The Development of Renewable Energies and Green Logistics: Reflections on Three Countries in Latin America

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***Abstract*—We examine the development of Sustainable (Green) Supply chains in Latin America, which were selected based on their Logistics Performance Index and initiatives in the development of renewable energies over a 10-year period. We based our empirical analysis on UN SDGs concerned with clean energy, innovation, sustainable communities, and climate action (SDGs 7, 9, 11, and 13, respectively). Using a modified RAM-DEA model, our results showed high logistics performance but significant divergence in green logistics performance among countries in Latin America. Chile, Brazil, and Argentina showed moderate levels of inefficiency, which were marked by high oil consumption, high output of CO_2 emissions from oil combustion, high energy-related CO_2 emissions per capita, and a relatively high mean annual concentration of particulate matter of 2.5 microns and below. However, according to our empirical analysis, the countries showed remarkably positive developments in good inputs, such as investment in R&D, as well as basic and applied research related to renewable energy and green logistics. The three highest-performing countries in this regard have been Argentina, Brazil, and Chile. However, these countries have also experienced immense challenges in implementing renewable energies. Following the empirical analysis, we discuss the policies of the three countries implementing their renewable energy strategies.**

***Keywords*—DEA, Latin America, sustainable development goals, efficiency, supply chains, sustainability, renewable energy, corporate social responsibility, logistics performance index**

I. Introduction

Supply chain management is an area of increasing strategic importance due to global competition, outsourcing of noncore activities to developing countries, short product life cycles, and shortened lead times in all aspects of the supply chain (Skjott-Larsen *et al.*, 2007). Management attention has moved from competition between firms to competition between supply chains and value chains (Ferrantino and Koten, 2019; Mangan and Christopher, 2005; Rakhmangulov *et al.*, 2017). The capability to establish close and long-term relationships with suppliers and other strategic partners has become a crucial factor in creating a competitive advantage. At the same time, various stakeholders, including consumers, shareholders, Non-Governmental Organisations (NGOs), public authorities, trade unions, and international organisations, are showing an increasing interest in environmental and social issues related to international business. Concepts such as supply chain sustainability (Abbasi and Nilsson, 2016; Koplin *et al.*, 2017), triple bottom line (Elkington, 1997), environmental management (Handfield *et al.*, 2005), corporate greening (Preuss, 2005), green supply (Bowen *et al.*, 2001; Sarkis J, 2003; Vachon and Klassen, 2006; Wang, 2010) and corporate social responsibility (CSR) in supply chains (Maloni and Brown, 2016; Pedersen and Andersen, 2016). Green supply chains have increasingly been studied and resulted in new findings by (Kwak *et al.*, 2018; Chan *et al.*, 2020; Stekelorum *et al.*, 2020) across various industries, company types (MNCs and SMEs), and countries. An increasing number of companies, especially large multinational corporations, have implemented environmental annual reports, sustainability strategies, and voluntary codes of conduct. However, despite many multinational corporations' efforts to implement social and environmental issues in their supply chains, a gap exists between the desirability of supply chain sustainability in theory and the implementation of sustainability in supply chains in practice (Akbari and McClelland, 2020).

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The green supply chain management model, which fully considers resource consumption and environmental impact of the supply chain has received wide attention in politics and business (Esen and Barky, 2017; Meckling and Hughes, 2018; Osintsev *et al.*, 2020; Zimon, 2017). The promotion of ecological aspects in many parts of consumer life and the continuous improvement of consumers' environmental awareness, not only are green products becoming favoured by the market but also sustainable supply chains (Kuiti *et al.*, 2019). Therefore, implementing green supply chain management practices and selling green products have become important measures for supply chain enterprises to occupy a favourable market position and obtain sustainable competitive advantages, so the topic is significant.

Specifically, we examine the development of renewable energies which are necessary for green supply chains and logistics efficiency using examples of Latin American countries.

