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MEXICO CAPSTONE 2023

BIOMASS ENERGY VALORIZATION IN MEXICO: AN INDUSTRIAL AND RURAL DEVELOPMENT SOLUTION

2023

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TABLE OF CONTENTS

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LIST OF ACRONYMS

BANOBRAS	National Bank of Public Works and Services
BBVA	Banco Bilbao Vizcaya Argentaria
CBPAR	Community-Based Participatory Action Research
CEL	Certificados de Energías Limpias (Clean Energy Certificates)
CFE	Community Forestry Enterprises
CONAPO	Consejo Nacional de Población (National Population Council)
DFC	Development Finance Corporation
EJ	Environmental Justice
EPA	United States Environmental Protection Agency
ESG	Environmental Social Governance
FIRA	Trust Funds for Agricultural Development
GDP	Gross Domestic Product
GEAPP	Rockefeller Foundation's Global Energy Alliance for People and the Planet
GEF	Global Environment Facility
GHG	Greenhouse gas
HLB Disease	Huanglongbing (HLB), also known as citrus greening, is the most serious disease of citrus.
IEA	International Energy Agency
IENEVO	Mexican energy developer, for constructing solar power assets in Mexico

LIST OF ACRONYMS

IMF	International Monetary Fund
IMP	Mexican Petroleum Institute
INECC	Instituto Nacional de Ecología y Cambio Climático
INEEL	Instituto Nacional de Electricidad y Energías Limpias
INEM	Inventario Nacional de Emisiones de Contaminantes
INIFAP	Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias
IPCC	Intergovernmental Panel on Climate Change
LIE	Ley de la Industria Eléctrica (Energy Industry Law)
Mt DM/yr	Megatons of dry matter per year
MW	Megawatt
NADB	North American Development Bank
NAFIN	Nacional Financiera
NDC	Nationally Determined Contributions (under the Paris Agreement)
NOMs	Normas Oficiales Mexicanas (Official Mexican Standards)
OECD	Organisation for Economic Co-operation and Development
PEMEX	Mexican Petroleum
PJ/year	Petajoul per year
SADER	Secretariat of Agriculture and Rural Development

LIST OF ACRONYMS

SAGARPA	Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food
SECON	Secretariat of Economy
SEDATU	Secretariat for Agrarian, Land and Urban Development
SEMARNAT	Ministry of Environment and Natural Resources
SENER	Secretariat of Energy
SHCP	Secretariat of Tax Collection and Administration
SHCP	Intergovernmental Panel on Climate Change
SHF	Sociedad Hipotecaria Federal
SINAICA	Sistema Nacional de Información de la Calidad del Aire
UNAM	Universidad Nacional Autónoma de México
UNECOFAE	Unión de Ejidos y Comunidades de Producción Forestal y Agropecuaria 'Gral. Emiliano Zapata' de la región noroeste del estado de Durango
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USMCA	United States-Mexico-Canada Agreement, a trade agreement between the named parties that entered into force on July 1, 2020.

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Abstract

The Mexican Petroleum Institute is currently researching the feasibility of biomass energy from agro-industrial waste to power industrial processes. Consultants from Columbia School of International and Public Affairs and the Columbia Law School investigated the use of forestry waste and agricultural waste – including sugarcane and citrus byproducts – as feedstocks for biomass energy paying special attention to social and environmental implications of such processes. Following a supply chain analysis of these solid biofuels, policy, legal, and financial recommendations are made to provide a roadmap for the valorization of biomass energy within Mexico.

Objective

This report will recommend ways to expand biomass production in Mexico by analyzing the opportunities and risks of this alternative energy source. Following an analysis of agricultural and forestry waste biomass supply chains, this Report will provide recommendations on implementing biomass development at the community and industrial scale taking into account the impacts on public health, environmental sustainability, gender equity, human rights, and Mexico's laws and regulations.

EXECUTIVE SUMMARY

Like many countries whose main source of wealth relies on fossil fuels, Mexico faces a critical challenge in crafting a sustainable path to incorporate low-carbon sources of energy into the country's sovereign energy portfolio. By scaling up renewable energy efforts, investing in electric vehicles, and improving energy efficiency to support this transition from linear to circular economy, Mexico can support a transition towards a net zero economy. This Report explains that, in addition to the aforementioned investments, biomass can play a significant role in Mexico's energy transition. In particular, biomass energy from agro-industrial waste can be used in industrial production processes and for rural energy development. However, implementing such projects will require a shift in the country's existing operational, legal, financial, and community-based collaboration approaches.

This report comprises seven main topics:

1. **Opportunities of Biomass Development:** This section details the rationale on why Mexico should continue to incorporate alternative forms of energy into its energy portfolio, drawing special attention to the impacts of climate change and lack of energy access.
2. **Biomass for Agricultural Industry:** This section outlines the feasibility of utilizing industrial agriculture byproducts –

including sugarcane bagasse and citrus peels– as biomass energy feedstock for agro-industrial energy consumption. It recommends policies for addressing the social, environmental and economic implications of biomass production within the citrus and sugarcane supply chains.

3. **Biomass for Forestry Industry:** This section will provide a landscape analysis of Mexico's forestry sector and identify targeted regions where there is the significant potential for biomass energy valorization. It will further provide an analysis of the environmental, social, and economic considerations that need to be taken into account for development.
4. **Rural and Community Development:** This section outlines the feasibility of utilizing biomass energy for rural development. It provides recommendations on using local biomass waste as a relatively low-cost input in microgrids and distributed energy sources to increase energy access in rural communities.
5. **Implementation.** In order to foster biomass production in Mexico, the country should build capacity in four key areas: operational, legal, financial, and community collaboration. This section provides policy recommendations to support capacity building within each area.
6. **Consolidated Recommendations:** This section contains a chart outlining the policy and legal recommendations presented throughout the report, including short-, medium-, and long-term recommendations.
7. **Conclusion**

With support from the federal government, as well as the industrial, agricultural and livestock sectors that are also involved in the generation of energy from biomass, feedstock as an energy input can aid Mexico in its efforts to reach net-zero emissions and ensure that all residents have access to reliable energy sources.

INTRODUCTION

Mexico is one of the largest exporters of petroleum products in the world.[1] However, as scientists increasingly draw attention to the dangers and risks of climate change,

countries are embarking on a parallel fight to decarbonize the economy, by transitioning away from fossil fuels, such as oil and gas, towards cleaner forms of energy. Biomass from agro-industrial waste is an abundant low-carbon energy source that can be useful for Mexico's forestry and agriculture sectors as well as for the purpose of rural development. Expansion of biomass energy production can

[1] International Trade Administration: "Mexico - Oil and Gas." https://www.trade.gov/country-commercial-guides/mexico-oil-and-gas

further enhance Mexico's energy sovereignty, strengthen its resilience to the global transition away from fossil fuels, and expand its clean energy portfolio.

