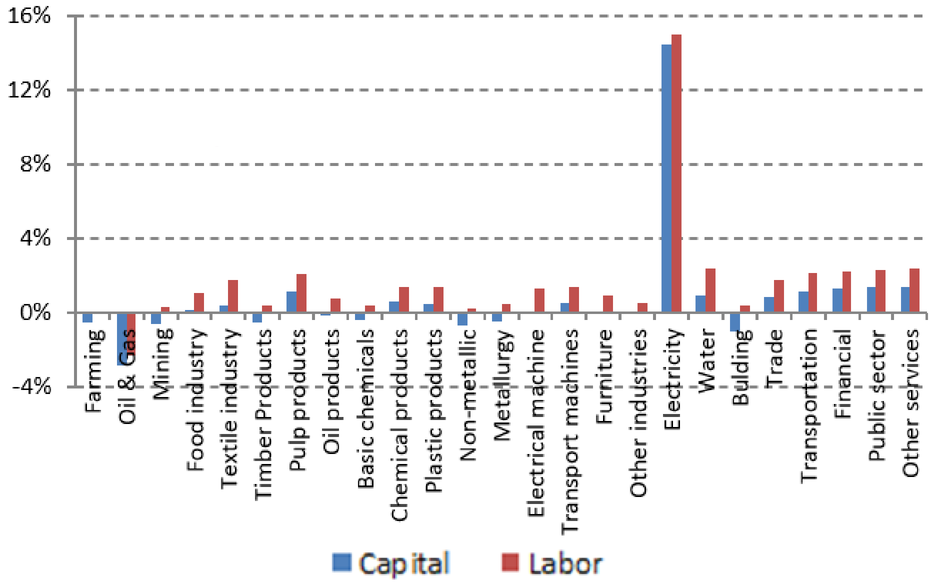


Figure 7. Demand for productions factor in Alternative Scenario.

5. Conclusion

The NDC approach and its initiatives are framed in the existing economic-energy structure, taking advantage of the hydropower potential. It emphasizes setting overall goals instead of goals for each initiative, so a specific analysis by initiative is difficult, mainly their involving performance according to investment levels. The NDC considers initiatives with high investment but low levels of GHG reduction.

More aggressive policies in the transportation sector focused on individual passenger or cargo transport are advisable, as they are significant GHG emitters. The NDC initiative is focused on the displacement of urban collective transport to reduce traffic jams, so the main objective is not to reduce fuel consumption or emissions. This condition implies high investment levels and generates distortions in the demand for productions factors. The electricity generated will be allocated for final consumption mainly in households and the transportation sector, through more efficient and less polluting technologies. In addition to satisfying domestic demand, the installed power capacity will entail large surpluses of electricity production, which should be allocated for export, avoiding oversupply in the domestic market.

The regional export of electricity is not guaranteed, because the bordering countries do not have shortages or immediate electricity requirements, and their expansion plans include hydropower plants. It would be desirable for the NDC to consider a less aggressive hydropower expansion, guaranteeing the supply for technological transitions in the domestic market and minimum levels of regional electricity exports. This approach does not guarantee the GHG reduction levels initially proposed in the NDC.

The NDC implementation has strong dependence on the hydropower expansion plan, so its feasibility has a high dependence on electricity exports. Another alternative would be to rethink the initiatives, since they are focused on household consumption, but do not generate added value in society. It is recommended that productive sectors be encouraged to utilize electricity surpluses through more efficient technologies, generating employment and added value. The NDC's goals are at the economic-environmental crossroads. Their total implementation must guarantee all market conditions to generate economic growth, and these are complex conditions in the current context. There is also the possibility of partial implementation that is aligned with the production structure, but that does not guarantee full compliance with the objectives proposed.

The implementation of Ecuador's NDC faces challenges similar to those of other economies transitioning to sustainable models. In Ecuador, a fossil fuel-dependent economy, the impact on its oil trade balance underscores the country's vulnerability to the initial costs of the energy transition. For example, South Korea, with a more diversified and technologically advanced economy, encounters challenges in international cooperation. Meanwhile, Brazil, with its strong reliance on the agricultural sector, faces significant impacts within that sector.

Although the CGE_EC model is robust, its primary limitation lies in its reliance on economic and energy data projections, which, despite being based on official sources, are susceptible to variations influenced by the policies of the government in power. While the NDC represents an international commitment, the successful execution of the action plan is contingent upon the availability of resources and the priorities set by the government.

As a methodological recommendation for evaluating climate change policies, the CGE_EC model should be hybridized with a technical model to develop an Integrated Assessment Model. This approach would generate valuable information for decision-making, even in the face of significant uncertainties, and help answer the critical question: What is the cost of going green?

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References

Aguiar, V., Gualavisí, M., & Sáenz, M. (2012). Analysis of the impact on the Ecuadorian economy of the application of real and effective tariff protection measures to industrial sectors with the MACEPES model (Spanish). In: Torres, P. (editor).