II. Background of Regional Cooperation among Countries in Latin America in Sustainability

In the Latin American and Caribbean (LAC) region, significant progress has already been achieved during the era of the Millennium Development Goals in terms of SDG 7 targets, when viewed in a global context. Access to electricity is estimated at 96% across the region, whereas globally the rate is only 85%. The region is in the 86th percentile in access to biofuels, which is ahead of the global average of 59%. As for energy efficiency, the indicators have consistently increased over the past 22 years, and the region has had a rate of improvement exceeding 43% for over two decades. The LAC region can be considered a global role model in renewable energy with a proportion of renewables reaching nearly 28% of total energy consumption, whereas the world average is at 18%.

Despite significant progress over the past two decades, challenges continue to exist, and countries have been addressing them. Most difficulties concern the dimension of multilateral cooperation, where the agenda of formal SDGs has helped initiate and accelerate multilateral cooperation in the region on several levels, which are explained further.

III. Existing Problems in Energy Supply in Latin America

A. Access

An analysis by the Latin American Energy Organization (OLADE) and the Inter-American Development Bank (IDB) demonstrates that although higher levels of access to electricity have been achieved, new connections to power resources remain slow in many LAC countries (United Nations Department of Economics and Social Affairs Sustainable Development, 2018; Timilsina and Shrestha, 2008). This is because remote settlements are difficult and often more expensive to reach due to underdeveloped infrastructure but can provide an impetus for households to install solar panels, which increase the level of electrical self-sufficiency. Rural electrification is one among several provisions within the integrated framework of the SDGs agenda (Sustainable Development Solutions Network, 2022). The goals and policies of the IADB are closely aligned with the broader goals and policies of the UN SDGs.

B. Technology Transfer

To promote energy for sustainable development there is a need for favourable access to and transfer of environmentally sound technologies, in particular to developing countries, through supportive measures that promote technology cooperation and that should enable the transfer of necessary technological know-how and the building up of economic, technical, and managerial capabilities for the efficient use and further development of transferred technology. Technology cooperation involves joint efforts by enterprises and governments, both suppliers of technology and its recipients. Therefore, such cooperation entails an iterative process, involving government, the private sector, and research and development facilities, to ensure the best possible results from the transfer of technology. Successful long-term partnerships in technology cooperation necessarily require continuing systematic training and capacity-building at all levels over an extended time.

C. Financial Cooperation

Many governments have initiated reforms aimed at improving regulatory frameworks and institutional set-ups to attract private-sector funding. Specific policies have been introduced to induce the flow of investment capital for energy technology for sustainable development. While more sustainable technologies often have lower operating costs than competing solutions, they sometimes require greater initial investments. Particular attention should therefore be paid to the difficulties of financing these essential infrastructure investments in developing countries.

D. Making Markets Work Effectively for Sustainable Development

On a regional level, bilateral cooperation between Argentina and Brazil in developing alternative sources of energy has set precedents for neighbour countries, and Chile's ambitions in developing renewable energy have elevated it to a leading country globally. Chile has considerable hydro, geothermal, solar, and wind energy resources, and it has been described as "a world leader in renewable energy development" (Madariaga and Allain, 2020). Unlike its large regional counterparts, many of Chile's efforts have been unilateral. 20% of Chile's energy supply comes from renewable energy sources (Madariaga and Allain, 2020; International Renewable Energy Agency (IRENA, 2022).

IV. Characteristics of the Energy Policies of Argentina and Brazil

The lack of coordination at the regional level is reflected in the various legal frameworks and public

policies that exist in Argentina and Brazil, which could be another indicator of the misalignment of inputs versus outputs, hence inefficiencies. Both States face the challenge of using their optimal natural conditions to generate renewable energy and define the options to exploit the vast reserves they have, in a context dominated by fossil fuels. This is so because oil and gas remain a symbol of national pride and independence and their exploitation is seen as necessary for the process of economic growth (Freier, 2016). Since these significant fossil energy sources are viewed positively by governments and rhetorically promoted as essential, political decision processes, however, have shown contradictory trends in favour of renewable sources of energy. The first implementation of a legal framework for renewable energy took place in Argentina. With the sanction of the National Regime for Wind and Solar Energy (Law 25,019 of 1998), Argentina expressed its interest in promoting the use of both sources through the stimulation of research in these areas and the implementation of differentiated tax structures.