Climate change and the need to decarbonize

The world faces immense and complex challenges on climate change. UN Secretary-General António Guterres highlighted during the 27th Conference of the Parties (COP27) to the United Nations Framework Convention on Climate Change (UNFCCC) that the world remains off track to reach the goals of the Paris Climate Agreement, and that accelerating the renewable energy transition is "essential to keep the 1.5 degree limit within reach."[2] The Paris Agreement, a multilateral treaty under the UNFCCC, aims to limit the increase of the global average temperature to well below 2°C, preferably to 1.5°C, above pre-industrial levels. Mexico, as a party to the Paris Agreement, has an obligation to peak its own greenhouse gas (GHG) emissions as soon as possible and begin reducing its emissions.[3] As such, Mexico is looking forward to transitioning to cleaner energy sources such as biomass energy.

"Mexico is looking forward to transitioning to cleaner energy sources, such as biomass."

The Intergovernmental Panel on Climate Change (IPCC) AR6 Synthesis Report: Climate Change 2023 concluded that human activities, principally through GHG emissions from industrial and commercial use, have "unequivocally caused global

[2] United Nations, "Statement by the Secretary-General at the Conclusion of COP27 in Sharm el-Sheikh," statement, November 19, 2022.

[3] "Paris Agreement." Conclusion date: December 12, 2015. United Nations Treaty Series Online, registration no. I-54113, https://unfccc.int/sites/default/files/english_paris_agreement.pdf, art. 4(1).

warming,"[4] with global surface temperature reaching 1.1°C above 1850–1900 temperatures in 2020.[5] Climate change is already affecting weather and climate events in every region across the globe, with rapid changes in the atmosphere, ocean, cryosphere and biosphere, and widespread losses and damages to nature and people.

Keeping global warming to 1.5°C to 2°C requires achieving net zero CO_2 emissions, meaning, the amount of CO_2 emitted must be less than or equal to the amount sequestered in Earth's systems.[6] Projected CO_2 emissions from existing fossil fuel infrastructure alone without additional abatement would far exceed the remaining carbon budget for 1.5°C.[7] To reach net zero emissions requires rapidly decarbonizing the world's economies and supply chains. Figure 1 shows the key milestones required to reach net zero, namely, by rapidly decreasing the amount of fossil fuels – coal, and petroleum-based fuel sources – and rapidly increasing the amount of alternative energy sources used – including solar, wind, hydropower, and biomass energy.

[4] IPCC, AR6 Synthesis Report: Climate Change 2023, "Summary for Policymakers," 4, https://www.ipcc.ch/report/sixth-assessment-report-cycle/, accessed April, 2023.

[5] IPCC, AR6 Synthesis Report: Climate Change 2023, "Summary for Policymakers," 4, https://www.ipcc.ch/report/sixth-assessment-report-cycle/, accessed April, 2023.

[6] IPCC, AR6 Synthesis Report: Climate Change 2023, "Summary for Policymakers," 20, https://www.ipcc.ch/report/sixth-assessment-report-cycle/, accessed April, 2023.

[7] Ibid.

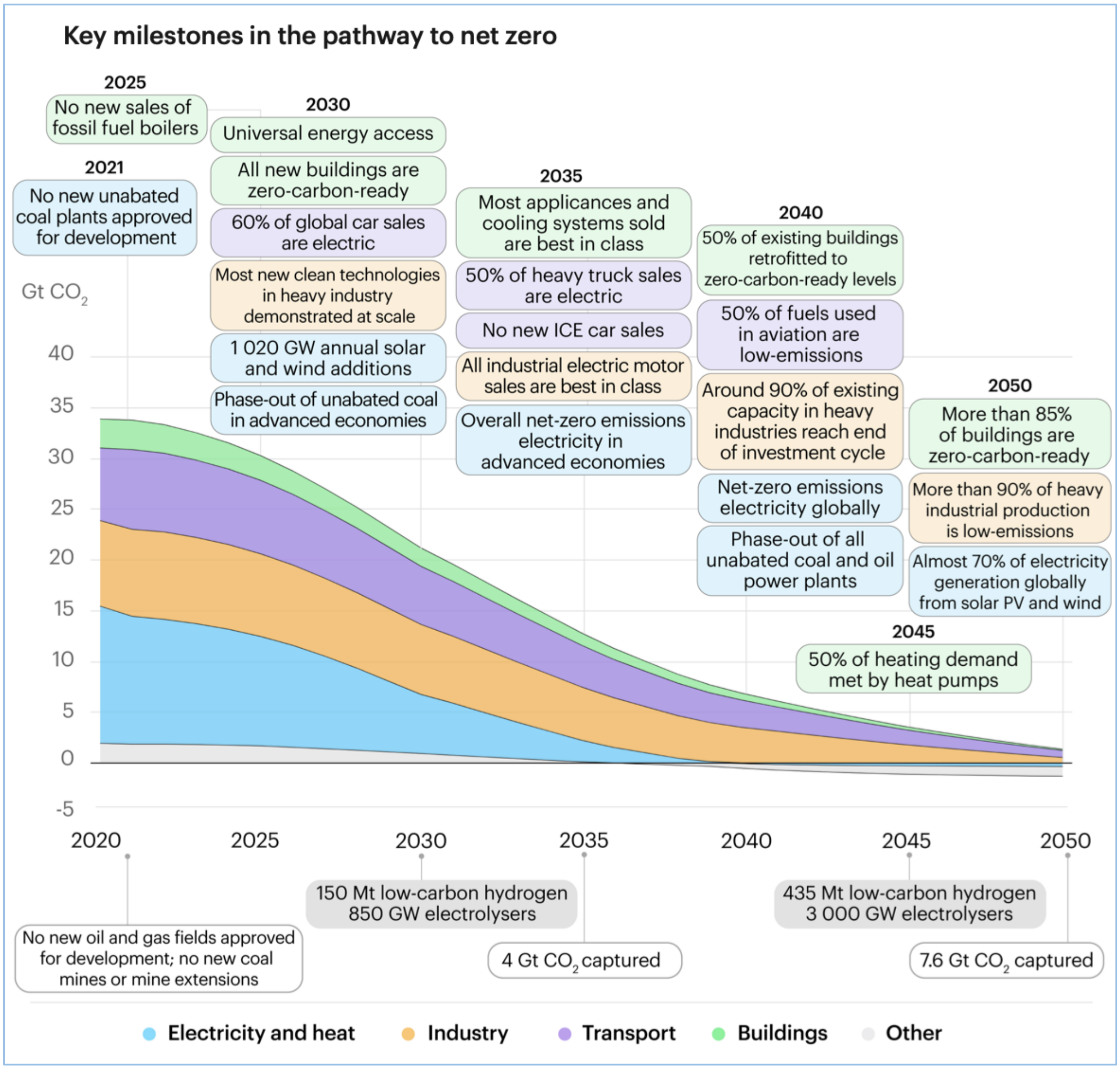

Figure 1: Key milestones in the pathway to net zero. Source: IEA Net Zero by 2050 Roadmap.

