CAF - WORKING PAPER #2024/02
First version: March 13, 2023
This version: May 23, 2024

The Economic Effects of an Accelerated Electrification and Decarbonization Process in Latin America

Gutiérrez-Meave, Raúl[1] | Núñez, Héctor[2] | Rosellón, Juan[3]

[1]PhD student, Department of Public Policy, Management and Analytics, University of Illinois Chicago. Research Assistant, Department of Economics, Center for Research and Teaching in Economics (CIDE)
rgutie34@uic.edu

[2]Professor, Department of Economics, Center for Research and Teaching in Economics (CIDE).
hector.nunez@cide.edu

[3]Professor, Department of Economics, Center for Research and Teaching in Economics (CIDE).
juan.rosellon@cide.edu

This research analyzes the potential economic effects of accelerated electrification and decarbonization in selected Latin American countries. Using an economic equilibrium model, four scenarios were evaluated: 1) a Business-as-Usual (BAU) scenario, 2) a BAU scenario with increased electricity interconnections, 3) a green scenario with an emphasis on higher renewable energy growth rates, and 4) a green scenario integrating both higher energy growth rates and interconnection improvements. We aim to assess the impact of these strategies on significant economic indicators by comparing the optimal solutions of each scenario, and determine the difference in gains. Our approach prioritizes the complexities of the energy sector while underscoring economic factors, enabling the identification of necessary compensatory redistributions. The comparison of these scenarios will provide policymakers and stakeholders with valuable insights into the costs and benefits of transitioning to a more sustainable energy system in Latin America.

KEYWORDS
Electrification, Decarbonization, Economic effects

BANCO DE DESARROLLO
DE AMÉRICA LATINA
Y EL CARIBE

CAF - DOCUMENTO DE TRABAJO #2024/02

Versión final: May 23, 2024

Los efectos económicos de un proceso acelerado de electrificación y descarbonización en América Latina

Gutiérrez-Meave, Raúl[1] | **Núñez, Héctor**[2] | **Rosellón, Juan**[3]

[1]PhD student, Department of Public Policy, Management and Analytics, University of Illinois Chicago. Research Assistant, Department of Economics, Center for Research and Teaching in Economics (CIDE)
rgutie34@uic.edu

[2]Professor, Department of Economics, Center for Research and Teaching in Economics (CIDE).
hector.nunez@cide.edu

[3]Professor, Department of Economics, Center for Research and Teaching in Economics (CIDE).
juan.rosellon@cide.edu

Este trabajo analiza los posibles efectos económicos de la electrificación y descarbonización aceleradas en países seleccionados de América Latina. Utilizando un modelo de equilibrio económico, se evaluaron cuatro escenarios: 1) un scenario Business-as - Usual, 2) un escenario BAU con mayores interconexiones eléctricas, 3) un escenario verde con énfasis en tasas de crecimiento más altas de energía renovable, y 4) un escenario verde que integra tanto tasas de crecimiento energético más altas como mejoras en la interconexión. El objetivo del presente trabajo es evaluar el impacto de estas estrategias en indicadores económicos significativos comparando las soluciones óptimas de cada escenario, y determinar la diferencia en los beneficios. Nuestro enfoque prioriza las complejidades del sector energético mientras enfatiza en los factores económicos, permitiendo la identificación de compensaciones necesarias. La comparación de estos escenarios proporcionará a los responsables de políticas y a las partes interesadas valiosos conocimientos sobre los costos y beneficios de la transición hacia un sistema energético más sostenible en América Latina.

KEYWORDS

Electrificación, descarbonización, efectos económicos.

1 | INTRODUCTION

The transition to sustainable energy sources has escalated into an imperative of utmost urgency, magnified by the ever-clearer ramifications of global warming on our energy systems. Climate change has led to a decrease in the use of fossil fuels for energy production, as countries around the world seek to decarbonize their economies in the short and medium term. In addition to environmental concerns, geopolitical events such as the war in Ukraine can also have a significant impact on energy systems, leading to a greater sense of urgency to shift to renewable energy sources.

The need to transition to low-carbon, climate-resilient societies has been widely recognized by scholars and practitioners in recent decades, culminating in the 2015 adoption of the global Paris Agreement on climate change. In this agreement, 194 countries made nationally determined commitments to limit emissions, with the goal of keeping global warming below 2°C.

Despite this global commitment, there is a significant disparity in each nation's capacity to achieve its national contributions. While some countries with robust private sectors, sophisticated governance structures, and ample access to funding have made significant progress in shifting to clean energy systems, many Latin American and Caribbean countries face significant challenges in achieving their renewable energy goals. However, even though they may lack some of these advantages, these countries still have the potential to achieve their goals and transition to sustainable energy systems.

Given this context, this study aims to explore the economic effects of an accelerated electrification and decarbonization process for a selection of Latin American countries. The scarcity of research on the economic implications of energy transition in Latin America underscores the importance of this study. By conducting a comprehensive analysis of the potential economic effects of energy transition, we aim to contribute to the existing literature and provide valuable insights for policy-making in the region.

2 | BACKGROUND

The transition to sustainable energy sources is a global priority, and Latin America is no exception. The region has abundant renewable energy resources, such as hydroelectric, solar, and wind power, that can help reduce carbon emissions and foster economic growth. However, several challenges hinder the energy transition in Latin America, including limited financing options, inadequate infrastructure, and political instability.

Moreover, the region's energy mix is still dominated by fossil fuels, particularly in countries such as Venezuela, Mexico, and Brazil. This situation poses a significant challenge to reducing greenhouse gas emissions and mitigating the impact of climate change. Consequently, policymakers, scholars, and practitioners are increasingly interested in understanding the economic implications of energy transition in Latin America, both for the environment and the economy. Specifically, our analysis focuses on Mexico, Trinidad and Tobago, Colombia, Ecuador, Peru, Chile, Argentina and Uruguay (see Figure 1).

The literature on the economic implications of energy transition in Latin America is still relatively sparse, and the existing studies focus on different aspects of the problem. For example, recent studies, such as those by Koengkan and Fuinhas (2020, 2022), examine the effects of decarbonization in Latin America regarding CO2 emissions and environmental degradation, while Hampl (2022) study examines the relationship between energy transition and inequality in the region. From a methodological perspective similar to this proposal, Löffler et al. (2017) and Oei et al. (2020) use the best configuration of a well-known techno-

Notes We also analyze the interconnections between Colombia-Ecuador-Peru (*Zona Andina*) and Chile-Argentina-Uruguay (*Cono Sur*).

FIGURE 1 Countries analyzed in this study.

economic model, namely Global Energy System Model (GENeSYS-MOD), for a group of regions, including Latin America, to model 100% renewable scenarios. This model has had specific applications for countries in the region, such as Mexico (Gutiérrez-Meave et al., 2021; Sarmiento et al., 2019). Specifically, GENeSYS-MOD minimizes the overall costs of delivering energy to key sectors such as electricity, transportation, and heating.

However, we diverge from this literature by employing a model that prioritizes the intricate details of the energy sector while emphasizing economic factors, rather than solely focusing on climate change or minimizing costs. Our model's goal is to maximize the total economic surplus, including the welfare of final consumers in an endogenous manner, providing valuable policy insights. This approach enables us to determine if compensating redistribution is necessary under a politically feasible scenario. To achieve this, we have designed a two-step process. In the first step, we create an endogenous-price partial equilibrium model that assesses the dynamics of each country energy industry. In the second step, we use the optimization model's results to calculate prospective changes in the national accounts, specifically those related to production, offering an in-depth analysis of the economic implications of our proposed scenarios.

Our approach takes into account the specific energy market characteristics of each country, allowing for a more nuanced analysis that considers the potential trade-offs and opportunities associated with the transition to sustainable energy sources. This is particularly relevant given the differences in natural resource endowments, institutional frameworks, and socioeconomic contexts among the countries we will analyze. Ultimately, our study aims to shed light on the economic implications of energy transition in Latin America and inform policy-making towards a sustainable and prosperous future.

3 | METHODS

We develop a mathematical programming economic equilibrium model for each country's fuel and electricity sectors. In the following sections we provide an overview of the model and the main assumptions.

3.1 | Model Overview

The model employs the economic surplus maximization approach first introduced by Samuelson (1952) and later developed by Takayama and Judge (1971). We follow the modeling strategy of more prominent and well-known price endogenous, sectoral, partial equilibrium models, such as Beach et al. (2012) for the U.S., Nuñez et al. (2013) for Brazil, and Hancevic et al. (2022) for Mexico. We project market conditions to 2050, and the model solves for each of the variables of interest, such as supply and demand quantities and prices, economic surpluses, and greenhouse gas emissions, for the proposed scenarios.[1]

In order to better explain the model, we first present its objective function, followed by its main constraints. Additionally, the model presented is a generalized version that can be applied to any country included in the study or combined to have more than one country in the same model. Costs associated with interconnections among countries can be included in the objective function, and constraints can include capacity associated with interconnections.

Table 1 displays the sets, parameters (which are exogenous to the model), and endogenous variables used in the model.

3.2 | Objective function

$$\mathrm{OF} = \mathrm{CS} - \mathrm{CT} - \mathrm{EPS} - \mathrm{FPS} - \mathrm{p}^{\mathrm{row}}\mathrm{Q}^{\mathrm{row}} \tag{1}$$

Where:

[1]The model proposed is being set up in the optimization software GAMS (General Algebraic Modeling System) and solved using a nonlinear programming solver CPLEX.

Symbol	Type	Description	Units
j	Set	Economic sectors	–
f	Set	Fossil fuels	–
g	Set	Power technology	–
s^c	parameter	Subsidies to consumers	% or $
t^c	parameter	Taxes paid by consumers	% or $
s^p	parameter	Subsidies to producers	% or $
t^p	parameter	Taxes paid by producers	% or $
t^{row}	parameter	Tariffs to imports	% or $
c^e	parameter	Costs of electricity production per unit	$ per MWh
c^u	parameter	Costs of transportation per unit	$ per unit
capacity	parameter	Generation capacity	MW
$transecap$	parameter	Transmission capacity	MWh
$\gamma_{g,f}$	parameter	conversion rate	
γ^m	parameter	Transmission loss factor	%
E	Variable	Electricity demand	MWh
H	Variable	Demand for fuels for heat in the industry	Fuel Unit
K	Variable	Demand for fuels for vehicle transportation	Fuel Unit
EG	Variable	Electricity generation	MWh
SE	Variable	Supply of electricity	MWh
SFE	Variable	Supply of fuel for electricity	Fuel Unit
SH	Variable	Supply of fuel for heat in industry	Fuel Unit
SK	Variable	Supply of fuel for transportation	Fuel Unit
SF	Variable	Total supply of fuels	Fuel Unit

TABLE 1 Symbols and Variables of the Model

OF	Objective function or Total Private Surplus
CS	Consumer Surplus
EPS	Electricity producers' surplus
FPS	Fossil fuel producers' surplus
p^{row}	International Price of the commodity
Q^{row}	Quantity imported from ROW
CT	Costs of transportation

3.2.1 | Consumer surplus

The model assumes the country is an aggregated consumer that has linear demands for electricity (E) and fuels (F) for four sectors: Residential, Transportation, Commerce (wholesale & retail trade, services, and public sector), and Industry. The model allows some degree of substitution between F and E in the projections to 2050. Let us call j the set of these sectors. Each of these demands curves are set based on initial prices, demand quantities and price elasticities, gathered from external sources. Consumer surplus (CS) is measured as the area between the downward-sloping demand curve and the price paid by the consumers. Consumers pay taxes (t^c) and receive subsidies (s^c) when consuming the corresponding product (E and F). Equation (2) expresses the consumer surplus in the objective function:

$$\begin{aligned} CS = \sum_j \left(\int_0^{QE_j} E_j(q_e)dq_e + (s_j^{c,E} - t_j^{c,E})E_j \right) \\ + \sum_j \sum_f \left(\int_0^{QF_{jf}} F_{jf}(q_{jf})dq_jf + (s_{jf}^c - t_{jf}^c)F_{jf} \right) \\ - \sum_j \left(\frac{\partial \int_0^{QE_j} E_j(q_e)dq_e}{\partial E_j} E_j \right) \\ - \sum_j \sum_f \left(\frac{\partial \int_0^{QF_{jf}} F_{jf}(q_{jf})dq_{jf}}{\partial F_{jf}} F_{jf} \right) \end{aligned} \tag{2}$$

Depending on each country, the model can assume whether the Rest of the World (ROW) does or does not import E or F.

3.2.2 | Electricity producer surplus

Producers receive the endogenous price paid by consumers minus the total cost of producing for electricity generated (EG) by solar, wind, geo, bio, hydro, nuclear, thermal gas, thermal coal, and thermal fuel oil (let us define this set of technologies as g). Similarly, producers pay taxes (t^p) and receive subsidies (s^p). Equation (3) represents this surplus in the objective function:

$$EPS = \sum_j \left(\frac{\partial \int_0^{QE_j} E_j(q_e)dq_e}{\partial E_j} E_j \right) - \sum_g (s_g^{p,eg} - t_g^{p,eg} - c_g^e)EG_g \tag{3}$$

3.2.3 | Fuel Producers Surplus

The model assumes linear cost curves for fuel supply (set f: natural gas, lpg, jetfuel, fuel oil, coal, uranium, diesel, and gasoline) for the electricity sector, heat in the Residential, Commerce, and Industry sectors, and fuel for vehicle transportation. Each of these supplies are set up based on initial prices, supply quantities and price elasticities, which are gathered from external sources and calibrated. Fuel producers surplus is equal to the area between the price received and the upward-sloping cost curve. Similarly, producers pay taxes (t^p) and receive subsidies (s^p). Equation (4) represents the area under the cost curves of producers in the objective function:

$$FPS = \sum_f \left(\frac{\partial \int_0^{SF_f} SF_f(.)ds f_f}{\partial s_f} SF_f - \int_0^{SF_f} SF_f(.)ds f_f + (s_f^p - t_g^f)SF_f \right) \tag{4}$$

3.2.4 | External Sector

Depending on the case, the model assumes the country is price taker to import and/or export some fuels. Imports will pay import tariffs when they are required (t^{row}). Equation (5) expresses the area under the cost curves of producers of the ROW in the objective function:

$$p^{ROW}Q^{ROW} = \sum_f (p_f^{row} + t_f^{row})SF_f^{row} \tag{5}$$

3.2.5 | Cost of Transportation

Electricity is transmitted and distributed in each country, so the objective function includes the cost of transportation (c) per MWh. Equation (6) displays this part of the objective function.

$$CT = \sum_n \sum_m c_n^{MWh} EG_n^{n,n1} \tag{6}$$

We also extend this restriction to include the cost of transportation of the different fuels.

3.3 | Constraints

The objective function (OF) is restricted to technical constraints, resource-limitation, market-balance, and non-negativity constraints.

- Electricity generation (EG) by technology and fuel:

$$EG_g \leqslant \sum_f \gamma_{g,f} SFE_{n,f} \qquad \forall g \tag{7}$$

- Electricity generation (EG) is restricted to the installed capacity (in MW):

$$EG_g \leqslant capacity_g \quad \forall g \tag{8}$$

- Electricity generation (EG) is the sum of all technologies:

$$EG \leqslant \sum_g EG_g \tag{9}$$

- Supply of electricity (SE) is the sum of EG and the imports of electricity from other countries (if allowed):

$$SE^E \leqslant EG + \sum_m (1 - \gamma^m) E^m \tag{10}$$

- Demand for electricity is restricted to the total supply of electricity:

$$\sum_j E_j \leqslant SE^E \tag{11}$$

- Electricity transmission is limited to transmission capacity:

$$EG \leqslant transecap \tag{12}$$

- Demand for fuels for sector j is constrained to the supply of fuels for that sector:

$$F_{jf} \leqslant SF_{jf} \qquad \forall f, j \tag{13}$$

- Sum of supply of fuel f for all sectors is less than or equal to the sum of the domestic and imported amounts:

$$\sum_{j} SF_{jf} \leqslant SF_{f} + SF_{f}^{row} \quad \forall f \tag{14}$$

- Non-negativity constraints.