Economic promotion instruments such as $15/MW remuneration and tax refunds are mentioned as the main reasons for the low performance of the renewable energy sector in Argentina (Guzowski and Recalde, 2008). In turn, ENARSA (Energ á Argentina S.A.) implemented the GENREN bidding program for small-scale projects. In the area of wind power, for example, only projects up to 50 MW were taken into account. Likewise, priority was given to national projects that excluded foreign investment.

To achieve a reliable electricity supply, Brazil required distributors to contract 100% of the forecast demand for their market (Dutra and Szklo, 2006), similar to countries such as Germany. Following the idea of competitiveness through bidding projects, the Brazilian government imposed a variety of responsibilities on producers. In the case of auctions for existing energy, the distribution companies inform the amount of energy they will contract 60 days in advance. Then, the Ministry of Mines and Energy, with all the amounts budgeted by the distributors, holds an auction with which it centralizes the process. The resulting contracts are bilateral between the generator and the energy distributor, without state intervention. As Rotaeche (2014) explains, wind energy has priority in the system, being exempt from the payment of Tax on the Circulation of Manufactures and Services (ICMS) and 75% of the Income Tax. The first exclusive wind energy auction took place in December 2009. To obtain financing from the National Bank for Economic and Social Development (BNDES), PROINFA requires that at least 60% of the wind farm contain local parts. Otherwise, when the generation company uses financing other than BNDES, it is possible to import all the necessary parts from abroad. On the other hand, the connections to the transmission network, the establishment of a transport system, the assembly and adequate civil engineering for towers and wind turbines are the responsibility of the producers, which makes wind energy 20–30% more expensive than in other countries that use this resource on a large scale.

V. Inputs Inefficiency Analysis Per Country

In this section, potential explanations are documented to explain the inefficiencies in the inputs and outputs found for Latin American countries in the next table according to (Wollenberg, 2022). The inputs and outputs of the countries with efficiencies lower than 1 are analysed. These are Chile's, Brazil's, and Argentina's.

TABLE I. Data Envelopment Analysis of Countries in Three Regions: Latin America, Europe, and GCC

	Efficiencies	slack_input			slack_output		
		7_cleanfuel	9_articles	9_rdex	9_lpi	7_co2twh	13_co2pc
Chile	0.97111	0	12.25	0.00	0.00	2.70	8.38
Panama	1	0	0.00	0.00	0.00	0.00	0.00
Brazil	0.89985	0	0.95	15.04	0.00	12.01	9.02
Mexico	1	0	0.00	0.00	0.00	0.00	0.00
Argentina	0.86972	0	1.95	1.25	3.88	1.67	0.00
Ecuador	1	0	0.00	0.00	0.00	0.00	0.00
Germany	1	0	0.00	0.00	0.00	0.00	0.00
Netherlands	1	0	0.00	0.00	0.00	0.00	0.00
Sweden	1	0	11.98	33.04	0.00	21.39	25.22
Austria	0.99797	0	0.00	13.14	0.00	3.56	10.48
UK	0.98251	0	8.20	0.00	0.00	4.61	29.22
Switzerland	0.98032	0	27.76	39.92	0.00	15.48	24.01
Emirates	1	0	0.00	0.00	0.00	0.00	0.00
Bahrain	1	0	0.00	0.00	0.00	0.00	0.00
Kuwait	1	0	0.00	0.00	0.00	0.00	0.00
Oman	1	0	0.00	0.00	0.00	0.00	0.00
Qatar	1	0	0.00	0.00	0.00	0.00	0.00
Arabia	1	0	0.00	0.00	0.00	0.00	0.00

Source: Authors' analysis of data from various sources

VI. Extended Model (RAM-DEA)

Since the model aims to minimise inputs, we selected oil consumption as the only input. In a similar way, the model maximises the good outputs and minimises the bad outputs. Following the same logic, the only good output chosen was the LPI. The rest of the outputs are related to CO_2, and therefore it is desirable to minimise them (bad outputs). To run the program and adapt the free library for R Programming, the bad outputs were introduced as inputs.