Climate change has reduced food security and negatively affected water security globally, hindering efforts to meet the Sustainable Development Goals as outlined in the 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015.[8] As Mexico's economy relies heavily on agriculture, and because a significant number of Mexicans face issues of food insecurity, the country

[8] United Nations, Department of Economic and Social Affairs, Sustainable Development. "The 17 Goals". https://sdgs.un.org/goals. Accessed April 2023.

has a vested interest in reaching global net zero emissions by 2060.[9] Further, climate change disproportionately impacts those who have contributed to the problem the least - dramatically affecting the lives of the poorest and most marginalized communities.

Currently, Mexico is one of the largest oil producers in the world, producing 1.9 million barrels daily in 2021.[10] Earnings from oil and gas accounted for 16 percent of total government revenues in 2021, making it a staple in the country's GDP.[11] Furthermore, Mexico's government-owned petroleum company, PEMEX, exerts disproportionate[12] market power over Mexico's energy infrastructure. The Mexico Secretariat of Energy is aware of the need to integrate alternative energy sources into its energy portfolio and has identified biomass as a potential alternative. Estimates suggest biomass could account for roughly 10 percent of Mexico's renewable energy portfolio, particularly for agro-industrial facilities and rural communities.[13]

Mexico's Nationally Determined Contribution (NDC) under the Paris Agreement identifies biomass energy as a decarbonization strategy to implement in 50% of the most vulnerable municipalities, particularly those with large development deficiencies.[14] The use of biomass for energy production in different nations has been motivated by different drivers which include lowering fossil-fuel dependency,

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[9] United Nations Convention on Climate Change, Mexico: Updated NDC 2022 https://unfccc.int/documents/624282. Accessed April 2023.

[10] International Trade Administration. "Mexico – Oil and Gas." https://www.trade.gov/country-commercial-guides/mexico-oil-and-gas

[11] International Trade Administration. "Mexico – Oil and Gas." https://www.trade.gov/country-commercial-guides/mexico-oil-and-gas

[12] PEMEX was the only company allowed to source or produce oil and gas until the 2013 constitutional reform.Reuters, "Mexico's Proven Oil and Gas Reserves Tick up Nearly 2%," *Reuters*, May 2, 2023, sec. Commodities, https://www.reuters.com/markets/commodities/mexicos-proven-oil-gas-reserves-tick-up-nearly-2-2023-05-02/.

[13] Gibrán S. Alemán-Nava et al., "Renewable Energy Research Progress in Mexico: A Review," *Renewable and Sustainable Energy Reviews* 32 (April 1, 2014): 140–53, https://doi.org/10.1016/j.rser.2014.01.004.

[14] SEMARNAT. (2022). Contribución Determinada a nivel Nacional: México. Actualización 2022. https://unfccc.int/sites/default/files/NDC/2022-11/Mexico_NDC_UNFCCC_update2022_FINAL.pdf. Accessed April 2023.

increasing energy security, decreasing greenhouse gas emissions, and embracing economic development and agricultural development.[15]

Biomass Energy's Role in the Energy Transition

Bioenergy is the largest source of renewable energy globally, accounting for 55% of renewable energy and over 6% of global energy supply.[16] The IEA's Global Net Zero Emissions by 2050 Scenario sees a rapid increase in the use of bioenergy to displace fossil fuels by 2030. Use of modern bioenergy has increased on average by about 7% per year between 2010 and 2021, and is on an upward trend.[17] More efforts are needed to accelerate modern bioenergy deployment to get on track with the Net Zero Scenario, which sees deployment increase by 10% per year between 2021 and 2030, while simultaneously ensuring that bioenergy production does not incur negative social and environmental consequences.[18]

Biomass Energy Overview

The scope of this paper is limited to solid biomass inputs for purposes of industrial and rural development use. This report does not include the use of liquid biofuels – such as ethanol or palm oil – in our analysis. Inputs for liquid biofuels compete directly with the Mexican food supply, so they are not recommended as feedstock for biofuel production.

While there are many sources of biomass energy, there are two major ways to harness biomass energy to generate electricity: burning and decomposition. Depending on what type of biomass is used, the organic waste is either burned to produce heat or decomposed to produce methane gas, which is then burned to produce heat. Heat – biomass energy – is used to boil water, which turns into steam. The steam spins a turbine, powering a generator and creating electricity that we can

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[15] Mendes Souza, G., Victoria, R.L., Joly, C.A., Verdade, L.M., 2015. Bioenergy and Sustainability: Bridging the Gaps. Scientific Committee on Problems of the Environment (SCOPE). Áttema Editorial, São Paulo, Brasil.

[16] International Energy Agency. "Bioenergy: Energy Systems Overview." https://www.iea.org/reports/bioenergy. Accessed April 2023.

[17] Ibid.

[18] Ibid.

use to power our lives.

Types of biomass energy

Biomass can be divided into two subcategories – solid biomass and liquid/gas biomass.

Solid biomass is anything organic that has not yet broken down into a gas or a liquid. There are many kinds of solid biomass. Biomass sources for energy include:[19]

- Wood and wood processing wastes—firewood, wood pellets, and wood chips, lumber and furniture mill sawdust and waste, and black liquor from pulp and paper mills
- Agricultural crops and waste materials—corn, soybeans, sugar cane, switchgrass, woody plants, and algae, and crop and food processing residues, mostly to produce biofuels
- Biogenic materials in municipal solid waste—paper, cotton, and wool products, and food, yard, and wood wastes
- Animal manure and human sewage for producing biogas/renewable natural gas

[19] US Energy Information Administration. "Biomass Explained" https://www.eia.gov/energyexplained/biomass/

Figure 2: Pellets from Sawmill Production Waste in Durango Mexico. Photo by Myriam Amezcua

Solid biomass can be turned into pellets, which can then be used as an energy input (Figure 2).