For market projection we use different rates of growth for fuel supply, electricity generation capacity, and technological progress ratio, which lead to costs reduction. It is worth noting that these parameters are not necessarily fixed over time. In the case of renewables, in particular, costs decrease while capacity increases over time. For the demand we follow the prospects and reports of each country as well as GDP and population growth rates. The green scenario assumes higher rates of adoption among other changing parameters. In all scenarios, it is assumed that electricity is dispatched by merit order.

To set up and validate the the model, we use the most recent year with available information for all countries included in the analysis, namely 2019 or the average 2018-2020. Once the model is validated, we proceed to project market conditions to 2050. After optimal values are found for the target year under all scenarios, we measure the economic surplus, environmental damage, and in sum the welfare changes.

3.4 | Complementary calculations

The partial equilibrium model is intended to analyze long-run effects and does not incorporate the intra-day issues that may happen due to, for example, congestion in a specific transmission line. We rather use annual data with some variables at the national level. Hence, for example, transmission capacity constraints will never be binding in our model, perhaps with the exception of inter-countries connections.

Once we obtain the results from the partial equilibrium model, we employ the energy-elasticity approach to perform complementary calculations and assess the likely changes in gross domestic product under the alternative scenarios (Al-Iriani (2006) provides a clear example of our modeling approach). Correspondingly, we also explore the ramifications of these scenarios on employment. [2] By considering the employment elasticity to GDP, we can estimate the potential changes in the labor market resulting from the different energy consumption patterns and electrification levels.

[2] While we do not specifically address differential employment impacts by industry in this research, the possibility exists for conducting additional analysis using an input-output matrix. This tool could offer a more detailed and specific insight into how various industrial sectors might be affected by energy transitions and related policies.

4 | SCENARIOS

We have developed four distinct scenarios for each country, exploring different energy pathways and their economic impacts.[3] The first scenario represents a "business as usual" approach (BAU), where renewable energy growth rates in each country follow historical trends. In the second scenario, dubbed the "green" scenario, we accelerate the electrification and growth rate of renewable energy in countries where it is most needed. The third scenario maintains a similar trajectory to BAU but involves expanding interconnections between countries to a greater extent, specifically focusing on the *Zona Andina* (Colombia, Ecuador and Peru) and *Cono Sur* (Chile, Argentina and Uruguay) regions. As for the fourth scenario, it involves the green scenario coupled with expanded interconnections between multiple countries' electric networks, aiming to expedite the achievement of green energy goals further (Egerer et al., 2015; Schill et al., 2015).

The primary challenge in these scenarios is transitioning to renewable energy without compromising the countries' capacity for economic growth. Therefore, our study's main objective is to examine the economic impacts of the alternative scenarios compared to the business as usual scenarios. Additionally, we aim to analyze the proportion of gains derived from faster adoption of renewables versus increased integration by comparing the different scenarios. Detailed information on all proposed scenarios, along with their specific assumptions, is provided in Table 2.

TABLE 2 Characteristics of Optimization Scenarios

Scenario	Characteristics
1. BAU	Renewable energy growth and electrification at historical rates. Interconnections between countries unchanged
2. Green scenario	Renewable energy growth rates and electrification increased. Interconnections between countries unchanged
3. BAU + Interconnections increase	Renewable energy growth at historical rates. Interconnections between countries expanded
4. Green scenario + Interconnections increase	Renewable energy growth rates and electrification increased. Interconnections between countries expanded

This table shows the characteristics of our four optimization scenarios.

Our approach to constructing these scenarios allows us to derive four optimal solutions based on each model's parameters, enabling us to compare the differences in gains. Importantly, our analysis goes beyond merely achieving GHG emission reduction targets; we also prioritize maximizing overall social welfare. This involves considering economic indicators such as GDP growth and job creation in both green and business as usual scenarios. Our study meticulously examines how energy market dynamics influence economic outcomes, including consumer and producer surpluses, employment, and output, while simultaneously taking into account the environmental implications.

[3]The model was validated against 2019 conditions for all countries. We present the results in Appendix A. The validation show small deviations, indicating that the model reasonably replicates the base-year market equilibrium conditions.

The projections of electrification scenarios stem from the underlying assumption of increased reliance on renewable sources within the energy mix. This strategic shift not only curtails costs but also naturally fosters elevated electricity demand rates, surpassing those in the BAU trajectory, where demand rates are tied to projected population growth. Moreover, while the prospects of electrifying freight and commercial vehicles by 2050 in a BAU scenario appear restrained due to the technological advancements necessitated for heavy transport and commercial vehicle electrification,[4] the landscape is anticipated to differ in light of the predominant market presence of passenger and light-duty vehicles, whose electrification could tangibly propel the overall electrification within the transportation sector. Given the substantial proportion of the vehicular fleet constituted by personal and light commercial vehicles across Latin America, it is a plausible assumption that their electrification alone can wield a disproportionately influential impact on the aggregate electrification rate spanning diverse transport modes. Particularly, each change in electricity demand across sectors, when juxtaposed with the BAU scenario, is bespoke to the country and sector in question, calibrated according to their distinctive circumstances (i.e., countries commencing from a higher baseline of electrification in sectors such as industrial process heating, commercial appliances, and residential climate control would observe comparatively marginal increments).

Moreover, our renewable energy forecasts derive firm grounding from an exhaustive review of pertinent studies, meticulously charting potential energy transition pathways for each nation, inherently aligned with the compass of the green scenario (e.g., (Iniciativa Climática De México, 2020; Unidad de Planeación Minero-Energética de Colombia, 2020; ENEL Perú, 2022; ENEL Argentina, 2023; Espinoza et al., 2022; Ministerio de Energía del Gobierno de Chile, 2022; Jupiter, Andrew, van Meurs, Pedro, 2021)). These studies provide evidence and insights into the feasibility and potential benefits of adopting renewable energy sources at an accelerated pace. By leveraging this knowledge, we can confidently present a realistic pathway for maximizing the utilization of green energy while keeping the economic impacts in focus.

Lastly, a key component of our modeling framework is the use of a recursive equilibrium model to represent enhanced regional electricity interconnections. This entails solving for the equilibrium of each country in a sequential manner, with the optimized solution for each country becoming an input for interconnected neighbors. Specifically, the model is initially solved for an individual country, incorporating expanded import and export capacity constraints to reflect increased transmission connections. This provides optimized electricity supply and demand balances for the country given greater integration. The optimal values for national supply, demand, and interconnection flows are then entered as exogenous parameters into the models for the neighboring trade partners when solving their equilibrium. This process continues recursively, passing updated electricity trade flow variables between sequentially solved country-level models.

The recursion converges when the endogenous interconnection flows between solved countries reach a stable equilibrium, balancing national electricity supply and demand through optimized cross-border electricity trade. This recursive approach enables computationally efficient solutions for the integrated regional system given increased interconnections. By passing updated electricity trade parameters in a recursive sequence, the models capture the economic benefits of greater grid integration and electricity sharing within the limitations of our methodology and data availability.

[4]We posit that the electrification of freight and commercial vehicles in Latin America will remain limited by 2050. The pervasive cost challenges, inadequate charging infrastructure, and current limitations in electric vehicle range and power engender a scenario where widespread electrification of heavy transport appears improbable without substantial technological breakthroughs.

The approach of building these scenarios provides four optimal solutions, according to the parameters of each model, which we aim to compare to determine the difference in gains. Remarkably, our analysis seeks to maximize social welfare beyond meeting GHG emission reduction targets, which are, of course, part of economic well-being. Moreover, instead of relying merely on GHG mitigation, we provide for both green and BAU scenarios with particular outcomes on economic indicators such as GDP growth and job creation. Concretely, this study examines energy markets' impact on economic outcomes (including consumer and producer surpluses, employment, and output) and the environment.

5 | DATA COLLECTION

The data used in this study were obtained from multiple sources. We obtained data on energy balances (information on import and export of energy sources, as well as sector-wise consumption), and installed electricity generation capacity by technology from the Sistema de Información energética of Latin America and the Caribbean, a database comprising data from 1970 to 2021, maintained by the Latin American Energy Organization (OLADE). Additionally, we obtained data on electricity production by source from the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA).

To gain insights into commodity prices, electricity tariffs, subsidies, and taxes for each country, we collected data from a variety of sources. This included the energy prices report in Latin America and the Caribbean by The World Bank and OLADE (2020), the Statistical Review of World Energy by (BP, 2019), and the International Monetary Fund (IMF). We also consulted national energy reports published by each country , which contained information on energy production, consumption, and prices, as well as policies and initiatives related to the energy sector. Specifically, we consulted agencies such as SENER (Mexico), MEEI (Trinidad and Tobago), the Ministry of Energy and Non-Renewable Natural Resources (Ecuador), the Ministry of Energy and Mines (Peru), the Ministry of Energy (Chile), the Ministry of Economy (Argentina), and The Ministry of Industry, Energy, and Mining (Uruguay).

Finally, we obtained the supply and demand elasticities from previous literature (Atalla et al., 2016; Bernstein and Madlener, 2011; Burke and Csereklyei, 2016; Dahl, 2012; Hernández et al., 2022; Frank and Maggio, 2015; Wood et al., 2022; Krichene, 2002; Nuñez, 2018, 2021). Despite our best efforts to gather as much data as possible, there were instances where we could not obtain complete data for certain countries and use some regional elasticities or are calibrated using the same model. Nonetheless, we conduct a sensibility check with this values to enhance the reliability of the model.

In order to perform a consistent and uniform analysis, we converted all variables to a common unit of measurement, namely British thermal units (BTU), which is a unit of energy used to measure heat. Basically it corresponds to the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit. In the context of energy consumption, BTU is used to measure the amount of energy required or produced by a particular sector or source. By converting all variables to BTU, we can standardize the units of measurement and make them comparable across different sources and sectors. This allows us to analyze and compare the demand and supply quantities for different energy sources and sectors, and a straightforward way to estimate the overall impact of energy consumption on the economy.

For example, the demand for electricity in the residential sector is typically measured in kilowatt-hours (kWh), while the demand for fuels for heat in the industry may be measured in gigajoules (GJ). By converting both of these variables to BTU, we can more easily compare the two and estimate the total energy demand for the country as a whole. Similarly, taxes and subsidies are also operationalized in terms of BTU, allowing us to calculate the net consumer surplus in a consistent and comparable way across all sectors.

6 | RESULTS

6.1 | Mexico

6.1.1 | Supply and Demand

Regarding the differences in overall energy demand between the green scenario and the BAU scenario in 2050, we can observe in Table 3 a difference of 1.91% in the transportation sector, which is accompanied by a 33.32% variation in electricity demand. Additionally, there is a 7.84% difference in the energy demand from the industrial sector (with a 29.43% variation in electricity demand), a 12.35% difference in the commercial sector (alongside an 18.69% variation in electricity demand), and a 4.20% difference in the residential sector (paired with a 18.69% variation in electricity demand). The differences in demand due to higher electrification in the green scenario amounts for almost 1% difference in electricity prices. Although this is a modest fall, it indicates a cost advantage in favor of the higher electrification under the green scenario. This cost advantage further strengthens the economic case for embracing sustainable practices and transitioning away from fossil fuels. Overall, for 2050, the total energy differences in demand within the green scenario, when referenced against the BAU, stand at 3.54%, with an electrification difference of 30.85%.

(a) Overall energy demand

	Change w.r.t BAU
Sector	Green
Transportation	1.91%
Industry	7.84%
Commerce	12.36%
Residential	4.20%
Total	3.54%

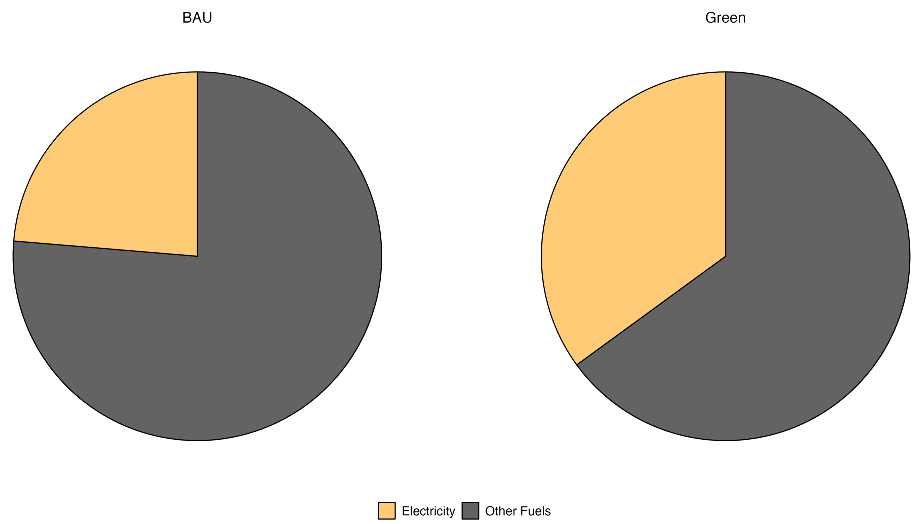
(b) Electricity demand

	Change w.r.t BAU
Sector	Green
Transportation	33.32%
Industry	29.43%
Commerce	29.74%
Residential	18.69%
Total	30.85%
Electricity price	-0.88%

TABLE 3 Changes in demand between scenarios compared to BAU

The supply of electricity in Mexico shows a substantial difference between the green and BAU scenarios in 2050. The green scenario projects 35% of the total supply for electricity, while the BAU scenario only projects 23% (see Figure 2). One of the most notable differences in fuel supply is seen in natural gas, where the green scenario reduces its supply by approximately 39.8% compared to the BAU scenario.

Relating to electricity generation, as shown in Figure 3 and Table 4, as electricity from renewable sources displaces gas-fired power generation, the power matrix in 2050 illustrates a significant shift towards renewable energy sources in the green scenario compared to BAU. Renewables are projected to contribute a remarkable 75% of the power generation under this scenario, whereas they account for only 33% in the BAU scenario. Furthermore, in the green scenario, the key contributors to power generation would be natural gas (25%, as opposed to 47% on the BAU), hydro (6.9%), wind (32%), and solar (33%). This substantial difference in power generation favoring renewables and marking a decline in natural gas utilization, finds feasibility in light of Mexico's ample solar and wind resources (Hancevic et al., 2017, 2022).



Notes This figure shows a comparison of the projected supply of electricity and other fuels in 2050 across scenarios.