Estudios industriales de la micro, pequeña y mediandа empresa, 1st ed. FLACSO Sede Ecuador. pp. 81–124.
Amigo, P., Cea-Echenique, S., & Feijoo, F. (2021). A two stage cap-and-trade model with allowance re-trading and capacity investment: The case of the Chilean NDC targets. Energy, 224, 120129. https://doi.org/10.1016/j.energy.2021.120129
Babatunde, K. A., Begum, R. A., & Said, F. F. (2017). Application of computable general equilibrium (CGE) to climate change mitigation policy: A systematic review. Renewable and Sustainable Energy Reviews, 78, 61–71. https://doi.org/10.1016/j.rser.2017.04.064
Bastidas, D., & Mc Isaac, F. (2019). Reaching Brazil's Nationally Determined Contributions: An assessment of the key transitions in final demand and employment. Energy Policy, 135, 110983. https://doi.org/10.1016/j.enpol.2019.110983
BCE. (2024). Macroeconomic statistics structural presentation 2024 (Spanish). Banco Central del Ecuador.
Benito, A. O., Castro Verdezoto, P. L., Burlot, A., et al. (2024). Hybrid power system for distributed energy deploying biogas from municipal solid waste and photovoltaic solar energy in Mendoza, Argentina. E3S Web of Conferences, 532, 01001. https://doi.org/10.1051/e3sconf/202453201001
Benito, A., Castro-Verdezoto, P. L., & Rodríguez, P. (2023). Prospective on the energy integration of distributed generation systems (Spanish). Reciamuc, 7(2), 375–389. https://doi.org/10.26820/reciamuc/7.(2).abril.2023.375-389
Bukowski, M., & Kowal, P. (2010). Large scale, multi-sector DSGE model as a climate policy assessment tool. Instytut Badań Strukturalnych, Warszawa, 3.
Castro Verdezoto, P. L., Vidoza, J. A., & Gallo, W. L. R. (2019). Analysis and projection of energy consumption in Ecuador: Energy efficiency policies in the transportation sector. Energy Policy, 134, 110948. https://doi.org/10.1016/j.enpol.2019.110948
Castro, M. P., Castro, P. L., & Cunha, M. P. (2018). Comparative Analysis of Energy Indicators of Member Countries of the Andean Community of Nations (Spanish). Revista Técnica "Energía," 14(1), 236–245. https://doi.org/10.37116/revistaenergia.v14.n1.2018.176
Chunark, P., Limmeechokchai, B., Fujimori, S., et al. (2017). Renewable energy achievements in CO2 mitigation in Thailand's NDCs. Renewable Energy, 114, 1294–1305. https://doi.org/10.1016/j.renene.2017.08.017
Cicowiez, M., & Sánchez, M. V. (2010). External Shocks and Social Protection Policies in Latin America (Spanish). Centro de Estudios Distributivos Laborales y Sociales.
Correa, R. (2004). Vulnerability of the Ecuadorian Economy (Spanish), 1st ed. PNUD.
Dai, H., Xie, Y., Liu, J., & Masui, T. (2018). Aligning renewable energy targets with carbon emissions trading to achieve China's INDCs: A general equilibrium assessment. Renewable and Sustainable Energy Reviews, 82, 4121–4131. https://doi.org/10.1016/j.rser.2017.10.061
Deka, A., Ozdeser, H., & Seraj, M. (2022). The effect of GDP, renewable energy and total energy supply on carbon emissions in the EU-27: new evidence from panel GMM. Environmental Science and Pollution Research, 30(10), 28206–28216. https://doi.org/10.1007/s11356-022-24188-x
den Elzen, M., Kuramochi, T., Höhne, N., et al. (2019). Are the G20 economies making enough progress to meet their NDC targets? Energy Policy, 126, 238–250. https://doi.org/10.1016/j.enpol.2018.11.027
Espinoza, V. S., Fontalvo, J., Martí-Herrero, J., et al. (2019). Future oil extraction in Ecuador using a Hubbert approach. Energy, 182, 520–534. https://doi.org/10.1016/j.energy.2019.06.061
Gurgel, A. C., Paltsev, S., & Breviglieri, G. V. (2019). The impacts of the Brazilian NDC and their contribution to the Paris agreement on climate change. Environment and Development Economics, 24(04), 395–412. https://doi.org/10.1017/s1355770x1900007x
Hajdukovic, I. (2021). Interactions among macroeconomic policies, the energy market and environmental quality. Environmental Economics and Policy Studies, 23(4), 861–913. https://doi.org/10.1007/s10018-021-00305-x
Hanna, R., Heptonstall, P., & Gross, R. (2024). Job creation in a low carbon transition to renewables and energy efficiency: a review of international evidence. Sustainability Science, 19(1), 125–150. https://doi.org/10.1007/s11625-023-01440-y
Hurtado, J., & Castro, P. (2023). Feasibility study of a small hydroelectric plant on a tributary of the Guayas River—Ecuador. Polo Del Conocimiento, 8(12), 1226–1238. https://doi.org/10.23857/pc.v8i12
Jácome, H., & Cicowiez, M. (2012). The Free Trade Agreement with the European Union: economic and distributive effects for Ecuador (Spanish). In: Torres, P. (editor). El retorno de las carabelas: Acuerdo Comercial Multipartes entre Ecuador y la Unión Europea, 1st ed. FLACSO Sede Ecuador. pp. 93–138.
Jia, H., Fan, S., & Xia, M. (2023). The Impact of Renewable Energy Consumption on Economic Growth: Evidence from