Both liquid and gas fuels can be produced from solid biomass. Biogas can be produced from solid biomass under controlled heating conditions through a process called gasification. This gas can then be used to produce liquid biofuel. Residues and wastes are primarily used for heat and power generation, while sugar, starch and oil crops are primarily used for fuel production.[20]

Benefits of Biomass Energy

Biomass power plants are often used to supply baseload power because their energy supply is predictable and steady, similar to petroleum inputs, unlike solar and wind inputs, which are less consistent. Use of orchard and forest trimmings along with other agricultural waste for biomass can reduce waste disposal and landfill costs. Additionally, this can help promote a more circular economy to reuse waste as a resource, which limits environmental and social impacts of landfills. Gasses produced from decomposing organic material in landfills are pollutants and, if highly concentrated, can be toxic, which poses a risk to surrounding communities. Additionally, as waste in landfills breaks down, significant amounts of potent greenhouse gases, methane and carbon dioxide, are emitted into the atmosphere. By expanding biomass energy, Mexico can limit national greenhouse gas emissions and further their climate goals.

[20] IEA Energy Technology Essentials. "Biomass for Power Generation and CHP". https://iea.blob.core.windows.net/assets/1028bee0-2da1-4d68-8b0a-9e5e03e93690/essentials3.pdf

In the short term, co-firing remains the most cost-effective use of biomass for power generation, along with small-scale, off-grid use.[21] At present, biomass co-firing in modern coal power plants with efficiencies up to 45% is the most cost-effective biomass use for power generation.[22]

However, projections show a need for increased scale-up of biomass energy with a scale-down of coal-fired generation in the long term. International Energy Agency (IEA) projections suggest that the biomass share in electricity production may increase from the current 1.3% to some 3%-5% by 2050[23]. This is a small contribution compared to the estimated total biomass potential (10%-20% of primary energy supply by 2050), but biomass is also used for heat generation and to produce fuels for transport. Due to the abundance of agro-industrial waste in rural regions of Mexico, biomass energy produced from this waste can be a viable option for rural energy development. Having the residues in close proximity reduces transportation costs. Additionally, considering agro-industrial waste is produced within the country, there is less reliance on foreign energy sources, which can strengthen Mexico's energy sovereignty.

Potential Risks and Drawbacks

One risk in using biomass is the potential emissions, since anything that is burned emits carbon dioxide into the atmosphere. The main concern surrounding biomass, however, has to do with the risk of unsustainable bioenergy production. Bioenergy comes from a variety of different sources. Some bioenergy sources – such as black liquor from paper production – are the by-product of an industrial process that would have taken place anyway. More commonly, though, bioenergy is sourced from purpose-grown crops or trees in a highly land-intensive process relative to other forms of energy. Unsustainable bioenergy production can have social consequences – such as impacts on food prices and competition for land use – as well as negative environmental externalities such as worsened biodiversity and net increases in

[21] IEA Energy Technology Essentials. "Biomass for Power Generation and CHP". https://iea.blob.core.windows.net/assets/1028bee0-2da1-4d68-8b0a-9e5e03e93690/essentials3.pdf

[22] IEA Energy Technology Essentials. "Biomass for Power Generation and CHP". https://iea.blob.core.windows.net/assets/1028bee0-2da1-4d68-8b0a-9e5e03e93690/essentials3.pdf

[23] International Energy Agency. "Energy Technology Perspectives 2006". https://www.iea.org/reports/energy-technology-perspectives-2006

greenhouse emissions. Biomass is only a renewable resource if the materials are harvested faster than crops or forests can be naturally regenerated.

Meeting the Net Zero Scenario will require bioenergy production to increase, but care must be taken to ensure that doing so does not result in significant negative effects for society or the environment. In accordance with these sustainability considerations, the International Energy Agency's global Net Zero Emissions Scenario requires that there is no expansion of cropland for bioenergy nor conversion of existing forested land into bioenergy crop production. This ensures that biomass use will not cause significant social or environmental externalities. Under this Net Zero Emissions Scenario, by 2030, 60% of bioenergy supply should come from waste and residues that do not require additional land use.[24]

Mexico's Biomass Landscape

As an effort to valorize biomass, and consistent with the Paris Agreement's objective, the Government of Mexico enacted the Promotion and Development of Bioenergetics Law (the "Bioenergetics Law") which was aimed at promoting and developing biomass and contributing to energy diversification and sustainable development.[25] In principle, the Bioenergetics Law aims to:

- Promote the production of inputs for bioenergy from agricultural, forestry, and algae activities, without jeopardizing food security
- Develop the production, commercialization, and efficient use of bioenergy to reactivate agriculture, generating employment and improving the quality of life of the vulnerable population
- Coordinate actions between the federal, state, and local governments, and with the social and business sectors
- Contribute to the reduction of greenhouse gas

[24] International Energy Agency. "Bioenergy". https://www.iea.org/fuels-and-technologies/bioenergy

[25] The Bioenergy Law narrowly defines "bioenergy" as fuels generated by biomass from organic matter of activities, agricultural, livestock, forestry, aquaculture, alga-culture, fisheries residues, domestic, commercial, industrial, microorganisms, and enzymes, as well as their derivatives, produced, by sustainable technological processes that comply with the specifications and quality standards set out by the authorized governmental institutions within the meaning of the Bioenergy Law, without jeopardizing the food security and sovereignty of the country in accordance with the provisions of articles 178 and 179 of the Sustainable Rural Development Law. It appears that the Government of Mexico expects more on bioenergy in the form of biofuel given Mexico is highly dependent on oil.

The Government of Mexico includes the use of biomass for energy production in the Program for Sustainable Production of Bioenergy Inputs and Scientific and Technological Development[26]. Residues, which do not compete with food or feed supplies, either from harvesting or from the processing of agriculture crops and timber, firewood and charcoal are also seen as feedstocks for heat and power generation that can be used independently or in an integrated biorefinery system.[27]

Biomass Energy and Mexico's Energy Transition

Mexico's bioenergy generation capacity has more than doubled in the past decade, from approximately 400 megawatts in 2010 to over 1,100 megawatts in 2018 as shown in Figure 3.[28] In the following years, the country's bioenergy capacity slightly decreased, adding up to 1,064 megawatts in 2021. That year, Mexico accounted for almost five percent of Latin America's bioenergy capacity.[29]