FIGURE 2 Fuel supply

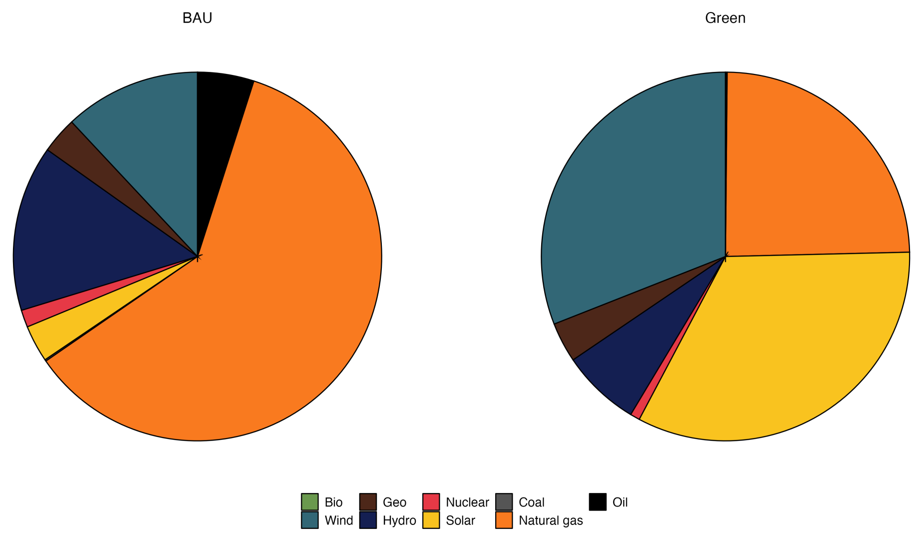
	Change w.r.t BAU
	Green
Coal	-97.3%
Natural gas	-47.0%
Oil	-96.2%
Nuclear	-26.8%
Hidro	-37.8%
Geo	43.6%
Wind	>100%
Solar	>100%
Bio	>100%

TABLE 4 Changes in fuel consumption for electricity generation

6.1.2 | Welfare analysis

With the optimization model solved for both the BAU and green scenarios, we can conduct comparative static analysis to evaluate the welfare implications. As explained in the methods section, one of the key objectives of this exercise is to contrast the model solutions for 2050, assessing the differences in consumer and producer surpluses for that specific year, which is the last in our simulation. These economic surpluses serve as metrics to gauge the overall net benefit that an economic activity provides to society. Likewise, all taxes and subsidies resulting from the economic activity sum up to the government revenue. After calculating the surpluses, we account for environmental damage costs by subtracting the social cost of carbon based on estimated CO2e emissions. This results in the net social welfare for each scenario.

As shown in Table 5, the comparative analysis of economic surplus for Mexico reveals remarkable benefits across various sectors in the green scenario compared to the BAU scenario. Notably, consumer surplus shows changes in transportation (180%), industry (26.1%), commerce (23.2%), and residential (6.64%). Additionally, producers also benefit,



Notes This figure presents a comparison of the projected use of energy sources in 2050 across scenarios.

FIGURE 3 Electricity generation

	Change w.r.t BAU
Surplus	Green
Consumer transportation	179.52%
Consumer commerce	23.18%
Consumer industry	26.11%
Consumer residential	6.64%
Producer electricity	59.28%
Producer fuels	190.19%
Government revenues	8.27%
Environmental Damage	-23.06%
Overall Welfare	175.03%

TABLE 5 Changes in economic surplus

with a 59.3% difference in electricity producer surplus and a notable 190% difference for fuel producer surplus due to the higher domestic gas production as substitute for the imported one, while environmental damage declines by 23.1% due to deployment of green energy sources.

Overall, the green scenario leads to a remarkable 175% difference in aggregate economic welfare compared to BAU in 2050. Of this economic welfare, 98% can be attributed to the consumer transportation surplus, derived from the accelerated electrification in this sector. These findings underscore the immense potential for substantial economic gains when ambitious decarbonization and electrification policies are pursued.

6.1.3 | Impact on Gross Domestic Product and Employment

Once we compute the total energy consumption for each scenario in the year 2050, we can assess its impact on the GDP. As previously discussed, Table 3 reveals that the green scenario results in an approximate 3.54% variation in total energy consumption compared to the BAU scenario in 2050. This disparity in energy demand primarily stems from the electrification effect achieved by this point in time. The greens scenario's significant focus on higher rates of renewable energy sources translates into a greater need for electricity, thereby correlating with the observed rise in overall energy consumption when compared to the BAU trajectory.

As energy is a critical input for most economic activities, it is well documented the strong relationship between energy demand growth and economic growth (e.g. Al-Iriani, 2006). Higher energy consumption can lead to increased economic activity, as it enables businesses to produce more goods and services and expand their operations. In this study, we employ the energy-GDP elasticity approach to estimate the potential change in GDP for a country pursuing a green growth scenario for the year of 2050. When comparing the total energy demand of the BAU and green scenarios in Table 3, we find a 3.54% higher total energy consumption in the later scenario respect to the former. Burke and Csereklyei (2016) find an energy-GDP elasticity of 0.59 for Latin America and the Caribbean. Applying this elasticity to Mexico implies that, for the year of 2050, the country's GDP would be 2.09% higher if it follows a green path rather than remaining on BAU trajectory. It is important to specify that the results are specific to the year 2050. This consideration is crucial as it emphasizes that the result difference in GDP between scenarios is for a single year. Therefore, the increased electrification and energy consumption under the green scenario could generate substantial long-term economic benefits for Mexico, supplementing the positive environmental impacts. By switching to a green growth pathway, Mexico stands to gain economically over the coming decades through higher GDP growth, along with achieving sustainability goals.

Furthermore, the amplified economic engagement fueled by increased energy consumption can yield a favorable impact on employment dynamics. Research has revealed an employment elasticity to GDP of 0.66 for the Latin American context (Morén and Wändal, 2019). By leveraging this elasticity, the envisaged 2.09% GDP difference within the green scenario translates to an approximate 1.38% difference in employment across Mexico for the year of 2050. This signifies that the trajectory towards sustainable practices not only nurtures economic advancement but also plays a pivotal role in generating employment opportunities, thereby augmenting the broader socio-economic welfare.

6.2 | Trinidad and Tobago

6.2.1 | Supply and Demand

In the context of Trinidad and Tobago, the disparity in overall energy demand for the year 2050 between the green scenario and the Business-as-Usual (BAU) scenario (refer to Table 6) is noteworthy. Specifically, there's an 11.25% variance in the transportation sector, accompanied by a substantial 49.74% fluctuation in electricity demand. Moreover, the industrial sector sees a 12.50% difference in energy demand, correlated with a significant 53.84% variation in electricity demand. Similarly, the commercial sector experiences a 37.16% difference in energy demand, coupled with a 52.34% variation in electricity demand, while the residential sector witnesses a 39.03% difference in energy demand and a corresponding 52.39% variation in electricity demand. The shift towards greater electrification in the green scenario accounts for a 3% difference in electricity prices compared to the BAU. Overall, the aggregate energy demand variance in the green scenario, in comparison to the BAU, is substantial at 13.56%, complemented by a notable electrification variation of 52.91%.

Even with these differences in electricity demand in the green scenario compared to BAU, as Trinidad and Tobago is a small economy with high dependence on fossil fuels, the supply of electricity shows a moderate variation between both scenarios. In 2050, the green

(a) Overall demand

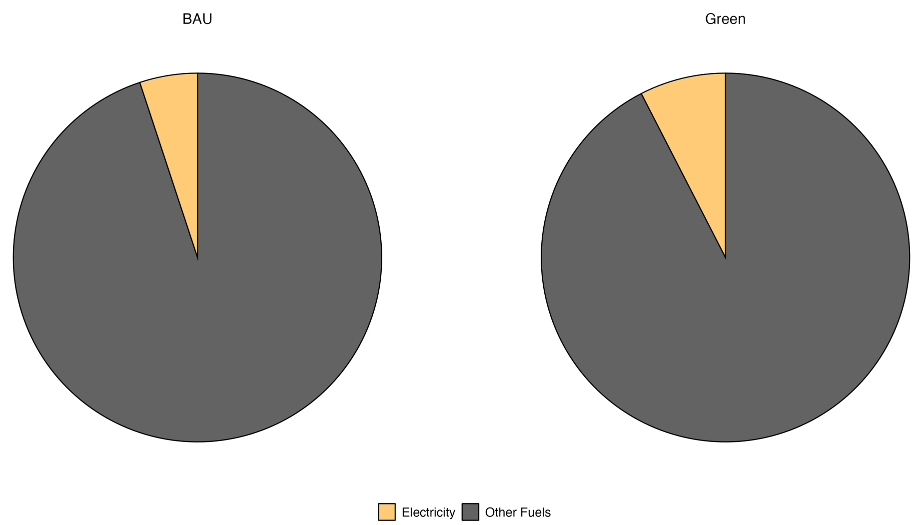
	Change w.r.t BAU
Sector	Green
Transportation	11.25%
Industry	12.50%
Commerce	37.16%
Residential	39.03%
Total	13.56%

(b) Electricity demand

	Change w.r.t BAU
Sector	Green
Transportation	49.74%
Industry	53.84%
Commerce	41.93%
Residential	52.34%
Total	52.91%
Electricity price	-3.05%

TABLE 6 Changes in demand between scenarios compared to BAU

scenario projects almost 8% of the total supply for electricity, while the BAU scenario only projects 5% (see Figure 4).



Notes This figure shows a comparison of the projected supply of electricity and other fuels in 2050 across scenarios.

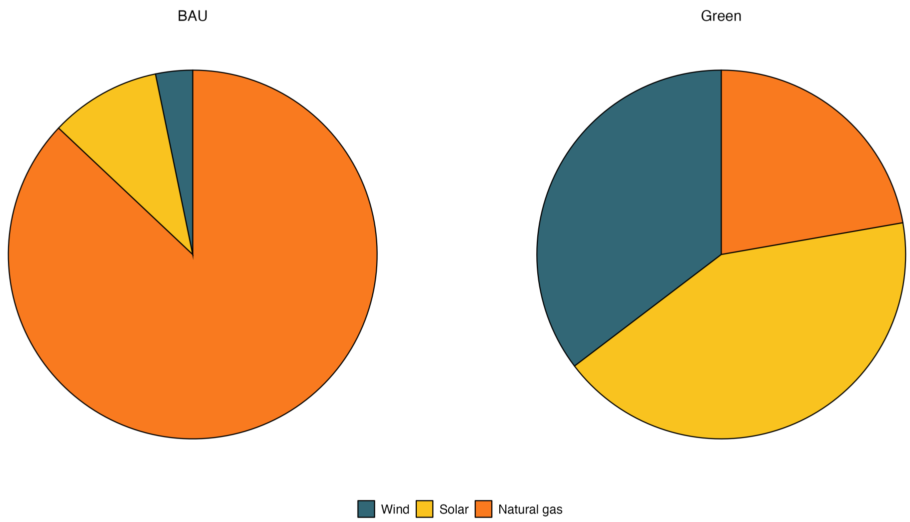
FIGURE 4 Fuel supply

	Change w.r.t BAU
	Green
Natural gas	-61%
Wind	>100%
Solar	>100%

TABLE 7 Changes in fuel consumption for electricity generation

Relating to electricity generation, as shown in Figure 5 and Table 7, as electricity from renewable sources displaces gas-fired power generation, the power matrix in 2050 illustrates a significant shift towards renewable energy sources in the green scenario. Renewables are projected to contribute a remarkable 77% of the power generation under this scenario, whereas they account for only 13% in the BAU scenario. Furthermore, in the green scenario, the key contributors to power generation would be natural gas (22.2%, as opposed to 87%

on the BAU), wind (35%), and solar (42%). This significant shift underscores the feasible capacity of Trinidad and Tobago to harness its inherent potential for renewable energy adoption.



Notes This figure presents a comparison of the projected use of energy sources in 2050 across scenarios.

FIGURE 5 Electricity generation

6.2.2 | Welfare analysis

As displayed in Table 8, the comparative analysis of economic surplus for Trinidad and Tobago reveals benefits across various sectors in the green scenario compared to BAU. Notably, in this scenario, consumer surplus shows changes with reference to BAU in transportation (14.61%), commerce (88.59%), industry (25.60%), and residential (86.54%). Moreover, electricity producers also enjoy advantages, with a 68.04% rise in electricity producer surplus in the green scenario, while the producers of fuels experience a reduction of surplus of almost 1%. Meanwhile, environmental damage diminishes by 0.19% in the green scenario, attributed to the accelerated deployment of green energy sources.

	Change w.r.t BAU
Surplus	Green
Consumer transportation	14.61%
Consumer commerce	88.59%
Consumer industry	25.60%
Consumer residential	86.54%
Producer electricity	68.04%
Producer fuels	-0.09%
Government revenues	15.95%
Environmental Damage	-0.19%
Overall Welfare	27.47%

TABLE 8 Changes in economic surplus

Overall, the green scenarios result in a 24.47% difference in aggregate economic welfare compared to the BAU scenario in 2050. Within this enhanced economic welfare, a 21% can be attributed to consumer transportation surplus, 72% consumer industry surplus, 20% electricity producer surplus, and 14.6% in environmental damage reduction.

6.2.3 | Impact on Gross Domestic Product and Employment

Table 6 shows that the green scenario lead to an approximate 13.56% difference in total energy consumption compared to the BAU scenario in 2050. Applying Latin America energy-GDP elasticity (0.59), we find that, for the year of 2050, the country's GDP would be 8% higher by following a green path rather than staying on the BAU trajectory. Furthermore, the expanded economic activity fueled by increased energy consumption has a favorable impact on employment. Using the GDP-employment elasticity for Latin America (0.66), the projected 5.66% GDP growth in the green scenario translates to an approximate 5.2% difference in employment across Trinidad and Tobago during 2050. This emphasizes that the shift towards sustainability in Trinidad and Tobago not only drives economic expansion but also acts as a crucial catalyst for generating employment opportunities, ultimately promoting an overall improvement in socio-economic welfare.

6.3 | Colombia

6.3.1 | Supply and Demand

Regarding Colombia's overall energy demand changes between the green scenario and the Business-as-Usual (BAU) scenario, Table 9 illustrates a difference of 11.29% in the transportation sector and a notable 31.36% variation in electricity demand. Furthermore, there's a 4.51% difference in energy demand within the industrial sector (alongside a 22.85% variation in electricity demand), a 13.28% difference in the commercial sector (paired with a 20.11% variation in electricity demand), and a 9.92% difference in the residential sector (accompanied by a 19.26% variation in electricity demand). These shifts in demand resulting from heightened electrification in the green scenario amount to a 21.54% difference in electricity prices compared to the BAU. Overall, the aggregate energy variation in demand within the green scenario, compared to the BAU, is a significant 9.61%, accompanied by a noteworthy electrification change of 25.43% for the year 2050.

Regarding the interconnection scenarios for the *Zona Andina*, once the model resolves the optimal import and export values recursively between the countries, a notable outcome emerges: Colombia becomes a net electricity importer from Ecuador. In the BAU + interconnection scenario, Colombia's electricity imports constitute 1.8% of its total domestic electricity supply in 2050. Contrastingly, in the Green + interconnection scenario, this import figure surges to 16.10%. These augmentations in cross-border electricity exchange have relatively minor ramifications on domestic energy demand. Specifically, there is a 0.30% variance in energy demand (paired with a 1.06% electricity demand variation) in the BAU + interconnection scenario compared to the BAU scenario in 2050. In the Green + interconnection scenario, the change observed is equivalent to the Green scenario.

Notably, the adjustments in electricity prices diverge between scenarios. In the BAU + interconnection scenario, electricity prices show a notable difference of -11.86% compared to the BAU scenario. The electricity prices remain consistent between the two green scenarios.