Countries along the Belt and Road. Sustainability, 15(11), 8644. https://doi.org/10.3390/su15118644

Kim, Y. G., Moon, J., & Kim, J. (2023). Evaluating the economic impacts of Korea's NDC (nationally determined contributions) implementation via carbon pricing: A global multiregional computable general equilibrium analysis. Journal of Climate Change Research, 14(3), 253–275. https://doi.org/10.15531/ksccr.2023.14.3.253

Machado, P. G., Cunha, M., Walter, A., et al. (2020). The potential of a bioeconomy to reduce Brazilian GHG emissions towards 2030: a CGE-based life cycle analysis. Biofuels, Bioproducts and Biorefining, 14(2), 265–285. https://doi.org/10.1002/bbb.2064

Machado, P. G., Cunha, M., Walter, A., et al. (2021). Biobased economy for Brazil: Impacts and strategies for maximizing socioeconomic benefits. Renewable and Sustainable Energy Reviews, 139, 110573. https://doi.org/10.1016/j.rser.2020.110573

MAE. (2017). Ecuador's Third National Communication to the United Nations Framework Convention on Climate Change (Spanish). Ministerio del Ambiente.

MAE. (2019). First nationally determined contribution (Spanish). Primera NDC Ecuador.

MERNNER. (2018). Electricity Master Plan 2018–2027 (Spanish). Ministerio de energía y minas.

MERNNER. (2021). National Energy Balance 2020 (Spanish). Ministerio de Energía y Recursos Naturales No Renovables.

MINEM. (2014). National Energy Plan 2014-2025 (Spanish). Ministerio de Energía Y Minas.

Montenegro, C., & Ramirez-Alvarez, J. (2022). Fuel subsidies in Ecuador: A Computable General Equilibrium model for targeting evaluation. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.4044106

Ortega-Pacheco, D., Benalcázar, E. A. & María-Pilar C. (2023). Analysis of the potential of residual biomass for electricity generation in countries of the Amazon basin (Spanish). In: Estudios sobre Economía Circular e Industria 4.0, 1st ed. Mawil. pp. 26–46.

Ortega-Pacheco, D., Castro-Verdezoto, P. L., Mendoza-Jiménez, M. J., et al. (2021). Social and Economic Contribution of the Bioeconomic Sector in Ecuador. In: Venkatramanan, V., Shah, S., Prasad, R. (editors). Sustainable Bioeconomy. Springer. pp. 35–65.

Pérez-Gelves, J. J., Castro-Verdezoto, P. L., Alvarado-Cantos, N. M., et al. (2024). Applying fuzzy logic and neural networks to forecasting in efficiency programs. E3S Web of Conferences, 532, 01006. https://doi.org/10.1051/e3sconf/202453201006

Pinzón, K. (2017). Dynamics between energy consumption and economic growth in Ecuador: A granger causality analysis. Economic Analysis and Policy, 57, 88–101. https://doi.org/10.1016/j.eap.2017.09.004

PNUD-MAAE. (2020). Methodology for the formulation of NDCs through participatory and inclusive processes, Ecuador experience (Spanish). Programa de las Naciones Unidas para el desarrollo.

Siriwardana, M., & Nong, D. (2021). Nationally Determined Contributions (NDCs) to decarbonise the world: A transitional impact evaluation. Energy Economics, 97, 105184. https://doi.org/10.1016/j.eneco.2021.105184

Sousa, R., Álvarez-Espinosa, A. C., Rojas Pardo, N., et al. (2020). Emissions trading in the development model of Colombia. Climate Policy, 20(9), 1161–1174. https://doi.org/10.1080/14693062.2020.1808436

Timilsina, G. R., Chang, Y., & Pang, J. (2024). Economic impacts of meeting China's NDC through carbon taxes with alternative schemes for recycling tax revenues. Resources, Conservation and Recycling, 207, 107696. https://doi.org/10.1016/j.resconrec.2024.107696

Tolliver, C., Keeley, A. R., & Managi, S. (2020). Drivers of green bond market growth: The importance of Nationally Determined Contributions to the Paris Agreement and implications for sustainability. Journal of Cleaner Production, 244, 118643. https://doi.org/10.1016/j.jclepro.2019.118643

UPME. (2022). Transmission Expansion Plan 2022–2036 (Spanish). Unidad de Planeación Minero Energética.

Vishwanathan, S. S., Fragkos, P., Fragkiadakis, K., & Garg, A. (2023). Assessing enhanced NDC and climate compatible development pathways for India. Energy Strategy Reviews, 49, 101152. https://doi.org/10.1016/j.esr.2023.101152