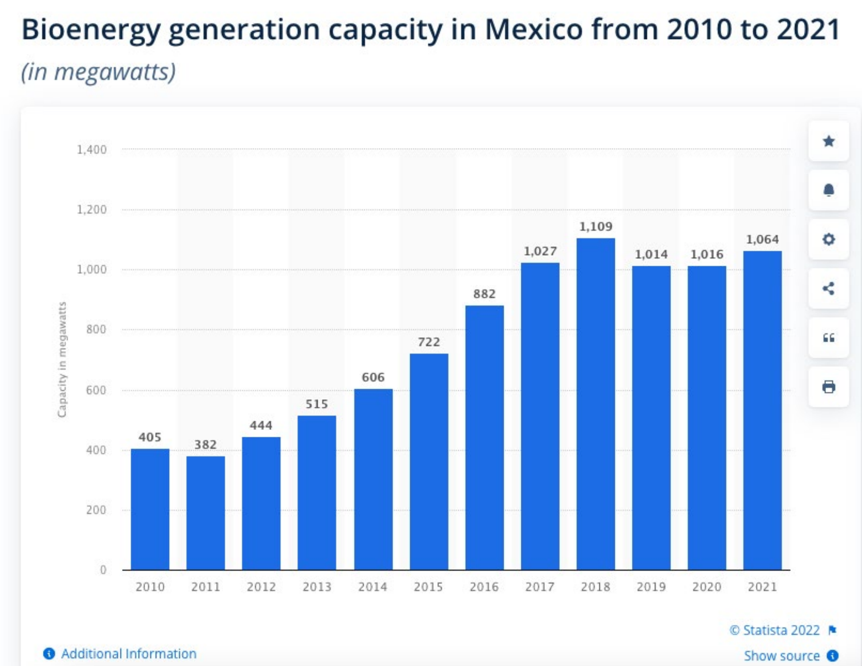


Figure 3: Source: Statista, "Bioenergy capacity in Latin America and the Caribbean from 2010 to 2022"

[26] Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA), 2009. Programa de Producción Sustentable de Insumos para Bioenergéticos y de Desarrollo Científico y Tecnológico. SAGARPA, México, 38 p.

[27] J. Amador Honorato-Salazar, Jhuma Sadhukhan. (2020. Annual biomass variation of agriculture crops and forestry residues, and seasonality of crop residues for energy production in Mexico.

[28] Statista. "Bioenergy capacity in Latin America and the Caribbean from 2010 to 2021" https://www.statista.com/statistics/665626/bioenergy-capacity-latin-america-caribbean/

[29] Ibid.

In Mexico, biomass energy produced from agro-industrial residues has the potential to expand opportunities for both industrial and rural development. Initially, waste byproducts produced within agricultural and forestry supply chains can be used as a fuel source for their corresponding processing facilities, thereby reducing industrial facility emissions and costs. Additionally, residues from these facilities and other agricultural operations can be used as a fuel source for rural communities through decentralized grid systems, thereby improving access to energy in rural regions of the country that do not have infrastructure connecting to the national grid. Although biomass energy will not make up a significant portion of Mexico's overall energy portfolio, it has the potential to be a significant source of energy to rural industries and communities alike, which can address critical economic, social, and environmental issues that will be explored further in the following sections.

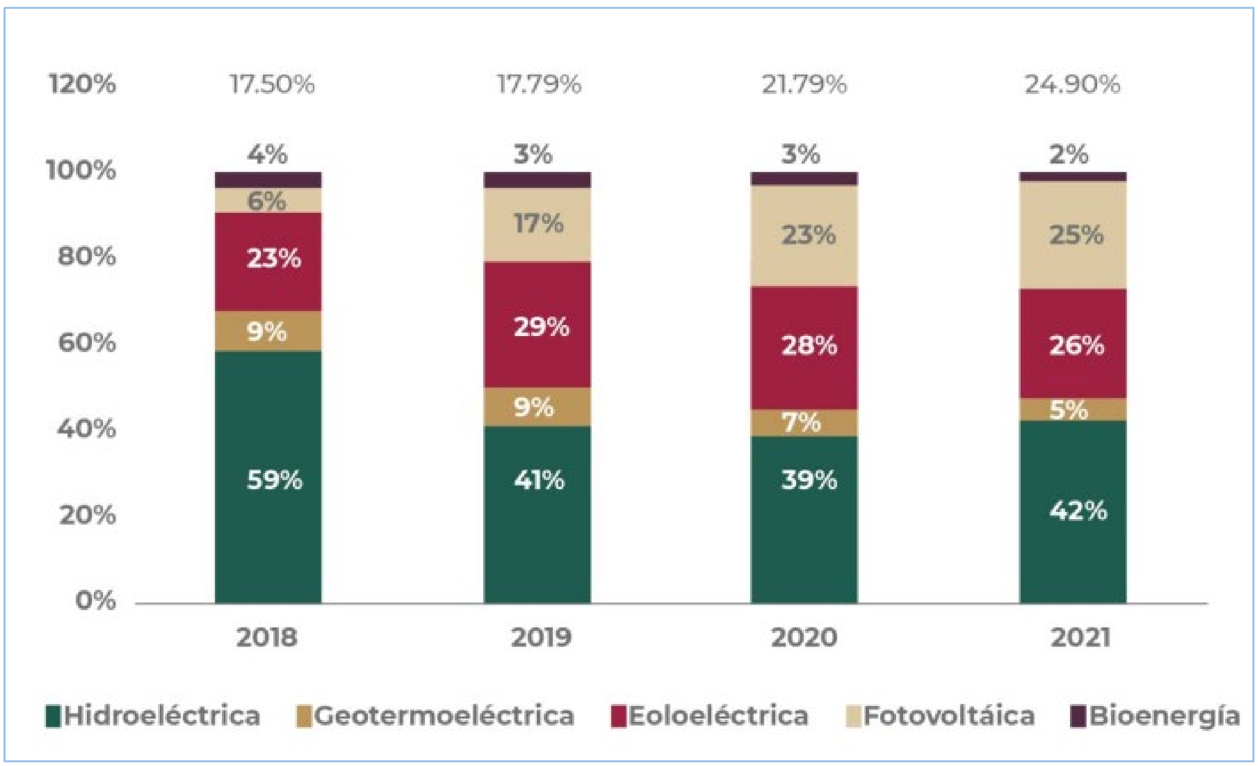
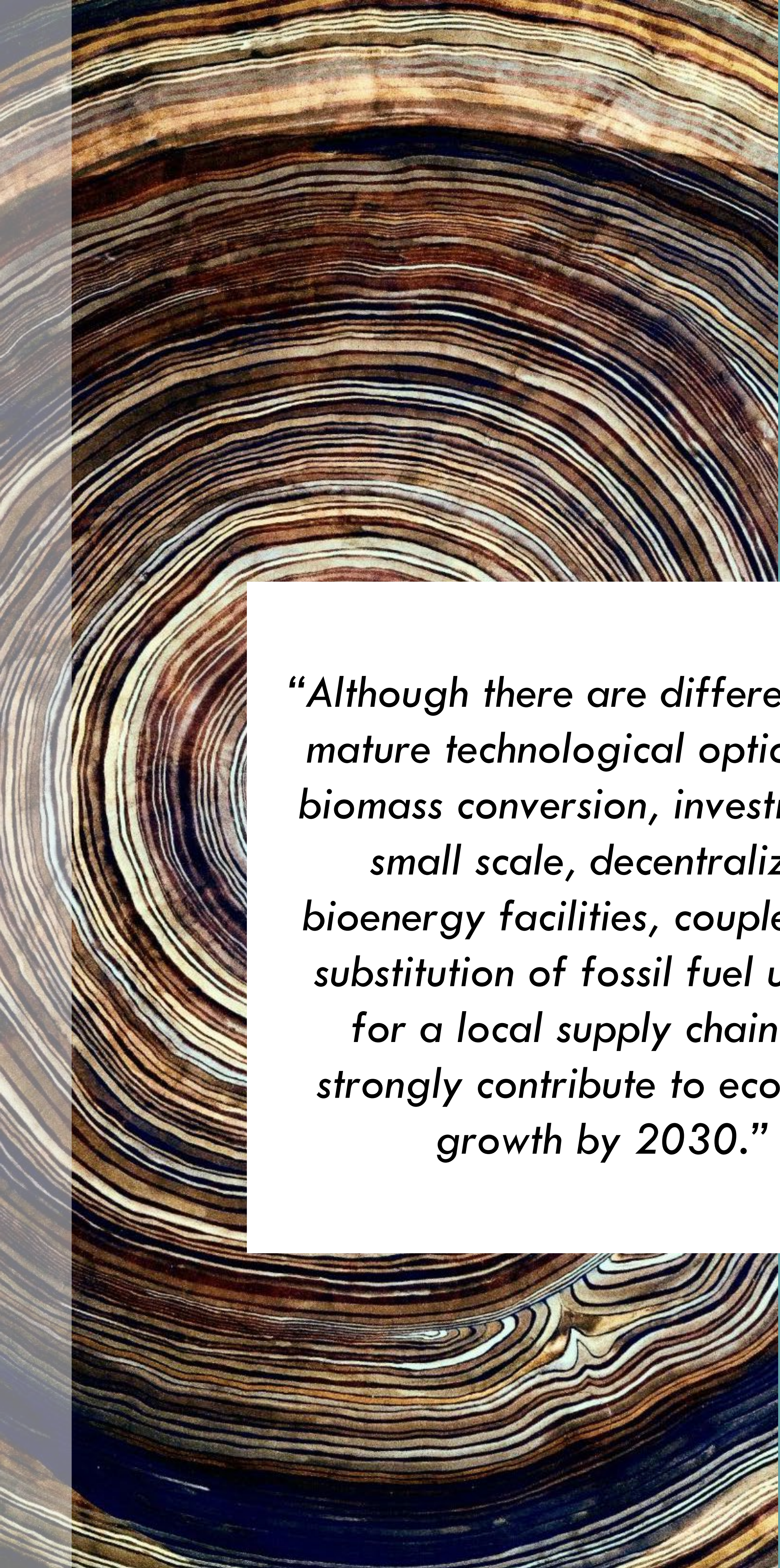