The supply of electricity in Colombia shows a substantial change between the green and BAU scenarios (with very slight differences when added the interconnections). In 2050, the two green scenarios project between 24-26% of the total supply for electricity, while

(a) Overall demand

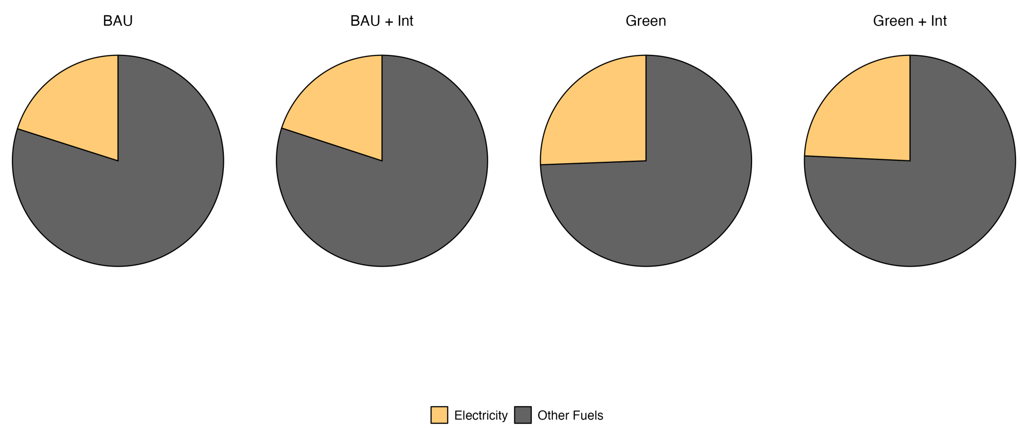
	Change w.r.t BAU		
Sector	BAU + Int	Green	Green + int
Transportation	0.01%	11.29%	11.29%
Industry	0.51%	4.51%	4.51%
Commerce	1.17%	13.28%	13.28%
Residential	0.82%	9.92%	9.92%
Total	0.30%	9.61%	9.61%

(b) Electricity demand

	Change w.r.t BAU		
Sector	BAU + Int	Green	Green + Int
Transportation	0.03%	31.36%	31.36%
Industry	2.58%	22.85%	22.85%
Commerce	1.78%	20.11%	20.11%
Residential	1.58%	19.26%	19.26%
Total	1.06%	25.43%	25.43%
Electricity price	-11.86%	-21.54%	-21.54%

TABLE 9 Changes in demand across scenarios compared to BAU

the BAU scenarios project 19-20% (see Figure 6). One of the most notable differences in fuel supply is seen in diesel oil, jet fuel and gasoline, where the green scenarios reduce its supply by approximately 22.2%, 23.7%, and 21.5% in 2050, compared to the BAU scenarios, respectively.



Notes This figure shows a comparison of the projected supply of electricity and other fuels in 2050 across scenarios.

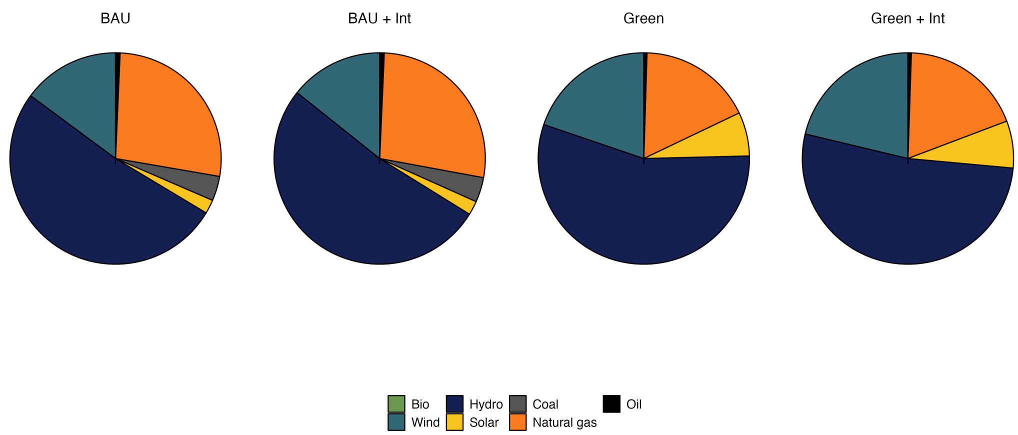
FIGURE 6 Fuel supply

	Change w.r.t BAU		
	BAU + Int	Green	Green + Int
Coal	0.0%	-100.0%	-100.0%
Natural gas	0.0%	-19.1%	-19.1%
Oil	0.0%	-11.9%	-11.9%
Hidro	0.0%	35.3%	18.4%
Wind	-4.6%	66.9%	66.9%
Solar	0.0%	>100%	>100%
Bio	-99.6%	-98.6%	-53.4%

TABLE 10 Changes in fuel consumption for electricity generation

Relating to electricity generation, as shown in Figure 7 and Table 10, as electricity from renewable sources displaces coal, oil-based and gas-fired generation, the power matrix in

2050 illustrates a significant shift towards renewable energy sources in the green scenario. Renewables are projected to contribute 82% of the country's power generation under this scenario in 2050, whereas they account for 68% in the BAU scenario. Furthermore, in the green scenario, the key contributors to power generation would be natural gas (17.40%, as opposed to 27.2% on the BAU), hydro (55.6%), wind (19.4%), and solar (6.68%). Regarding the power mix, we see small differences between the interconnection scenarios compared to BAU and green.



Notes This figure presents a comparison of the projected use of energy sources in 2050 across scenarios.

FIGURE 7 Electricity generation

6.3.2 | Welfare analysis

As displayed in Table 11, the comparative analysis of economic surplus reveals that Colombia would be better off across various sectors in all scenarios under the green scenario compared to the BAU in 2050. Notably, in both the green and green + interconnection scenarios, consumer surplus shows substantial variations in transportation (182.2%), commerce (37.2%), industry (21.3%), and residential (31.6%). Moreover, producers also enjoy benefits, with a 0.41% difference in electricity producer surplus in the green scenario (4.76% in the green + interconnection scenario), and a 9.97% difference for fuel producer surplus. Meanwhile, environmental damage goes down by 11.11% in the green scenario, attributed to the strategic deployment of green energy sources. This positive trend amplifies slightly further (11.27%) when interconnections are factored in, due to changes in electricity importation from Ecuador.

Overall, the green scenarios result in a 176.90% difference in aggregate economic welfare compared to the BAU scenario in 2050 (176.92% when interconnections are integrated into the model). Within this enhanced economic welfare, a significant 97% can be attributed to the consumer transportation surplus, a direct outcome of the accelerated electrification in this sector. These findings collectively underscore the substantial advantages across various sectors, brought about by a proactive embrace of green energy and regional energy collaborations.

	Change w.r.t BAU		
Surplus	BAU + Int	Green	Green + Int
Consumer transportation	0.05%	182.23%	182.23%
Consumer commerce	3.01%	37.24%	37.24%
Consumer industry	2.18%	21.30%	21.30%
Consumer residential	2.39%	31.63%	31.63%
Producer electricity	-16.37%	0.41%	4.76%
Producer fuels	-0.00%	9.97%	9.97%
Government revenues	-0.32%	-25.51%	-25.51%
Environmental Damage	-0.01%	-11.11%	-11.27%
Overall Welfare	0.01%	176.90%	176.92%

TABLE 11 Changes in economic surplus

6.3.3 | Impact on Gross Domestic Product and Employment

Table 9 clearly demonstrates that adopting the green scenarios results in an estimated 9.61% difference in total energy consumption in 2050 when compared to the Business-as-Usual (BAU) scenario. By applying the Latin America energy-GDP elasticity (0.59), it is evident that in 2050, Colombia's GDP could see a notable increase of 5.66% by embracing the green trajectory rather than adhering to the BAU path. Moreover, using the GDP-employment elasticity specific to Latin America (0.66), the expected 5.66% growth in GDP under the green scenario is estimated to correspond to a significant 3.74% increase in employment throughout Colombia by 2050. This surge in employment has the potential to significantly alleviate the country's persistently high unemployment rate, marking a substantial positive impact. This emphasizes that transitioning towards sustainability not only stimulates economic expansion but also holds a pivotal role in generating employment opportunities, thereby enhancing overall socioeconomic welfare.

6.4 | Ecuador

6.4.1 | Supply and Demand

Regarding the difference in overall energy demand between the green scenario and the BAU in 2050, we can observe in Table 12 a shift of 21.86% in the transportation sector, which is accompanied by a notable 139.93% variation in electricity demand. Additionally, there is a 19.94% difference in the energy demand from the industrial sector (with a 52.77% variation in electricity demand), a 68.61% difference in the commercial sector (alongside an 93.61% variation in electricity demand), and a 31.98% difference in the residential sector (paired with a 85% variation in electricity demand). The variations in demand due to higher electrification in the green scenario amounts for a 20.20% difference in electricity prices compared to BAU. Overall, the total energy differences in demand within the green scenario, when referenced against the BAU, stand at 26.40%, with an electrification variation of 96.40% in 2050, compared to BAU.

With respect to the interconnection scenarios for the *Zona Andina*, once the model resolves the optimal import and export values recursively between the countries, Ecuador becomes a net electricity exporter to Colombia and Peru. In the BAU + interconnection scenario, Ecuador's electricity exports constitute 6.9% of its total domestic electricity supply in 2050. Contrastingly, in the Green + interconnection scenario, this export figure surges to 31.1%. These augmentations in cross-border electricity exchange have relatively minor ramifications on domestic energy demand. Specifically, there is a 0.01% variance in energy demand in the BAU + interconnection scenario compared to the BAU scenario. In the Green + interconnection scenario, the shift observed is equivalent to the Green scenario (26.40% vs 26.42%, both compared to BAU).

The adjustments in electricity prices diverse slightly across scenarios. In the BAU + interconnection scenario, electricity prices vary by 0.06% compared to BAU. In the green + interconnection, the prices vary by 20.25% compared to BAU, similar to the green scenario, that shows a variation of 20.20% compared to BAU.

(a) Overall demand

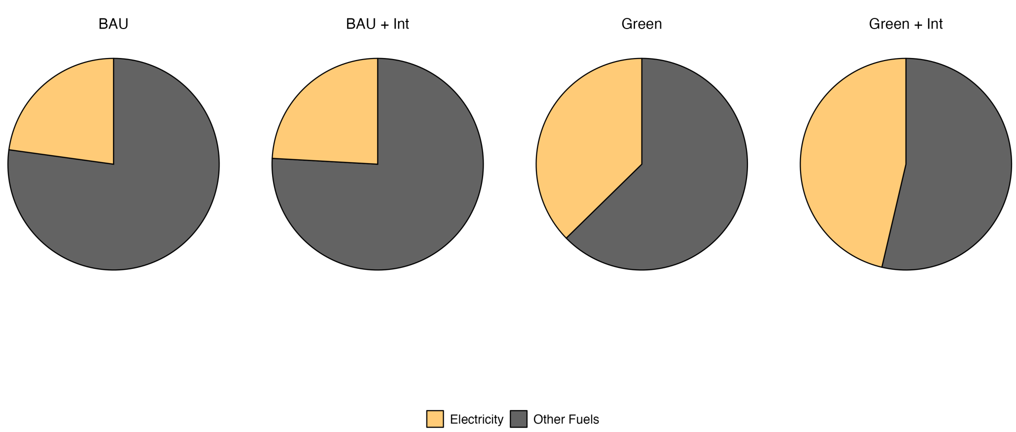
	Change w.r.t BAU		
Sector	BAU + Int	Green	Green + int
Transportation	0.01%	21.86%	21.87%
Industry	0.03%	19.94%	19.96%
Commerce	0.05%	68.61%	68.65%
Residential	0.01%	31.98%	31.99%
Total	0.01%	26.40%	26.42%

(b) Electricity demand

	Change w.r.t BAU		
Sector	BAU + Int	Green	Green + Int
Transportation	0.05%	139.93%	139.98%
Industry	0.06%	52.77%	52.81%
Commerce	0.06%	93.61%	93.66%
Residential	0.02%	85.00%	85.02%
Total	0.05%	96.43%	96.48%
Electricity price	-0.06%	-20.20%	-20.25%

TABLE 12 Changes in demand across scenarios compared to BAU

The supply of electricity in Ecuador shows a significant change between the green and BAU scenarios (with even more substantial variations when the interconnections are taken into account). In 2050, the two green scenarios project between 37-46% of the total supply for electricity, while the BAU scenarios project 22-24% (see Figure 8). One of the most notable differences in fuel supply is seen in natural gas, where the green scenarios reduce its supply by approximately 18.72% compared to the BAU scenarios.



Notes This figure shows a comparison of the projected supply of electricity and other fuels in 2050 across scenarios.

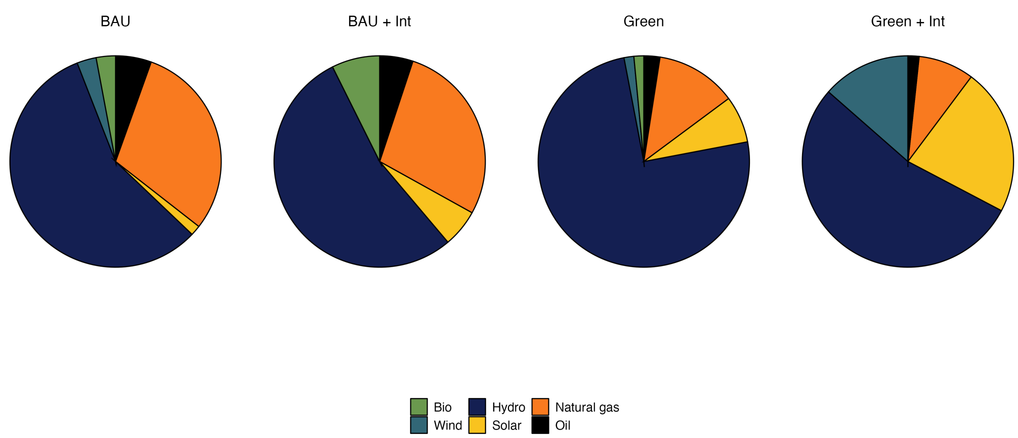
FIGURE 8 Fuel supply

Relating to electricity generation, as shown in Figure 9 and Table 13, as electricity from renewable sources displaces oil-based and gas-fired generation, the power matrix in 2050 illustrates a significant shift towards renewable energy sources in the green scenario. Renewables are projected to contribute to 85% of the country's total power generation under this scenario, whereas they account for 64% in the BAU scenario. Furthermore, in the green

	Change w.r.t BAU		
	BAU + Int	Green	Green + Int
Natural gas	0.0%	-19.1%	-19.1%
Oil	0.0%	-11.9%	-11.9%
Hidro	1.6%	>100%	>100%
Wind	-100.0%	0.0%	>100%
Solar	>100%	>100%	>100%
Bio	>100%	0.0%	-100.0%

TABLE 13 Changes in fuel consumption for electricity generation

scenario, the key contributors to power generation would be natural gas (12%, as opposed to 30% on the BAU), hydro (75%), wind (2%), and solar (7%). The differences between the BAU + interconnection and BAU scenarios are moderate (67% of the power mix comes from renewables when adding the interconnections, attributed to increases in hidro and solar generation). A more marked contrast emerges when comparing the green + interconnection scenario to the pure green scenario. Facilitated by Ecuador's electricity export to Colombia and Peru (amounting to 31.10% of its domestic supply), wind and solar generation surge to command over 14% and 22%, respectively, of Ecuador's total electricity mix.



Notes This figure presents a comparison of the projected use of energy sources in 2050 across scenarios.

FIGURE 9 Electricity generation

6.4.2 | Welfare analysis

As displayed in Table 14, the comparative analysis of economic surplus for Ecuador reveals benefits across sectors in 2050 for all scenarios compared to the BAU scenario. Notably, in both the green and green + interconnection scenarios, consumer surplus shows variations in transportation (43.3%), commerce (152%), industry (32%), and residential (67%). Moreover, producers also enjoy advantages, with a 51.26% variation in electricity producer surplus in the green scenario (172.21% in the green + interconnection scenario due to the substantial increase in exports), and a 0.73% difference for fuel producer surplus. Meanwhile, environmental damage diminishes by 2.21% in the green scenario and 0.45% in the green + interconnection scenario, compared to BAU.