VII. Slack-inputs for Chile and Brazil

A. Chile-SDG 9 Articles

Chile experienced a continuous increase in research articles published between 1976 and 2015 according to Koch and Vanderstraeten (2018) as shown in the chart below by the same authors.

TABLE II. RAM-DEA ANALYSIS OF COUNTRIES IN THREE REGIONS: LATIN AMERICA, EUROPE, AND GCC

Country	Efficiencies	slacks input	slacks good output	slacks bad output		
		oil consumption / pop	sdg9_lpi	sdg7_co2twh	sdg11_pm25	sdg13_co2pc
Chile	0.9182	0	0.01374499	0.4172016	10.437927	1.685191
Panama	1.0000	0	0	0	0	0
Brazil	1.0000	0	0	0	0	0
Mexico	0.8893	0	0.00383475	0.7491509	9.789111	1.147607
Argentina	0.8818	0	0.24880736	0.7504053	1.396596	1.955532
Ecuador	0.8476	0.974588	0.51406246	0.8357081	2.750121	0
Germany	1.0000	0	0	0	0	0
Netherlands	0.8545	28.436985	0	0.6905334	2.444003	2.93779
Sweden	1.0000	0	0	0	0	0
Austria	0.8457	0	0.40368432	0.7976046	6.094739	2.205929
United Arab Emirates	0.5558	47.705637	0.389807	1.3621163	31.024	17.910526
Bahrain	0.5274	10.864393	1.05375	0.9105406	55.8	18.428576
Kuwait	0.3926	90.989133	0.934662	1.0848241	48.665	18.373526
Oman	0.5188	7.581091	1.209135	1.9300983	30.752	10.350959
Qatar	0.2129	72.034962	0.654609	1.8570852	71.874	39.752532
Saudi Arabia	0.3745	70.537221	0.75157	1.4805146	68.649	14.116663

Source: Authors' analysis of data from various sources

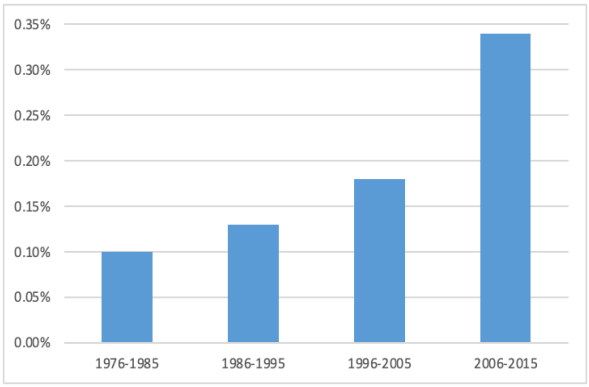

Figure 1. Percentage of total chilean articles
Note. Adapted from Koch and Vanderstraeten (2019)

This increase has not been fully leveraged to be reflected in the reduction neither on energy-related CO_2 emissions per capita nor renewable electricity output (percent of total electricity output) (tCO_2/capita). There are several potential explanations for that mismatch. As a starting point, assuming that research and correspondent publications in Chile have a strong focus on sustainability can be wrong. In fact, Adebayo *et al.* (2021) found that technological innovation is ineffective in reducing consumption-based carbon emissions, which implies that Chile's technological innovation is not directed toward manufacturing green technology. On the other hand, there could be other important factors incentivizing the reduction of CO_2 emissions such as taxation. In that regard, Chile introduced a tax reform on carbon dioxide (CO_2) emissions in 2017. The reform is restricted to large industrial and power generation sources with thermal power greater than 50 megawatts**.** According to Mardones and Flores (2022), a tax of US$5 per ton of CO_2 for industrial sources of more than 50 MW of thermal power is wholly ineffective in reducing emissions. In addition, according to Joo *et al.* (2014), Chile is dependent on carbon energy consumption for its rapid economic growth, causing considerable CO_2 emissions. This suggests that Chile should make more effort to develop energy-efficient technologies and renewable energy sources to achieve green growth based on lower CO_2 emissions.