Figure 4: Evolution of renewable energy in Mexico. Source: Podesen 2022-2036.

Now, Mexican policymakers are faced with decisions regarding the energy transition. Mexico should consider the use of biomass as one of the main ways to obtain energy, in addition to hydroelectric, solar, and wind energy. Although there are different and mature technological options for biomass conversion, investment in small scale, decentralized bioenergy facilities, coupled with substitution of fossil fuel use, fit for a local supply chain will strongly contribute to economic growth by 2030.[30]

[30] "The Role of Biomass Supply Chains for Bioenergy in the Post-COVID-19 Economy | Bioenergy," accessed April 20, 2023, https://www.ieabioenergy.com/blog/publications/the-role-of-biomass-supply-chains-for-bioenergy-in-the-post-covid-19-economy/.https://www.ieabioenergy.com/blog/publications/the-role-of-biomass-supply-chains-for-bioenergy-in-the-post-covid-19-economy/"The Role of Biomass Supply Chains for Bioenergy in the Post-COVID-19 Economy | Bioenergy."



"Although there are different and mature technological options for biomass conversion, investment in small scale, decentralized bioenergy facilities, coupled with substitution of fossil fuel use, fit for a local supply chain will strongly contribute to economic growth by 2030."

PART I: BIOMASS FOR ENERGY CONSUMPTION

Introduction

The process of generating energy from biomass waste has been described in prior sections of this report. The purpose of this section is to articulate the specific processes of sector-specific biomass energy within the Mexican context. This section begins with a description of agricultural byproducts that have been identified as potential biomass sources (specifically, citrus peels and sugarcane bagasse) and then discusses the feasibility of forestry residues. Agriculture and forestry are lucrative industries for Mexico. Agriculture employs over 12% of the working population[31], and

[31] The World Bank. n.d. "Employment in agriculture (% of total employment)." World Bank Data. Accessed April 4, 2023. https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=MX.

both industries together add nearly $50 billion to Mexico's annual GDP.[32] Additionally, Mexico has almost 2 million square kilometers of land area, of which, one half is utilized for agriculture sectors, and about 10% is used specifically for crop production.[33] Both agricultural and forestry residues are ubiquitous in Mexico and have the opportunity for scalability within the country as concluded in an analysis of literature and interviews with government agencies, research institutions, and relevant stakeholders.

Agriculture

Critically, Mexico's agriculture industry generates about 28 million tons of solid residue annually.[34] As an abundant resource, agro-industrial waste is underutilized as much of the residue is inappropriately managed and only a small amount is used for animal feed or other purposes.[35] As such, many of these residues have significant potential as inputs for biomass energy generation in combined heat and power systems to supply agro-industrial processing facilities with electricity. These industrial energy systems can enhance the energy security of these facilities, reduce electricity costs, and mitigate environmental and social concerns.[36]

Mexico produces many crops including grains such as corn and wheat, tropical fruits such as citrus and cacao, a variety of vegetables, agave, and sugarcane. According to a study by Honorato-Salazar and Sadhukhan, there are approximately 88 megatons of dry matter per year (Mt DM/yr) of crop residues generated in Mexico, of which

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[32] The World Bank. n.d. "Agriculture, forestry, and fishing, value added (current US$)." World Bank Data. Accessed April 4, 2023. https://data.worldbank.org/indicator/NV.AGR.TOTL.CD?locations=MX.