	Change w.r.t BAU		
Surplus	BAU + Int	Green	Green + Int
Consumer transportation	0.01%	43.34%	43.36%
Consumer commerce	0.07%	152.24%	152.35%
Consumer industry	0.03%	31.97%	32.01%
Consumer residential	0.01%	67.08%	67.10%
Producer electricity	8.87%	51.26%	172.21%
Producer fuels	-0.00%	0.73%	0.73%
Government revenues	0.01%	29.60%	29.61%
Environmental Damage	0.44%	-2.21%	-0.45%
Overall Welfare	1.16%	46.00%	61.19%

TABLE 14 Changes in economic surplus

The green scenario result in a 46% variation in aggregate economic welfare compared to the BAU scenario in 2050 (61.19% when interconnections are integrated into the model). Within this enhanced economic welfare, a 45% can be attributed to consumer transportation surplus, 6% consumer industry surplus, 10% commercial consumer surplus, 23% residential consumer surplus, 13% electricity producer surplus, and 9% in environmental damage reduction. These findings collectively underscore the substantial advantages across various sectors, brought about by a proactive embrace of green energy.

6.4.3 | Impact on Gross Domestic Product and Employment

Table 12 shows that the green scenarios lead to an approximate 26.4% variation in total energy consumption compared to the BAU scenario. Applying Latin America energy-GDP elasticity (0.59), we find that, for 2050, the country's GDP would be 15.5% higher by following a green path rather than staying on the BAU trajectory. Furthermore, using the GDP-employment elasticity for Latin America (0.66), the projected 15.5% GDP difference in the green scenario translates to an approximate 10.2% difference in employment across Ecuador in 2050.

6.5 | Peru

6.5.1 | Supply and Demand

In the case of Peru, Table 15 shows the variations in overall energy demand between the green scenario and the BAU. As shown in the table, results show a 7.09% difference in the transportation sector, which is accompanied by a 60.13% variation in electricity demand. Additionally, there is a 5.86% difference in the energy demand from the industrial sector (with a 20.63% variationin electricity demand), a 11.80% difference in the commercial sector (alongside an 18.53% variation in electricity demand), and a 17.94% difference in the residential sector (paired with a 41.11% variation in electricity demand). The variations in demand due to higher electrification in the green scenario amounts for a 4.62% difference in electricity prices compared to BAU. Overall, the total energy variation in demand within the green scenario, when referenced against the BAU, stands at 8.48% and an electrification change of 38.86%.

With respect to the interconnection scenarios for the *Zona Andina*, once the model resolves the optimal import and export values recursively between the countries, Peru also becomes a net electricity importer from Ecuador. In the BAU + interconnection scenario, Peru's electricity imports constitute 1.6% of its total domestic electricity supply in 2050. Contrastingly, in the Green + interconnection scenario, this import figure surges to 18.9%. These augmentations in cross-border electricity exchange have relatively minor ramifications on domestic energy demand. Specifically, there is a 0% variance in energy demand in the BAU + interconnection scenario compared to the BAU scenario. In the Green + interconnection scenario, the shift observed is equivalent to the Green scenario. Moreover, the adjustments in electricity prices when adding the interconnections also don't diverge across scenarios.

(a) Overall demand

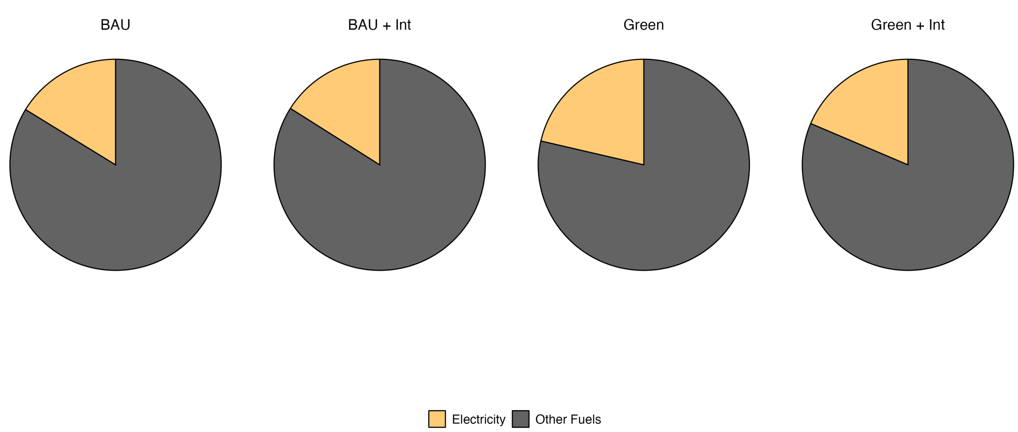
	Change w.r.t BAU		
Sector	BAU + Int	Green	Green + int
Transportation	-0.00%	7.09%	7.09%
Industry	-0.00%	5.86%	5.86%
Commerce	-0.00%	11.80%	11.80%
Residential	-0.00%	17.94%	17.94%
Total	-0.00%	8.48%	8.48%

(b) Electricity demand

	Change w.r.t BAU		
Sector	BAU + Int	Green	Green + Int
Transportation	-0.00%	60.13%	60.13%
Industry	-0.00%	20.63%	20.63%
Commerce	-0.00%	18.53%	18.53%
Residential	-0.00%	41.11%	41.11%
Total	-0.00%	38.86%	38.86%
Electricity price	0.00%	-4.62%	-4.62%

TABLE 15 Changes in demand across scenarios compared to BAU

The supply of electricity in Peru shows a slight change between the green and BAU scenarios (with very slight differences when added the interconnections). In 2050, the two green scenarios project between 19-21% of the total supply for electricity, while the BAU scenarios project 15-16% (see Figure 10).



Notes This figure shows a comparison of the projected supply of electricity and other fuels in 2050 across scenarios.

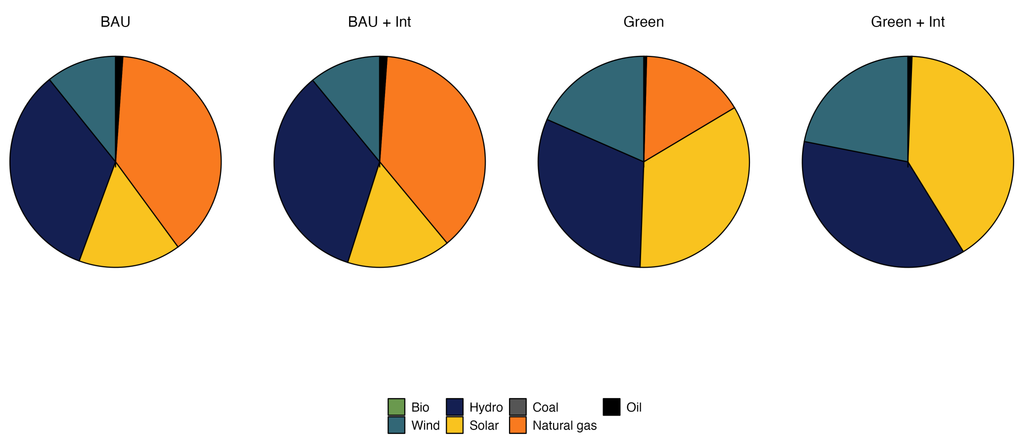
FIGURE 10 Fuel supply

Relating to electricity generation, as shown in Figure 11 and Table 16, as electricity from renewable sources displaces fossil-based generation, the power matrix in 2050 illustrates a significant shift towards renewable energy sources in the green scenario. Renewables are projected to contribute 84% of the country's power generation under this scenario in 2050, whereas they account for 60% in the BAU scenario. Furthermore, in the green

	Change w.r.t BAU		
	BAU + Int	Green	Green + Int
Coal	-86.8%	-93.6%	-77.6%
Natural gas	-4.0%	-42.7%	-99.6%
Oil	0.0%	-46.5%	-46.5%
Hidro	0.0%	28.0%	28.0%
Wind	0.0%	>100%	>100%
Solar	0.0%	>100%	>100%
Bio	-84.2%	-95.8%	-70.8%

TABLE 16 Changes in fuel consumption for electricity generation

scenario, the key contributors to power generation would be natural gas (16%, as opposed to 39% on the BAU), hydro (31%), wind (18%), and solar (34%). The differences between the BAU + interconnection and BAU scenarios are minor. However, comparing the green + interconnection scenario to the green scenario shows a significant change: With Peru importing electricity from Ecuador (18.90% of its domestic supply), its reliance on fossil fuels for power generation plummets to just 1% of the energy mix. Under this scenario, renewables account for approximately 99% of Peru's power generation in 2050.



Notes This figure presents a comparison of the projected use of energy sources in 2050 across scenarios.

FIGURE 11 Electricity generation

6.5.2 | Welfare analysis

As Table 17 shows, the comparative analysis of economic surplus reveals that Peru would be better off across various sectors in all scenarios under the green scenario compared to the BAU. Notably, in both the green and green + interconnection scenarios, consumer surplus shows variations in transportation (12.79%), commerce (28.67%), industry (15.35%), and residential (33.32%). Moreover, producers also enjoy advantages, with a 54.81% difference in electricity producer surplus in the green scenario (69.39% in the green + interconnection scenario), and a 0.89% variation for fuel producer surplus. Meanwhile, environmental damage diminishes by 6.06% in the green scenario, attributed to the strategic deployment of green energy sources. This positive trend amplifies considerably (12.62%) when interconnections are factored in, due to changes in electricity importation from Ecuador.

	Change w.r.t BAU		
Surplus	BAU + Int	Green	Green + Int
Consumer transportation	-0.00%	12.79%	12.79%
Consumer commerce	-0.00%	28.67%	28.67%
Consumer industry	-0.00%	15.35%	15.35%
Consumer residential	-0.00%	35.32%	35.32%
Producer electricity	1.13%	54.81%	69.39%
Producer fuels	0.00%	0.89%	0.89%
Government revenues	-0.00%	-15.40%	-15.40%
Environmental Damage	-0.46%	-6.06%	-12.62%
Overall Welfare	0.03%	17.88%	18.25%

TABLE 17 Changes in economic surplus

Overall, the green scenarios result in a 17.88% difference in aggregate economic welfare compared to the BAU scenario in 2050 (18.25% when interconnections are integrated into the model). Within this enhanced economic welfare, a 45% can be attributed to consumer transportation surplus, 11% consumer industry surplus, 15% commercial consumer surplus, 11% residential consumer surplus, 5% electricity producer surplus, and 5% in environmental damage reduction.

6.5.3 | Impact on Gross Domestic Product and Employment

Table 15 shows that the green scenarios lead to an approximate 8.48% variation in total energy consumption compared to the BAU scenario. Applying Latin America energy-GDP elasticity (0.59), we find that by 2050 the country's GDP would be 5% higher by following a green path rather than staying on the BAU trajectory. Furthermore, using the GDP-employment elasticity for Latin America (0.66), the projected 5% GDP growth in the green scenario translates to an approximate 3% increase in employment across Peru in 2050.

6.6 | Chile

6.6.1 | Supply and Demand

With respect to the variations in overall energy demand between the green scenario and the BAU in 2050, we can observe in Table 18 a difference of 34.34% in the transportation sector, which is accompanied by a 184.15% variation in electricity demand. Additionally, there is a 12.93% difference in the energy demand from the industrial sector (with a 24.79% variation in electricity demand), a 15.34% difference in the commercial sector (alongside an 25.24% variation in electricity demand), and a 12.11% difference in the residential sector (paired with a 24.46% variation in electricity demand). The changes in demand due to higher electrification in the green scenario amounts for a 9.86% difference in electricity prices compared to BAU. Overall, the total energy change in demand within the green scenario, when referenced against the BAU, stands at 24.97% and an electrification change of 74.16% in 2050.

Regarding the interconnection scenarios for the *Cono Sur*, once the model resolves the optimal import and export values recursively between the countries, Chile becomes a net electricity importer. Specifically, there is a *swap* Uruguay-Argentina-Chile, whereby the goal is to send renewable energy from Uruguay to Chile through Argentina (similar to the one depicted in (CAF and Comisión de Integración Energética Regional (CIER), 2012) between Paraguay-Argentina-Chile). Under this interconnected system, in the BAU + interconnection scenario, Chile's electricity imports constitute 6.8% of its total domestic electricity supply in 2050. Contrastingly, in the Green + interconnection scenario, this import figure surges to 9.40%. However, despite these enhanced cross-border energy exchanges, there are no discernible repercussions on either domestic energy demand or pricing structures. This stability holds across comparisons between the BAU and BAU + interconnection scenarios, as well as between the green and green + interconnection scenarios.

(a) Overall demand

	Change w.r.t BAU		
Sector	BAU + Int	Green	Green + int
Transportation	0.00%	34.34%	34.34%
Industry	0.00%	12.93%	12.93%
Commerce	0.00%	15.34%	15.34%
Residential	0.00%	12.11%	12.11%
Total	0.00%	24.97%	24.97%

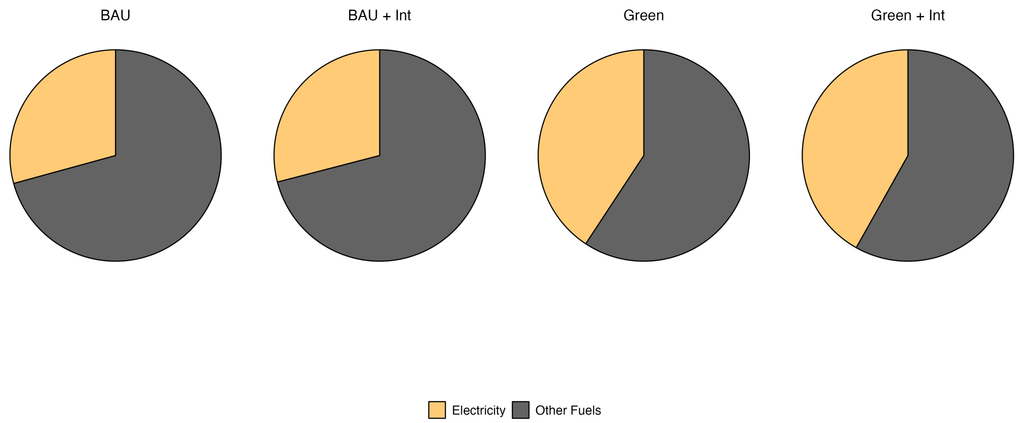
(b) Electricity demand

	Change w.r.t BAU		
Sector	BAU + Int	Green	Green + Int
Transportation	0.00%	184.15%	184.15%
Industry	0.00%	24.79%	24.79%
Commerce	0.00%	25.24%	25.24%
Residential	0.00%	24.46%	24.46%
Total	0.00%	74.16%	74.16%
Electricity price	-0.00%	-9.86%	-9.86%

TABLE 18 Changes in demand across scenarios compared to BAU

The supply of electricity in Chile shows a substantial difference between the green and BAU scenarios (with slight differences when added the interconnections). In 2050, the two green scenarios project between 40-42% of the total supply for electricity, while the BAU scenarios project 29% (see Figure 12). Notably, there is a coal supply difference of -97.6% in the green scenario, with a partial offset by a natural gas supply difference of 367% compared to the BAU scenario in 2050. This dramatic coal-to-gas transition introduces a nuanced dimension to the energy transition. This increase might seem contradictory at first glance, given natural gas's fossil fuel nature. However, by embracing natural gas as a bridge fuel, Chile aims to maintain a reliable energy supply while simultaneously reducing its carbon footprint. Therefore, this shift can be rationalized by considering the immediate advantages of natural gas as a transitional fuel.