B. Brazil–SDG 9 R&D Expense

Brazil has experienced a continuous increase in research expenses as percent of GDP between 2000 and 2018 as shown in the chart below based on Word Bank info.

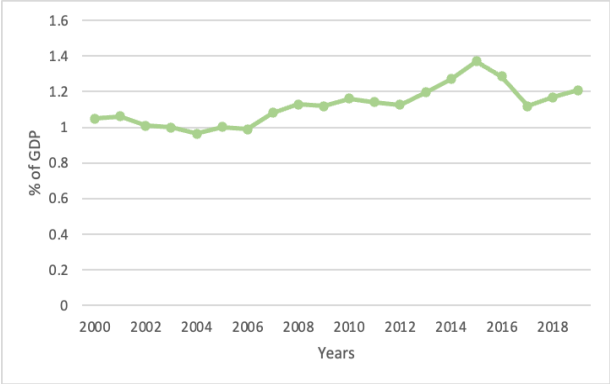

Figure 2. R&D Expenditure in Brazil as Percent of GDP
Note. Adapted from World Bank (2022)

This increase has not been fully leveraged to be reflected in the reduction neither on energy-related CO_2 emissions per capita nor renewable electricity output (percent of total electricity output) (tCO_2/capita). Ahmad and Raza, 2020 found that there is an inverse relation between Technology Innovation and CO_2 emission in the Brazilian case. In other words, the higher the technological Innovation the lower the CO_2 emission. This seems contradictory to our findings that despite R&D expenses having increased in Brazil, CO_2 emissions have not been reduced. It seems that R&D expense is not being used effectively to reduce CO_2 emissions.

VIII. SLACK-OUTPUTS FOR CHILE, BRAZIL, AND ARGENTINA

SDG 7: Renewable electricity output (percent of total electricity output)

According to the World Bank, the LPI in Argentina has reduced from 2.98 in 2007 to 2.89 in 2018. Even though the decrease can be perceived as marginal, LPI is expected to improve with time as countries invest in improving logistics performance. That is the reason why it appears as a positive slack output when compared with their peer-

efficient ultimate benchmark targets. In the last LPI report of 2018, Argentina has the lowest LPI score of 2.89 vs. its peers in this analysis: Brazil has 2.99 and Chile has 3.32 as the top country in this sample for LPI.

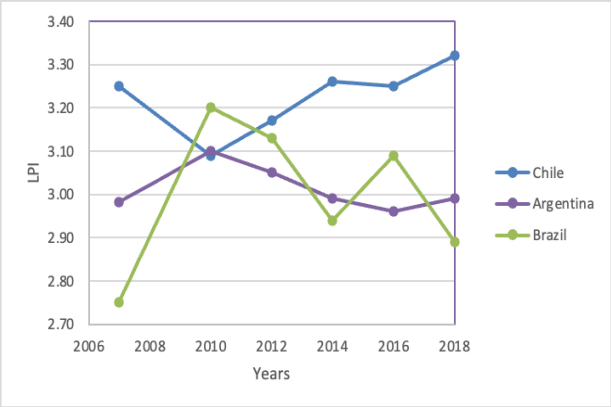

Figure 3. LPI of Chile, Argentina, and Brazil
Note. Adapted from World Bank (2018)