[33] AgriFarming. 2021. "Farming In Mexico, Crops, Livestock, FAQs." Agri Farming. https://www.agrifarming.in/farming-in-mexico-crops-livestock-faqs.

[34] Amezcua-Allieri, Myriam A., Jorge Aburto, and Elias Martinez-Hernandez. 2021. "Assessing the Cost of Biomass and Bioenergy Production in Agroindustrial Processes." Energies 14, no. 14 (July). https://doi.org/10.3390/en14144181.

[35] Carrillo-Parra, A., Rutiaga-Quiñones, J.G., Ríos-Saucedo, J.C. et al. Quality of Pellet Made from Agricultural and Forestry Waste in Mexico. Bioenerg. Res. 15, 977–986 (2022). https://doi.org/10.1007/s12155-021-10327-8

[36] Manzini Poli, Fabio L., Jorge M. Islas-Samperio, Carlos A. García Bustamante, Julio C. Sacramento Rivero, Genice K. Grande-Acosta, Rosa M. Gallardo-Álvarez, Ricardo Musule Lagunes, Freddy Navarro Pineda, and Christian Alvarez Escobedo. 2022. "Sustainability Assessment of Solid Biofuels from Agro-Industrial Residues Case of Sugarcane Bagasse in a Mexican Sugar Mill" Sustainability 14, no. 3: 1711. https://doi.org/10.3390/su14031711

about 38 (Mt DM/yr) are available for energy feedstock production.[37] Nearly all of the available dry material is sourced from five main crops: maize (43.3%), sorghum (25.5%) and sugarcane (18.1%), followed by wheat (6.3%), barley (1.6%) and beans (1.0%).[38]

Sugarcane bagasse has been identified as the main agricultural crop that can be used for industrial biomass energy production due to its overall abundance and scalability. Although the Mexican sugar industry is the second-largest agricultural industry in the country, accounting for 0.5% of the national GDP and 2.5% of the gross manufacturing, the industry's growth has been largely stagnant. Currently, about a quarter of the sugarcane is converted into bagasse, which generates energy for the milling process. However, the energy produced from bagasse surpasses the energy requirement for the mills, which creates an opportunity for the industry to sell surplus electricity to the grid or store it for low supply periods.[39]

Additionally, the Mexican sugar industry is a significant source of domestic employment. While sugarcane producers are experiencing low incomes despite receiving 8% of the country's agricultural subsidies each year as a result of trade liberalization policies that Mexico had pursued in prior years, 51 sugar mills in 15 states provide jobs for an estimated 930,000 people in direct jobs and 2.2 million indirect jobs.[40] Further, this industry indirectly supports over 12 million people in 227 rural communities.[41]

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[37] Honorato-Salazar, J. A., and Jhuma Sadhukhan. 2020. "Annual biomass variation of agriculture crops and forestry residues, and seasonality of crop residues for energy production in Mexico." Food and Bioproducts Processing 119 (January): 1-19. https://doi.org/10.1016/j.fbp.2019.10.005.

[38] Honorato-Salazar, J. A., and Jhuma Sadhukhan. 2020. "Annual biomass variation of agriculture crops and forestry residues, and seasonality of crop residues for energy production in Mexico." Food and Bioproducts Processing 119 (January): 1-19. https://doi.org/10.1016/j.fbp.2019.10.005.

[39] Sørensen, Ole Emmik, and Bo Riisgaard Pedersen. "Mexico: Vast Bio-Energy Potential in Mexican Sugar Cane Industry." Danish Energy Agency. Danish Energy Agency, April 30, 2015. https://ens.dk/en/press/mexico-vast-bio-energy-potential-mexican-sugar-cane-industry.

[40] Gro Intelligence. "Mexico's Sugar Industry Struggles to Remain Competitive." Gro Intelligence, March 20, 2018. https://www.gro-intelligence.com/insights/mexico-sugar-industry-struggles-to-remain-competitive; Sørensen, Ole Emmik, and Bo Riisgaard Pedersen. "Mexico: Vast Bio-Energy Potential in Mexican Sugar Cane Industry." *Danish Energy Agency*. Danish Energy Agency, April 30, 2015. https://ens.dk/en/press/mexico-vast-bio-energy-potential-mexican-sugar-cane-industry.

[41] Aguilar-Rivera, N., D. A. Rodríguez L., V. Enríquez R., A. Castillo M., and A. Herrera S. "The Mexican Sugarcane Industry: Overview, Constraints, Current Status and Long-Term Trends." *Sugar Tech* 14, no. 3 (July 3, 2012): 207–22. https://doi.org/10.1007/s12355-012-0151-3.

Mexico's top sugar producing areas are in the Gulf states of Veracruz, Oaxaca, and Tabasco and the Pacific states of Nayarit, Jalisco, Michoacán, and Colima. The annual production value is highest in Veracruz, estimated at approximately $896 million USD.[42] The 227 sugar producing municipalities are home to 12 million people and contribute 7.1% to the national agricultural production value. Further, sugarcane production has been shown to reduce marginalization rates - for example, municipalities in Veracruz that produce sugarcane have a lower marginalization index than those that do not. The National Population Council (CONAPO) in Mexico is responsible for calculating the Marginalization Index (*Índice de Marginación*). The Marginalization Index is a measurement used in Mexico to assess the socioeconomic conditions and development levels of different regions within the country. It takes into account various factors such as education, income, housing, access to basic services, and population density. The index is commonly used to identify areas that require targeted development policies and resources.[43]

In conclusion, the sugarcane industry's economic and employment benefits are overshadowed by the contested wider benefits of sugarcane production, which come at a considerable cost. The negative impacts of air and water pollution, waste management challenges, and biodiversity loss pose inherent economic expenses that cannot be ignored.[44]

The competition for land-use between sugarcane and other food crops is a significant issue, jeopardizing global food production. The expansion of sugarcane production contributes to indirect land-use changes that negatively affect biodiversity and endemic species, threatening ecological balance.

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[42] Gro Intelligence. "Mexico's Sugar Industry Struggles to Remain Competitive." Gro Intelligence, March 20, 2018. https://www.gro-intelligence.com/insights/mexico-sugar-industry-struggles-to-remain-competitive.