Relating to electricity generation, as shown in Figure 13 and Table 19, as electricity from renewable sources displaces coal-based generation, the power matrix in 2050 illustrates a significant shift towards renewable energy sources in the green scenario. Renewables are projected to contribute 80% of the country's power generation under this scenario in 2050, whereas they account for 75% in the BAU scenario. Furthermore, in the green scenario, the key contributors to power generation would be natural gas (20%, replacing the 22% of coal from the BAU), Geo (16%), wind (19.4%), and solar (45%). In both the BAU and green transition scenarios, higher electricity imports allow Chile to increase its renewable share while decreasing reliance on fossil fuels. With greater interconnection in the BAU scenario, Chile's renewable share rises to 83% in 2050, up from 75% without added imports. Similarly, in the green transition scenario, imports help push the renewable share to 87% in 2050, compared to 80% without added imports. These results demonstrate how increased interconnection enables Chile to curb domestic fossil fuel usage and instead harness imported renewable energy from Uruguay. By leveraging cross-border connections, Chile can more rapidly transition away from fossil fuel electricity generation.



Notes This figure shows a comparison of the projected supply of electricity and other fuels in 2050 across scenarios.

FIGURE 12 Fuel supply

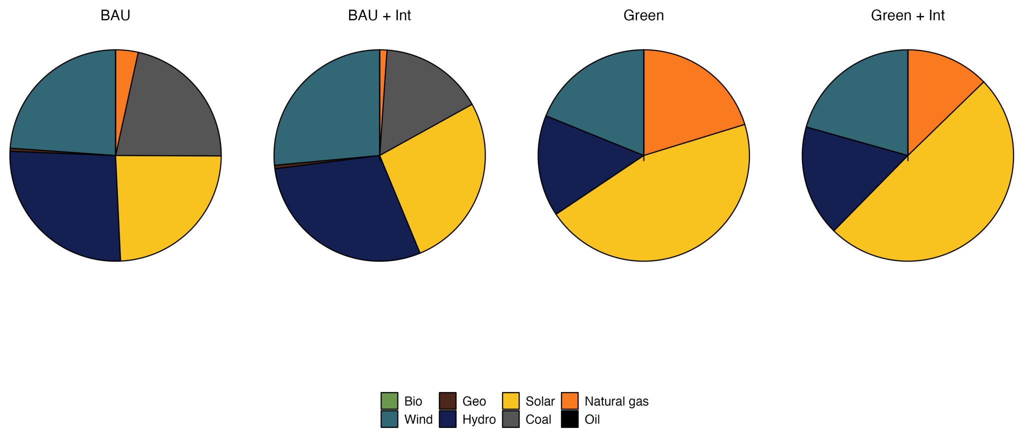
	Change w.r.t BAU		
	BAU + Int	Green	Green + Int
Coal	-33.8%	-100%	-100%
Natural gas	-71.0%	>100%	>100%
Oil	>100%	>100%	>100%
Hidro	0.0%	0%	0%
Geo	0.0%	-100%	-100%
Wind	0.0%	34%	34%
Solar	0.0%	>100%	>100%
Bio	>100%	>100%	>100%

TABLE 19 Changes in fuel consumption for electricity generation

6.6.2 | Welfare analysis

As shown in Table 20, the comparative surplus analysis for Chile reveals benefits across sectors in all scenarios versus the BAU. Notably, in the green and green + interconnection scenarios, consumer surplus shows large differences in transportation (250%), commerce (41.17%), industry (38.90%), and residential (35.11%). Producers also benefit, with a 71.78% difference in electricity producer surplus in the green scenario (80% in the green + interconnection scenario), and a 140.13% variation for fuel producers (158.83% in the green + interconnection scenarios). This arises from the coal-to-gas transition. With coal plants being supplanted, producing electricity from natural gas plants results in more market share and profits. Meanwhile, environmental damage decreases by 0.58% in the green scenario, further amplifying to 6.98% with interconnections, due to changes in electricity imports from Uruguay. Moreover, environmental damage also declines in the BAU + interconnection scenario (by 5.36%) when considering electricity imports coming from Uruguay.

Overall, the green scenarios result in a remarkable 155.12% difference in aggregate economic welfare compared to the BAU scenario in 2050 (155.60% when interconnections are integrated into the model). Within this enhanced economic welfare, 73% can be attributed to the consumer transportation surplus, a direct outcome of the accelerated electrification in



Notes This figure presents a comparison of the projected use of energy sources in 2050 across scenarios.

FIGURE 13 Electricity generation

	Change w.r.t BAU		
Surplus	BAU + Int	Green	Green + Int
Consumer transportation	0.00%	250.00%	250.00%
Consumer commerce	0.00%	41.17%	41.17%
Consumer industry	0.00%	38.90%	38.90%
Consumer residential	0.00%	35.11%	35.11%
Producer electricity	5.00%	71.78%	80.00%
Producer fuels	40.26%	140.13%	158.83%
Government revenues	0.00%	175.15%	175.15%
Environmental Damage	-5.36%	-0.58%	-6.98%
Overall Welfare	0.29%	155.12%	155.60%

TABLE 20 Changes in economic surplus

this sector.

6.6.3 | Impact on Gross Domestic Product and Employment

Table 18 shows that the green scenarios lead to an approximate 24.97% difference in total energy consumption compared to the BAU scenario. Applying Latin America energy-GDP elasticity (0.59), we find that in 2050 the country's GDP would be 14.73% higher by following a green path rather than staying on the BAU trajectory. Furthermore, using the GDP-employment elasticity for Latin America (0.66), the projected 14.73% GDP difference in the green scenario translates to an approximate 9.72% variation in employment across Chile in 2050.

6.7 | Argentina

6.7.1 | Supply and Demand

With respect to the variations in overall energy demand between the green scenario and the BAU in 2050, we can observe in Table 21 a difference of 23.13% in the transportation sector, which is accompanied by a 168.71% variation in electricity demand. Additionally, there is a 7.23% difference in the energy demand from the industrial sector (with a 26.33% variation in electricity demand), a 14.83% difference in the commercial sector (alongside an 26.38% variation in electricity demand), and a 5.55% difference in the residential sector (paired with a 24.56% variation in electricity demand). The variations in demand due to higher electrification in the green scenario amounts for a 10.34% difference in electricity prices compared to BAU. Overall, the total energy differences in demand within the green scenario, when referenced against the BAU, stand at 13.99% and an electrification change of 64.60%.

Regarding the interconnection scenarios for the *Cono Sur*, once the model resolves the optimal import and export values recursively between the countries, Argentina becomes a net electricity importer from Uruguay. In the BAU + interconnection scenario, Argentina's electricity imports constitute 5.5% of its total domestic electricity supply in 2050. Contrastingly, in the Green + interconnection scenario, this import figure surges to 6.80%. However, despite these enhanced cross-border energy exchanges, there are no discernible repercussions on either domestic energy demand or pricing structures. This stability holds across comparisons between the BAU and BAU + interconnection scenarios, as well as between the green and green + interconnection scenarios.

(a) Overall demand

Sector	Change w.r.t BAU: BAU + Int	Green	Green + int
Transportation	0.00%	23.13%	23.13%
Industry	0.00%	7.23%	7.23%
Commerce	0.00%	14.83%	14.83%
Residential	0.00%	5.55%	5.55%
Total	0.00%	13.99%	13.99%

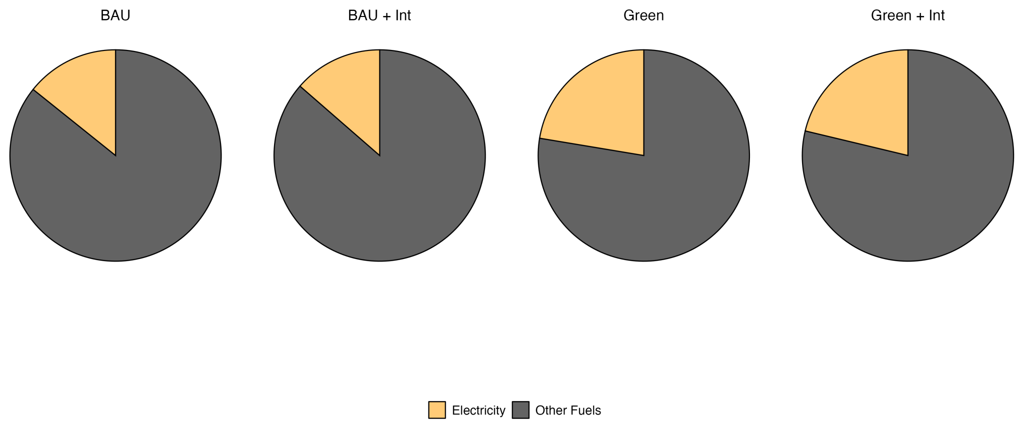
(b) Electricity demand

Sector	Change w.r.t BAU: BAU + Int	Green	Green + Int
Transportation	0.00%	168.71%	168.71%
Industry	0.00%	26.33%	26.33%
Commerce	0.00%	26.38%	26.38%
Residential	0.00%	24.56%	24.56%
Total	0.00%	64.60%	64.60%
Electricity price	-0.00%	-10.34%	-10.34%

TABLE 21 Changes in demand across scenarios compared to BAU

The supply of electricity in Argentina shows a substantial change between the green and BAU scenarios (with very slight differences when added the interconnections). In 2050, the two green scenarios project between 21-22% of the total supply for electricity, while the BAU scenarios project 13-14% (see Figure 14). One of the most notable differences in fuel supply is seen in fuel oil, diesel oil, jet fuel and gasoline, where the green scenarios reduce its supply by approximately 5.65%, 2.76%, 2.56%, and 2.51% in 2050, compared to the BAU scenarios, respectively.

Relating to electricity generation, as shown in Figure 15 and Table 22, as electricity from renewable sources displaces gas-fired generation, the power matrix in 2050 illustrates a significant shift towards renewable energy sources in the green scenario. Renewables are projected to contribute 77% of the country's power generation under this scenario, whereas they account for 50% in the BAU scenario. Furthermore, in the green scenario, the key contributors to power generation would be natural gas (23%, as opposed to 49% on the BAU), hydro (19%), wind (8%), and solar (49%) in 2050. Adding electricity importations from Uruguay increases the renewable share in both scenarios, as Argentina reduces fossil fuel



Notes This figure shows a comparison of the projected supply of electricity and other fuels in 2050 across scenarios.

FIGURE 14 Fuel supply

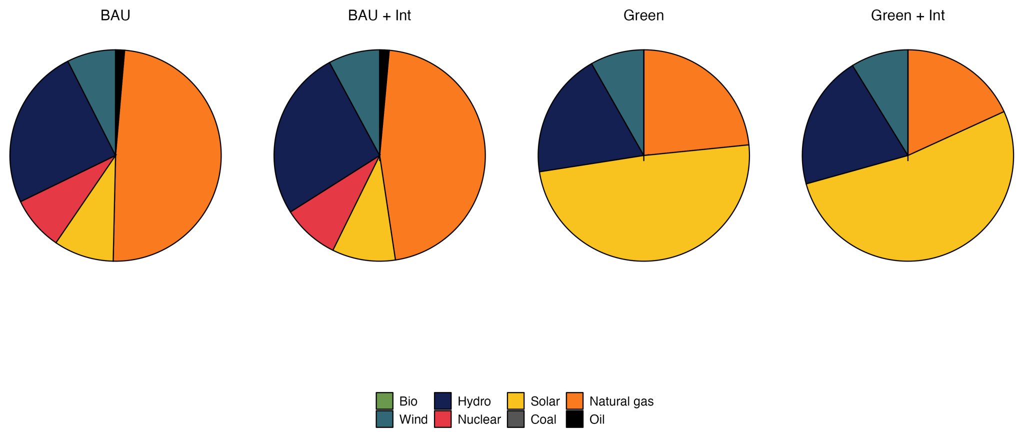
	Change w.r.t BAU		
	BAU + Int	Green	Green + Int
Coal	67%	4.6%	-94.54%
Natural gas	-11%	-21.4%	-42.79%
Oil	0%	-100.0%	-100.00%
Nuclear	0%	-100.0%	-100.00%
Hidro	0%	28.0%	28.02%
Wind	0%	81.5%	81.52%
Solar	0%	>100%	>100%
Bio	>100%	-2.6%	-95.46%

TABLE 22 Changes in fuel consumption for electricity generation

generation. Specifically, the renewable proportion rises to 52% in the BAU + interconnection scenario, up from 43% without added imports. Even more dramatically, it reaches 82% in the green + interconnection scenario, compared to 80% without added imports. This highlights how greater interconnections allow Argentina to decrease domestic fossil fuel generation and instead increase renewable imports from Uruguay. By leveraging cross-border transmission, Argentina can rapidly scale up its renewable share and reduce reliance on fossil fuels like natural gas and oil. The enhanced integration provides flexibility for Argentina to tap into Uruguay's greener grid and advance its own decarbonization.

6.7.2 | Welfare analysis

As displayed in Table 23, the comparative analysis of economic surplus shows that Argentina would be better off across various sectors in all scenarios under the green scenario compared to the BAU. Notably, in both the green and green + interconnection scenarios, consumer surplus experiences substantial variations in transportation (62.90%), commerce (36.23%), industry (20.76%), and residential (17.88%). Moreover, electricity producers also enjoy advantages, with a 70.66% difference in electricity producer surplus in the green scenario



Notes This figure presents a comparison of the projected use of energy sources in 2050 across scenarios.

FIGURE 15 Electricity generation

(78.59% in the green + interconnection scenario), while there is a decrease of 2.16% for fuel producer surplus. Meanwhile, environmental damage diminishes by 2.49% in the green scenario, attributed to the strategic deployment of green energy sources. This positive trend amplifies slightly further (5.34%) when interconnections are factored in, due to changes in electricity importation from Uruguay. Moreover, environmental damage also declines in the BAU + interconnection scenario (by 1.42%) when considering electricity imports coming from Uruguay.

	Change w.r.t BAU		
Surplus	BAU + Int	Green	Green + Int
Consumer transportation	0.00%	62.90%	62.90%
Consumer commerce	0.00%	36.23%	36.23%
Consumer industry	0.00%	20.76%	20.76%
Consumer residential	0.00%	17.88%	17.88%
Producer electricity	4.96%	70.66%	78.59%
Producer fuels	-0.00%	-2.16%	-2.16%
Government revenues	0.00%	-5.04%	-5.04%
Environmental Damage	-1.42%	-2.49%	-5.34%
Overall Welfare	0.23%	42.07%	42.40%

TABLE 23 Changes in economic surplus

Overall, the green scenarios result in a 42.07% variation in aggregate economic welfare compared to the BAU scenario in 2050 (42.40% when interconnections are integrated into the model). Within this enhanced economic welfare, a significant 51% can be attributed to the consumer transportation surplus, 14% consumer industry surplus, and 15% consumer residential surplus, a direct outcome of the accelerated electrification in these sectors.

6.7.3 | Impact on Gross Domestic Product and Employment

Table 9 shows that the green scenarios lead to an approximate 13.99% variation in total energy consumption compared to the BAU scenario. Applying Latin America energy-GDP elasticity (0.59), we find that by 2050 the country's GDP would be 8.25% higher by following a green path rather than staying on the BAU trajectory. Furthermore, the expanded economic activity fueled by increased energy consumption has a favorable impact on employment. Using the GDP-employment elasticity for Latin America (0.66), the projected 8.25% GDP difference in the green scenario translates to an approximate 5.44% variation in employment across Argentina in 2050. This signifies that the shift towards sustainability not only promotes economic growth but also plays a key role in creating job opportunities, thereby improving overall socioeconomic welfare.