IX. Conclusion

In the Latin American countries in our study, significant progress has already been achieved during this era: access to electricity and biofuels. As for energy efficiency, the rate of improvement is very high. It can be considered a global role model in renewable energy. Despite significant progress, challenges continue. Most difficulties concern the dimension of multilateral cooperation. Although higher levels of access to electricity, connections to power resources remain slow, for example, in rural areas. With Mexico and Brazil among the top energy consumers globally, there is much room to scale up energy efficiency. From the perspective of sustainability practices, the obstacles in cooperation in Latin America should be pointed such as a growing weakening of international cooperation, caused by defensive policies in response to the negative impacts of globalisation, such as increasing social and economic differences resulting in protectionism. The bilateral cooperation between Argentina and Brazil in developing alternative sources of energy has set precedents for neighbour countries, for example. Latin America has mostly clean electricity compared to the rest of the world because of high levels of investment in hydropower resources. However, the share of renewable energy in total energy consumption is very low, caused by a lack of infrastructure for energy transportation. Progressive policies have helped shift electricity markets towards more renewables by focusing on improving incentives. However, transportation remains one of the sectors with considerable opportunities for improvement.

A common problem remains CO_2 emissions, especially those experienced by the larger economies of Brazil, Chile, and Argentina. Although investments in research and development are being made (Rdex–SDG 9), especially in Brazil, the effects of these investments have not yet fully materialised in the case of Brazil. Chile has also made significant progress in academic research of sustainability as evidenced by SDG 9, but, similar to Brazil, the effects are not yet matched by outputs. A similar scenario of academic research applies to Argentina.

In Brazil, oil and gas remain a symbol of national independence and their exploitation is seen as necessary for economic growth. On the other hand, a faster implementation of renewable sources could result from the existence of a legal framework related to climate change. It has aimed to reduce carbon dioxide emissions by using clean energy. It initially focused on the use of biomass, hydroelectric projects of small scale, and wind power. But the government imposed a variety of responsibilities on producers. For example, obtaining financing from the government requires that the wind initiative contains local parts in a high percentage. Also, the connections to the transmission network and the civil engineering expenses for wind energy are the responsibility of the producers. Brazil has experienced a continuous increase in research expenses. This increase has not been fully leveraged to be reflected in the reduction neither on energy-related CO_2 emissions per capita nor renewable electricity output. It is supposed that the higher the technological innovation, the lower the CO_2 emission. This seems contradictory to the findings that despite R&D expenses having increased in Brazil, CO_2 emissions have not been reduced. It seems that R&D expense is not being used effectively to reduce CO_2 emissions. The LPI in Argentina has reduced over the last 15 years. Even though the decrease can be perceived as marginal, LPI is expected to improve with time as countries invest in improving logistics performance. Argentina has a lower LPI score compared with Brazil and Chile. That is the reason why it appears as a positive slack output when compared with their peer-efficient ultimate benchmark targets. Also, Argentina has very favourable natural conditions for renewable energy, but the economic policies implemented during the last decade and the restrictions on access to foreign currency, have been the main factors that have decreased investment in renewable energies. On the other hand, Chile experienced a continuous increase in research articles published between 1976 and 2015. This increase has not been fully leveraged to be reflected in the reduction neither on energy-related CO_2 emissions per capita or renewable electricity output. There are several potential explanations for that mismatch. As a starting point, assuming that research and correspondent publications in Chile have a strong focus on sustainability can be incorrect. On the other hand, there could be other important factors incentivizing the reduction of CO_2 emissions such as taxation. In that regard, Chile introduced a tax reform on carbon dioxide (CO_2) emissions. A tax per ton of CO_2 is wholly ineffective in reducing emissions. In addition, Chile is dependent on carbon energy consumption for its rapid economic growth, causing considerable CO_2 emissions. This suggests that Chile should make more effort to develop energy-efficient technologies and renewable energy sources to achieve green growth based on lower CO_2 emissions.

Conflict of Interest

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

José Guadalupe Octavio Cabrera Lazarini contributed research on the energy policies and bilateral cooperation in renewable energies between Brazil and Argentina as well as writing; Alexander Wollenberg was involved in establishing the research methodology, significance of the research, and writing; Juan José Cabrera Lazarini contributed to the country analyses of Brazil, Argentina, and Chile with qualitative and empirical data as well as providing research guidance and direction; Gizela Nicol Olivares Rodríguez contributed to the collection of data, empirical analysis, and writing; Ameya Sathya Kakade contributed to data collection and analysis; all authors had approved the final version.

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