6.8 | Uruguay

6.8.1 | Supply and Demand

Regarding the variations in overall energy demand between the green scenario and the BAU, we can observe in Table 24 a difference of 21.41% in the transportation sector, which is accompanied by a notable 127.01% variation in electricity demand. Additionally, there is a 9.63% difference in the energy demand from the industrial sector (with a 18.53% variation in electricity demand), a 14.71% difference in the commercial sector (alongside an 16.95% variation in electricity demand), and a 12.96% difference in the residential sector (paired with a 18.62% variation in electricity demand). Since Uruguay is already on a path to 100% renewable energy, the variations in demand brought on by increased electrification in the green scenario result in no difference in electricity pricing in this scenario compared to BAU in 2050. Overall, the total energy difference in demand within the green scenario, when referenced against the BAU, stand at 16.91% and an electrification change of 40.94% compared to BAU in 2050.

With respect to the interconnection scenarios for the *Cono Sur*, once the model resolves the optimal import and export values recursively between the countries, Uruguay becomes a net electricity exporter to Argentina and Chile. In the BAU + interconnection scenario, Uruguay's electricity exports constitute 54.10% of its total domestic electricity supply. Contrastingly, in the Green + interconnection scenario, this export figure surges to 63.10%. These augmentations in cross-border electricity exchange have moderate ramifications on domestic energy demand. Specifically, there is a 0.39% variance in energy demand in the BAU + interconnection scenario compared to the BAU scenario. In the Green + interconnection scenario, the shift observed is slighly superior to the green scenario (16.91% vs 18.95%, both compared to BAU).

The electricity price effects are more pronounced. With interconnection in the BAU case, prices fall 4.87% compared to the base scenario. More dramatically, prices plunge 25.47% relative to BAU under the interconnected green transition scenario. This suggest that by exporting its renewable surplus, Uruguay exerts downward pressure on electricity costs while enabling greener outcomes across the *Cono Sur*.

The supply of electricity in Uruguay shows a significant difference between the green and BAU scenarios (with major differences when added the interconnections in the green scenario). In 2050, the two green scenarios project between 72-83% of the total supply for electricity, while the BAU scenarios project 59% (see Figure 16).

As shown in Figure 17 and Table 25, the differences in renewable use between the BAU and green scenarios for Uruguay are minor, as the country is already on a path to achieve near 100% renewable share in both mixes (99% in BAU and 100% in green in 2050). In the

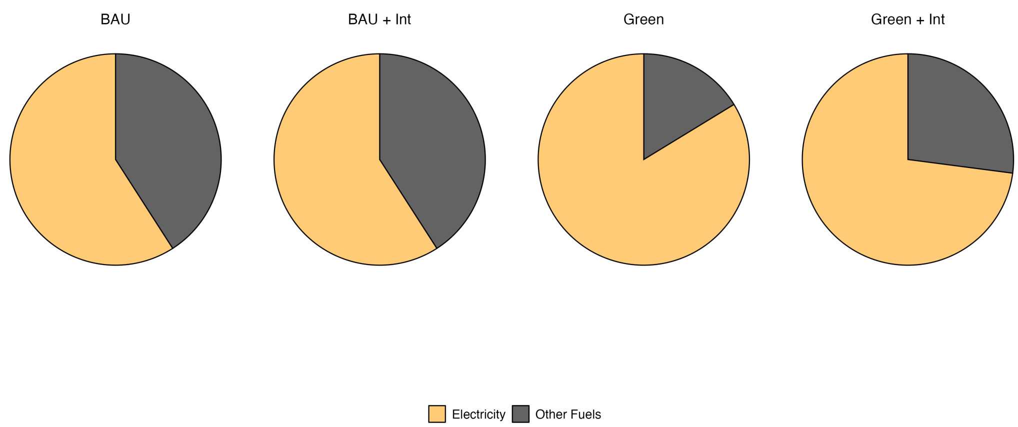
(a) Overall demand

	Change w.r.t BAU		
Sector	BAU + Int	Green	Green + int
Transportation	0.06%	21.41%	21.80%
Industry	0.73%	9.63%	13.20%
Commerce	0.60%	14.71%	17.82%
Residential	0.86%	12.96%	17.45%
Total	0.39%	16.91%	18.95%

(b) Electricity demand

	Change w.r.t BAU		
Sector	BAU + Int	Green	Green + Int
Transportation	0.37%	127.01%	129.28%
Industry	1.20%	18.53%	24.83%
Commerce	0.69%	16.95%	20.55%
Residential	1.24%	18.62%	25.08%
Total	0.92%	40.94%	45.82%
Electricity price	-4.87%	0.00%	-25.47%

TABLE 24 Changes in demand across scenarios compared to BAU



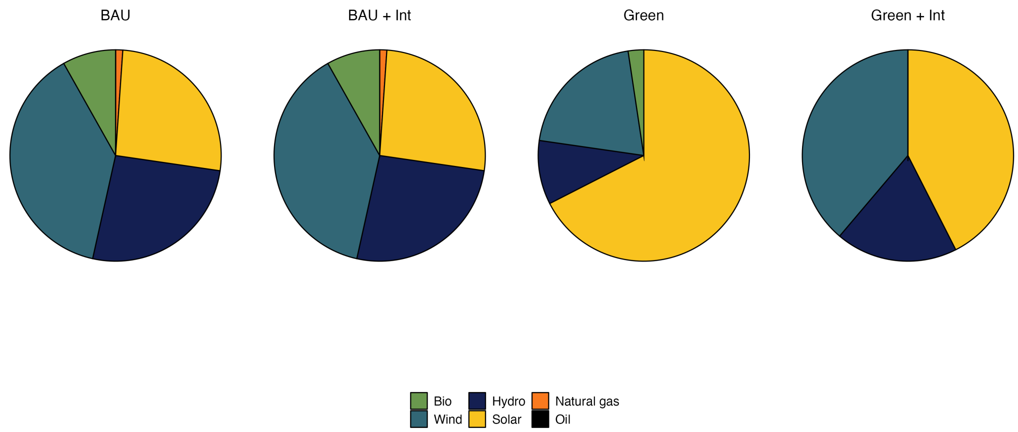
Notes This figure shows a comparison of the projected supply of electricity and other fuels in 2050 across scenarios.

FIGURE 16 Fuel supply

	Change w.r.t BAU		
	BAU + Int	Green	Green + Int
Natural gas	0%	-100%	-100%
Oil	-100%	-100%	-100%
Hidro	0%	28%	28%
Wind	0%	82%	82%
Solar	0%	>100%	>100%
Bio	0%	0%	-100%

TABLE 25 Changes in fuel consumption for electricity generation

green scenario, the key contributors would be hydro (10%), wind (20%), and solar (67%). The differences between the BAU + interconnection and BAU scenarios are minimal. A more marked contrast emerges when comparing the green + interconnection scenario to the pure green scenario. Motivated by Uruguay's electricity exports to Argentina and Chile (amounting to 63.10% of its domestic supply), wind generation increases to 39% of the total share, while solar decreases to 43% in the green + interconnection scenario.



Notes This figure presents a comparison of the projected use of energy sources in 2050 across scenarios.

FIGURE 17 Electricity generation

6.8.2 | Welfare analysis

As displayed in Table 26, the comparative analysis of economic surplus for Uruguay reveals benefits across various sectors in all scenarios compared to the BAU scenario. Regarding the BAU + interconnections scenario, there is a notable change in 69.28% of electricity producers surplus, derived from the increased interconnection. With respect to both the green and green + interconnection scenarios, consumer surplus show large differences in transportation (163.80% and 168.08%), commerce (35.47% and 43.73%), industry (25.59% and 35.87%), and residential (29.29% and 40.67%). Moreover, electricity producers enjoy a remarkable rise in economic surplus in both green scenarios (106.83% in the green and 210.21% in the green + interconnections scenario, derived from the increase in exports), and a 0.98% decrease for fuel producer surplus. Meanwhile, environmental damage diminishes by 28.53% in the green scenario and only 1.02% in the green + interconnection scenario, compared to BAU. This, again, is because Uruguay already has a nearly 100% renewable matrix, so increasing exports implies expanding capacity, which has some environmental impact. For instance, according to the Intergovernmental Panel on Climate Change (Schlömer et al., 2014), solar photovoltaic energy carries a median environmental impact of 48 gCO2 equivalent per kWh, while onshore wind energy has a median impact of 11 gCO2 equivalent per kWh.

The green scenario result in a 91.74% difference in aggregate economic welfare compared to the BAU scenario in 2050 (116.42% when interconnections are integrated into the model). Within this enhanced economic welfare, a 45% can be attributed to consumer transportation surplus and 29% to electricity producer surplus. These findings collectively underscore the substantial advantages across various sectors, brought about by a proactive embrace of green energy and increased regional electricity interconnections.

6.8.3 | Impact on Gross Domestic Product and Employment

Table 24 shows that the green scenarios lead to an approximate between 17% and 19% increase in total energy consumption compared to the BAU scenario. Applying Latin America energy-GDP elasticity (0.59), we find that by 2050 the country's GDP would be 10-11% higher by following a green path rather than staying on the BAU trajectory.

	Change w.r.t BAU		
Surplus	BAU + Int	Green	Green + Int
Consumer transportation	0.36%	163.80%	168.08%
Consumer commerce	1.33%	35.47%	43.73%
Consumer industry	1.69%	25.59%	35.87%
Consumer residential	1.78%	29.29%	40.67%
Producer electricity	69.28%	106.83%	210.21%
Producer fuels	-0.11%	-0.98%	-0.98%
Government revenues	0.63%	27.12%	30.50%
Environmental Damage	-0.00%	28.53%	1.02%
Overall Welfare	14.56%	91.74%	116.42%

TABLE 26 Changes in economic surplus

Furthermore, using the GDP-employment elasticity for Latin America (0.66), the projected 10-11% GDP difference in the green scenario translates to an approximate 7% difference in employment across Uruguay by 2050. This signifies that the shift towards sustainability not only promotes economic growth but also plays a key role in creating job opportunities, thereby improving overall socioeconomic welfare.

7 | CONCLUSIONS, LIMITATIONS AND POLICY IMPLICATIONS

The analysis presented in this report sheds light on the economic effects of an accelerated electrification and decarbonization process across selected Latin American countries, namely Mexico, Trinidad and Tobago, Colombia, Peru, Ecuador, Chile, Argentina, and Uruguay. Employing a mathematical programming economic equilibrium model rooted in the economic surplus maximization approach, we explored four distinct scenarios: Business as Usual (BAU), Green, BAU + interconnections, and Green + interconnections.

Specifically, the analysis revealed that the integration of renewable energies and the subsequent reduction of fossil fuel dependency contribute significantly to improving economic performance and environmental sustainability. This transition facilitates a decline in electricity prices, diminishes environmental harm, bolsters the resilience of the energy sector, while improving key economic metrics like GDP and employment. Furthermore, the introduction of interconnections, both in the *Zona Andina* and *Cono Sur* contexts, amplifies these gains, leading to enhanced outcomes as the proportion of renewable energy sources escalates in each region. Importing countries stand to benefit from cleaner power matrices and reduced reliance on fossil fuel-based generation, underscoring the regional advantages of increased cross-border energy cooperation.

However, while providing valuable insights, our model has inherent limitations that warrant acknowledgment. The modeling approach, though robust, simplifies intricate real-world dynamics within regional energy systems. Complex factors like technological changes, future uncertainties, behavioral responses, and broader economic effects are not fully captured. Input data quality directly impacts result accuracy, and assumptions around costs, policies, and consumer actions may not align with latest developments or persist long-term. Additionally, the model's static one-year structure cannot fully reflect the complex temporal effects. By not integrating these time dynamics, the model may miss pivotal feedbacks, adjustments, and developments that characterize the energy transition process. For instance, in the green scenario, the electricity producer absorbs a significantly larger surplus, which should promote the entry of new players in the market, something that we do not explicitly model.

Additionally, we do not take into account other emerging technologies, such as green hydrogen, as a viable alternative to fossil fuels and electrification. The exclusion of these considerations is primarily due to the limited availability of specific data and other considerations (for instance, we do not consider storage). Importantly, our green scenario results for Chile (who is a leader in the development of green hydrogen) imply a significant growth of natural gas. However, we recognize the immense potential of green hydrogen to play a relevant role in the transition towards a cleaner energy matrix, as it could substitute a considerable portion of this natural gas.

Furthermore, the model's static structure does not capture potential temporal effects within years as the transition advances. Also, broader economic, social and political factors shaping policy outcomes are not reflected. Specifically, Energy transitions are multifaceted, and the "green" scenario we propose, driven by technological advancements in renewables and economic growth, is just one facet. An alternative scenario could unfold, for instance, when considering a "carbon tax-driven energy transition," characterized by a negative shock to energy supply and the potential for an economic downturn. Real-world energy transitions likely fall somewhere on the spectrum between these polar scenarios, featuring both a positive impetus for renewables and a concurrent challenge to fossil fuels.

To foster a more balanced and comprehensive perspective, we advocate for a broader discussion that encompasses the prospects and implications of a carbon tax-driven energy transition. While acknowledging the complexities and economic repercussions, such an approach may prove vital in mitigating emissions. Our study initiates this dialogue by recognizing these alternative pathways, and we call upon future research to investigate deeper into the dynamics and trade-offs inherent in these scenarios. Such an understanding will empower policymakers to make informed decisions that harmonize environmental and economic goals within the context of sustainable energy transitions. Overall, while limitations exist, the model yields critical insights to inform energy policy—but prudent interpretation considering these caveats is advised.

Even with its limitations, this analysis highlights the significant benefits that strategically pursuing electrification and decarbonization can unlock for Latin American countries, both individually and collectively. To capitalize on these opportunities, policymakers should prioritize and provide incentives for renewable energy investments, electrification and electricity access expansion, efficiency improvements, and clean power trading. Recognizing differing national contexts, policies and partnerships should be tailored to local needs while aligning with shared regional decarbonization ambitions. By pursuing ambitious decarbonization goals and partnerships across Latin America, countries can drive sustainable growth, improve health outcomes, and contribute to climate global efforts.

In conclusion, this study provides insights into the potential for electrification and decarbonization in Latin America. The modeling and analysis illustrate promising pathways for reducing emissions while supporting economic growth. At the same time, it is clear there are still uncertainties and knowledge gaps. Further research will be key to developing nuanced strategies that align with Latin America's diverse priorities and particularities. By continuing to explore these complex dynamics through energy modeling and empirical studies, we can work toward exploring decarbonization pathways that balance environmental sustainability, social equity, and broad-based economic development across Latin America.

REFERENCES

Al-Iriani, M. A. (2006) Energy–gdp relationship revisited: an example from gcc countries using panel causality. *Energy policy*, **34**, 3342–3350.

Atalla, T., Bigerna, S., Bollino, C. A. et al. (2016) Quantifying worldwide demand elasticities as a policy tool. *Tech. rep.*

Beach, R. H., Zhang, Y. W. and McCarl, B. A. (2012) Modeling bioenergy, land use, and ghg emissions with fasomghg: model overview and analysis of storage cost implications. *Climate Change Economics*, **3**, 1250012.

Bernstein, R. and Madlener, R. (2011) Residential natural gas demand elasticities in oecd countries: an ardl bounds testing approach.

BP (2019) Estatistical review of world energy. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf. Accessed on: April 8, 2023.

Burke, P. J. and Csereklyei, Z. (2016) Understanding the energy-gdp elasticity: A sectoral approach. *Energy Economics*, **58**, 199–210.

CAF and Comisión de Integración Energética Regional (CIER) (2012) *Nuevas oportunidades de interconexión eléctrica en América Latina*. Bogotá: CAF. URL: https://scioteca.caf.com/handle/123456789/418.

Dahl, C. A. (2012) Measuring global gasoline and diesel price and income elasticities. *Energy Policy*, **41**, 2–13.

Egerer, J., Rosellón, J. and Schill, W.-P. (2015) Power system transformation toward renewables: An evaluation of regulatory approaches for network expansion. *The Energy Journal*, **36**.

ENEL Argentina (2023) Hoja de ruta de transición energética 2030-2050. *Tech. rep.* URL: https://www.enel.com.ar/content/dam/enel-ar/ActualizaciÃşn%20de%20la%20Hoja%20de%20ruta%20de%20TransiciÃşn%20EnergÃľtica%20en%20Argentina.pdf.

ENEL Perú (2022) Hoja de ruta de transición energética 2030-2050. *Tech. rep.* URL: https://www.enel.pe/es/sostenibilidad/transicion-energetica-peru-2050.html.

Espinoza, V. S., Fontalvo, J., Ramírez, P., Martí-Herrero, J. and Mediavilla, M. (2022) Energy transition scenarios for fossil fuel rich developing countries under constraints on oil availability: The case of ecuador. *Energies*, **15**, 6938.

Frank, L. E. and Maggio, S. (2015) Review of household demand elasticities in argentina. *Agronomía & Ambiente*, **35**.

Gutiérrez-Meave, R., Rosellón, J. and Sarmiento, L. (2021) The effect of changing marginal-cost to physical-order dispatch in the power sector. URL: https://www.rff.org/publications/working-papers/effect-of-changing-marginal-cost-to-physical-order-dispatch-in-the-power-sector/. Working Paper.

Hampl, N. (2022) Equitable energy transition in latin america and the caribbean: Reducing inequity by building capacity. *Renewable and Sustainable Energy Transition*, **2**, 100035.

Hancevic, P. I., Nuñez, H. M. and Rosellón, J. (2017) Distributed photovoltaic power generation: Possibilities, benefits, and challenges for a widespread application in the mexican residential sector. *Energy Policy*, **110**, 478–489.

Hancevic, P. I., Núñez, H. M. and Rosellón, J. (2022) Mexico's energy prospects: Gains from renewable sources over a fossil fuel-dominated environment. *Economics of Energy & Environmental Policy*, **11**.

Hernández, C. F. A. C., Picazo, M. C., Ramos, A. E. G. and Muñoz, J. S. Z. (2022) Elasticidad de los combustibles fósiles en méxico/elasticities of fossil fuels in mexico. *EconomíaUNAM*, **19**, 119–163.

IEA () International energy agency. https://www.iea.org/countries. Accessed on: April 8, 2023.

IMF () International monetary fund. https://data.imf.org/?sk=77413f1d-1525-450a-a23a-47aeed40fe78. Accessed on: Jun 5, 2023.

Iniciativa Climática De México (2020) Rutas sectoriales de descarbonización para méxico: Documento de política 1. *Tech. rep.* URL: https://www.iniciativaclimatica.org/wp-content/uploads/2020/08/Rutas-sectoriales-de-descarbonizaciÃşn-para-MÃľxico_Documento-de-PolÃŋtica-1.pdf.

IRENA () International renewable energy agency. https://www.irena.org. Accessed on: April 8, 2023.

Jupiter, Andrew, van Meurs, Pedro (2021) Suggested energy transition policy for trinidad and tobago: The next fifty years. *Tech. rep.* URL: https://sta.uwi.edu/eng/chemical/suggested-energy-transition-policy-trinidad-and-tobago-next-fifty-years.

Koengkan, M. and Fuinhas, J. A. (2020) Exploring the effect of the renewable energy transition on co2 emissions of latin american & caribbean countries. *International Journal of Sustainable Energy*, **39**, 515–538.

— (2022) Does the energy transition process decrease the environmental degradation in latin american and caribbean countries? In *Globalisation and Energy Transition in Latin America and the Caribbean: Economic Growth and Policy Implications*, 199–244. Springer.

Krichene, N. (2002) World crude oil and natural gas: a demand and supply model. *Energy economics*, **24**, 557–576.

Löffler, K., Hainsch, K., Burandt, T., Oei, P.-Y., Kemfert, C. and Von Hirschhausen, C. (2017) Designing a model for the global energy system—genesys-mod: an application of the open-source energy modeling system (osemosys). *Energies*, **10**, 1468.

Ministerio de Energía del Gobierno de Chile (2022) Energía 2050. *Tech. rep.* URL: https://www.energia.gob.cl/sites/default/files/energia_2050_-_politica_energetica_de_chile.pdf.

Morén, V. and Wändal, E. (2019) The employment elasticity of economic growth-a global study of trends and determinants for the years 2000-2017.

Nuñez, H. (2018) Building a bioethanol market in mexico. *Tech. rep.*

Nuñez, H. M. (2021) Biomethane for electricity in mexico: A prospective economic analysis. *Economics of Energy & Environmental Policy*, **10**, 197–215.

Nuñez, H. M., Önal, H. and Khanna, M. (2013) Land use and economic effects of alternative biofuel policies in brazil and the united states. *Agricultural Economics*, **44**, 487–499.

Oei, P.-Y., Burandt, T., Hainsch, K., Löffler, K., Kemfert, C. et al. (2020) Lessons from modeling 100% renewable scenarios using genesys-mod. *The Energy Journal*, **9**, 103–120.

OLADE () Sistema de información energética of latin america and the caribbean. https://sielac.olade.org. Accessed on: April 8, 2023.

Samuelson, P. A. (1952) Spatial price equilibrium and linear programming. *The American economic review*, **42**, 283–303.

Sarmiento, L., Burandt, T., Löffler, K. and Oei, P.-Y. (2019) Analyzing scenarios for the integration of renewable energy sources in the mexican energy system—an application of the global energy system model (genesys-mod). *Energies*, **12**, 3270.

Schill, W.-P., Egerer, J. and Rosellón, J. (2015) Testing regulatory regimes for power transmission expansion with fluctuating demand and wind generation. *Journal of Regulatory Economics*, **47**, 1–28.

Schlömer, S., Bruckner, T., Fulton, L., Hertwich, E., McKinnon, A., Perczyk, D., Roy, J., Schaeffer, R., Sims, R., Smith, P. and Wiser, R. (2014) *Annex III: Technology-specific cost and performance parameters*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Takayama, T. and Judge, G. G. (1971) Spatial and temporal price and allocation models.

The World Bank and OLADE (2020) Energy prices report in latin america and the caribbean.

Unidad de Planeación Minero-Energética de Colombia (2020) Plan energético nacional 2020-2050. *Tech. rep.* URL: https://www1.upme.gov.co/DemandayEficiencia/Paginas/PEN.aspx.

Wood, D., Larson, J., Jones, J., Galperin, D., Shelby, M. and Gonzalez, M. (2022) World oil price impacts on country-specific fuel markets: Evidence of a muted global rebound effect. *Energy Economics*, **111**, 106024.

A | MODEL VALIDATION

In this section, we compare the simulated results to the actual data in the base year (i.e. 2019). The validation results demonstrate minor deviations from observed data, affirming the accurate depiction of underlying patterns in the region's energy markets by our model. This assurance underscores the reliability of our projections to 2050.

	Mexico		Trinidad		Colombia		Ecuador		Peru		Argentina		Uruguay	
	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated
Transportation														
Gasoline	1.53E+15	1.79E+15	1.75E+13	2.18E+13	2.40E+14	2.98E+14	1.17E+14	1.12E+14	8.78E+13	1.52E+14	2.76E+14	3.35E+14	2.60E+13	2.91E+13
Diesel oil	5.57E+14	6.69E+14	1.29E+13	1.63E+13	2.08E+14	2.62E+14	1.35E+14	1.29E+14	1.80E+14	2.44E+14	3.11E+14	3.83E+14	2.65E+13	3.20E+13
Fuel oil	2.76E+12	3.38E+12			7.08E+11	1.87E+12	2.49E+13	3.24E+13	1.67E+13	3.72E+13	1.75E+13	2.81E+13		
Natural gas	2.60E+12	2.74E+12			1.77E+13	2.30E+13			2.91E+13	5.22E+13	8.14E+13	9.54E+13		
Electricity	3.79E+12	3.79E+12			3.61E+11	3.87E+11	3.75E+10	1.58E+10	3.97E+11	5.31E+11	1.81E+12	9.67E+11	6.61E+09	3.63E+09
GLP	6.00E+13	6.88E+13					2.74E+11	3.43E+11	3.09E+13	4.74E+13				
Jet fuel	1.81E+14	1.99E+14	3.45E+12	4.07E+12	5.62E+13	6.34E+13	1.44E+13	1.78E+13	4.50E+13	8.27E+13	6.99E+13	8.34E+13	8.36E+10	9.75E+10
Industry														
Gasoline	1.23E+12	1.72E+12	3.79E+11	5.14E+11	3.63E+11	4.51E+11	8.13E+11	7.78E+11	1.94E+09	3.66E+09			1.99E+10	5.35E+10
Diesel oil	5.76E+13	6.92E+13	3.80E+12	5.61E+12	2.37E+12	3.30E+12	2.10E+13	2.33E+13	8.08E+12	1.13E+13	4.05E+12	5.07E+12	6.93E+11	2.55E+11
Fuel oil	1.29E+13	1.58E+13			4.46E+11	5.71E+11	9.26E+12	1.2E+13	2.17E+12	4.02E+12	5.93E+12	7.48E+12	5.39E+12	4.20E+11
Natural gas	5.12E+14	5.37E+14	2.18E+14	2.64E+14	8.89E+13	1.16E+14	1.50E+12	2.93E+12	5.10E+13	9.14E+13	3.08E+14	3.65E+14	6.97E+11	5.34E+11
Electricity	5.84E+14	5.49E+14	1.75E+13	1.24E+13	6.20E+13	6.01E+13	3.56E+13	3.77E+13	6.64E+13	6.37E+13	1.71E+14	1.39E+14	2.06E+13	1.06E+13
Coal	1.78E+14	2.34E+14			8.60E+13	1.15E+14			2.10E+13	2.04E+13	1.72E+12	2.39E+12		
GLP	4.37E+13	5.01E+13	9.83E+10	1.83E+11	4.18E+12	5.83E+12	3.94E+12	4.94E+12	1.63E+13	2.50E+13	7.25E+12	9.02E+12	6.33E+11	5.02E+11
Commerce														
Natual Gas	1.05E+13	1.11E+13			1.78E+13	2.22E+13			8.35E+12	1.51E+13	4.81E+13	5.64E+13	3.98E+11	7.61E+11
Diesel oil			2.40E+11	3.54E+11			4.49E+12	5.22E+12	6.79E+12	8.76E+12	4.05E+12	5.07E+12	2.07E+11	8.65E+11
Electricity	8.51E+13	7.91E+13	3.16E+12	2.80E+12	5.60E+13	5.82E+13	2.48E+13	2.67E+13	4.88E+13	5.22E+13	1.07E+14	8.77E+13	1.72E+13	1.16E+13
GLP	5.89E+13	6.76E+13			2.45E+12	7.55E+12	2.28E+12	2.86E+12	3.63E+12	5.57E+12	7.91E+12	9.84E+12	2.87E+11	1.11E+12
Fuel oil							2.69E+11	3.5E+11	4.31E+08	7.98E+08	2.08E+12	2.62E+12	3.54E+11	6.52E+12
Gasoline							1.17E+11	1.12E+11	1.69E+10	3.96E+10			4.78E+10	2.23E+10
Residential														
Natual Gas	2.98E+13	3.15E+13			4.90E+13	6.11E+13	1.96E+10	3.19E+10	6.20E+12	1.11E+13	3.37E+14	4.15E+14	8.84E+11	9.76E+11
Electricity	2.21E+14	2.12E+14	1.75E+13	1.28E+13	8.49E+13	9.09E+13	2.62E+13	2.39E+13	5.41E+13	5.28E+13	1.48E+14	1.32E+14	2.49E+13	1.37E+13
GLP	2.36E+14	2.70E+14	2.28E+12	4.25E+12	1.72E+13	2.40E+13	3.65E+13	3.94E+13	3.76E+13	5.76E+13	4.74E+13	5.91E+13	4.36E+12	5.08E+12

TABLE A.1 Simulated versus observed demand quantities for 2019. Note: All figures are reported in BTU.

	Mexico		Trinidad		Colombia		Ecuador		Peru		Argentina		Uruguay	
	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated
Domestic														
Natural Gas	4.53E+14	4.09E+14	1.16E+15	9.37E+14	4.05E+14	3.34E+14	2.35E+13	2.24E+13	5.02E+14	4.13E+14	1.51E+15	1.13E+15		
Coal	2.66E+14	2.20E+14			2.30E+15	1.93E+15			5.55E+12	5.92E+12		2.05E+12		
GLP	1.73E+14	2.12E+14	2.13E+13	2.11E+13	2.72E+13	3.74E+13	7.11E+12	9.32E+12	6.64E+13	8.60E+13	1.20E+14	1.05E+14	4.44E+12	4.73E+12
Fuel oil	3.84E+14	3.11E+14	6.61E+13		1.16E+14	1.09E+14	9.80E+13	1.03E+14	9.44E+13	9.44E+13	6.68E+13	5.51E+13	7.17E+12	6.94E+12
Diesel oil	2.02E+14	1.92E+14	6.69E+13	5.56E+13	2.86E+14	2.66E+14	6.75E+13	1.02E+14	1.14E+14	1.84E+14	4.17E+14	3.93E+14	3.61E+13	3.31E+13
Jet Fuel	7.30E+13	8.44E+13	1.77E+13	1.42E+13	4.82E+13	4.59E+13	1.54E+13	1.25E+13	2.88E+13	2.30E+13	6.16E+13	6.18E+13	4.26E+12	3.62E+12
Gasoline	4.84E+14	4.72E+14	7.73E+13	5.83E+13	2.00E+14	2.33E+14	6.24E+13	9.49E+13	1.38E+14	1.30E+14	2.59E+14	3.31E+14	2.55E+13	2.92E+13
Uranium	1.48E+14	1.35E+14												
Imported														
Natural Gas	1.34E+15	1.08E+15			4.82E+11	3.21E+04	2.35E+13				2.26E+14	9.51E+13	3.22E+12	3.30E+12
Coal	2.62E+14	2.62E+14							1.64E+13	1.44E+13	2.17E+13	3.39E+11	1.19E+11	
GLP	1.62E+14	2.45E+14	3.11E+12	5.17E+05			7.11E+12	3.82E+13	2.69E+12	4.95E+13				1.96E+12
Fuel oil	9.81E+13	5.86E+05				2.96E+03			1.21E+12			4.88E+03	1.53E+12	1.69E+02
Diesel oil	6.26E+14	5.46E+14				1.14E+04	6.75E+13	5.57E+13	1.43E+14	7.99E+13	7.87E+13	3.34E+03	2.36E+14	1.60E+01
Jet Fuel	1.16E+14	1.14E+14			2.59E+12	1.75E+13	1.54E+13	5.31E+12	1.66E+13	5.97E+13	8.93E+12	2.16E+13	3.98E+09	
Gasoline	1.20E+15	1.32E+15			5.38E+13	6.61E+13	4.69E+13	1.81E+13	3.24E+13	2.16E+13	1.56E+13	4.38E+12	9.88E+12	1.95E+02
Uranium											8.76E+13	1.53E+14		

TABLE A.2 Simulated versus observed supply quantities for 2019. Note: All figures are reported in BTU.