[43] Secretaría del Medio Ambiente y Recursos Naturales. "SEMARNAT." Semarnat.gob.mx, 2023. http://dgeiawf.semarnat.gob.mx:8080/ibi_apps/WFServlet?IBIF_ex=D1_R_POBREZA00_02&IBIC_user=dgeia_mce&IBIC_pass=dgeia_mce.

[44] Manzini Poli, Fabio L., Jorge M. Islas-Samperio, Carlos A. García Bustamante, Julio C. Sacramento Rivero, Genice K. Grande-Acosta, Rosa M. Gallardo-Álvarez, Ricardo Musule Lagunes, Freddy Navarro Pineda, and Christian Alvarez Escobedo. 2022. "Sustainability Assessment of Solid Biofuels from Agro-Industrial Residues Case of Sugarcane Bagasse in a Mexican Sugar Mill" Sustainability 14, no. 3: 1711. https://doi.org/10.3390/su14031711

Sugarcane burning exacerbates environmental problems, leading to heightened air pollution, increased greenhouse gas emissions, and water resource strain due to changing irrigation needs. These negative externalities not only harm the environment but also have adverse implications for public health and sustainable water management.

Moreover, the social impacts on farmers' health and well-being cannot be disregarded. The burning of sugarcane fields exposes farmers and nearby communities to harmful pollutants, raising concerns about respiratory health. Additionally, the economic impacts, including production costs and labor conditions, demand careful attention to ensure fair and sustainable practices within the industry.

Addressing the challenges associated with sugarcane production requires a strong foundation of robust and transparent scientific evidence to inform policy development in Mexico. It is crucial to prioritize comprehensive research, incorporating diverse perspectives and stakeholder engagement. Such evidence-based policymaking will enable informed decisions that balance economic interests with environmental sustainability and social well-being.[45]

In conclusion, mitigating the negative externalities of sugarcane production necessitates a holistic approach. It is imperative to promote sustainable practices, invest in research and innovation, and foster inclusive dialogue among all stakeholders. By doing so, we can strive for a sugarcane industry that maximizes economic benefits while minimizing its adverse effects, ensuring a sustainable future for both Mexico and the wider global community.

In addition to sugarcane bagasse, studies have shown that citrus peels can also be a lucrative biomass input source for juice factory energy production.[46] In 2021, Mexico

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[45] El Chami, Daniel, André Daccache, and Maroun El Moujabber. "What Are the Impacts of Sugarcane Production on Ecosystem Services and Human Well-Being? A Review." *Annals of Agricultural Sciences* 65, no. 2 (November 2020). https://doi.org/10.1016/j.aoas.2020.10.001.

[46] Martinez-Hernandez, E., Magdaleno Molina, M., Melgarejo Flores, L.A. Palmerín Ruiz, E. Zermeno Eguia-Lis, J.A. Rosas, A., Aburto, J. and Amezcua-Allieri, M. A. 2019. "Energy-water nexus strategies for

produced 170,000[47] metric tons of orange juice and around 4.3 million metric tons of oranges,[48] most of which were produced in the eastern region of Veracruz.[49] In addition, the northern regions of Nuevo Leon and Tamaulipas are large producers of fresh oranges and processors of orange juice. Waste accounts for 50-60% off the total mass of oranges produced, with 50-65% of the total waste mass being peels.[50] Therefore, Mexico has a potential 1.08 to 1.68 million tons[51] of orange peels available for biomass energy production that would otherwise be disposed of or used for other purposes.

It is clear that Mexican industries have the potential to utilize agro-industrial waste to create solid biofuels for industrial processing electricity generation. There are many benefits to reusing these residues including the avoidance of improper waste management practices that cause social and environmental harm, long-term cost reductions, and reducing industry reliance on fossil fuel energy sources, which thereby also reduces operational greenhouse gas emissions.[52] However, as discussed in future sections of this report, there are key steps the Mexican government must take in order to scale biomass energy from agro-industrial waste. It is important to understand how the biomass energy generation process occurs in order to identify

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the energetic valorization of orange peels based on techno-economic and environmental impact assessment." Food and Bioproducts Processing 117:380–387.

[47]Trenda, Eloise. 2022. "Orange juice production volume in Mexico." Statista. https://www.statista.com/statistics/955250/mexico-orange-juice-production-volume/.

[48] Osoyo, Ariel, and Rhiannon Elms. 2021. "Citrus Annual." USDA Foreign Agricultural Service. https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Citrus%20Annual_Mexico%20City_Mexico_12-15-2021.

[49] Elms, Rhiannon, and Ariel Osoyo. 2020. "Mexico Citrus Update." USDA Foreign Agricultural Service. https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Mexico%20Citrus%20Update_Mexico%20City_Mexico_05-27-2020.

[50]Martinez-Hernandez, E., Magdaleno Molina, M., Melgarejo Flores, L.A. Palmerín Ruiz, E. Zermeno Eguia-Lis, J.A. Rosas, A., Aburto, J. and Amezcua-Allieri, M. A. 2019. "Energy-water nexus strategies for the energetic valorization of orange peels based on techno-economic and environmental impact assessment." Food and Bioproducts Processing 117:380–387.

[51] This number was estimated assuming we multiply 4.3M tonnes of oranges produced by 50% (to account for the portion of waste) and then the result subsequently by an additional 50% to estimate the total mass of peels

[52] Manzini Poli, Fabio L., Jorge M. Islas-Samperio, Carlos A. García Bustamante, Julio C. Sacramento Rivero, Genice K. Grande-Acosta, Rosa M. Gallardo-Álvarez, Ricardo Musule Lagunes, Freddy Navarro Pineda, and Christian Alvarez Escobedo. 2022. "Sustainability Assessment of Solid Biofuels from Agro-Industrial Residues Case of Sugarcane Bagasse in a Mexican Sugar Mill" Sustainability 14, no. 3: 1711. https://doi.org/10.3390/su14031711

critical environmental, social and economic considerations that will guide effective policymaking.

Biomass Energy Production Processes

Sugarcane Bagasse

In sugarcane production, juice is extracted by crushing the stalks, leaving behind a fibrous residue called bagasse. This bagasse undergoes a washing process to extract as much liquid as possible and is then heated to reduce its moisture content. Afterwards, the bagasse is burned in a thermal power plant at a temperature exceeding 500 degrees. The resulting combustion generates steam that drives turbines to generate electricity. In most cases, the majority of this electricity is supplied to local electrical grids, with the remaining electricity reserved to meet the needs of the production plant where the combustion occurs.[53]

The most energy efficient way to utilize sugarcane bagasse for energy production is through pelletization - a process in which the moisture content in residues is reduced, grinded into small particles, compressed, cooled, dried and packaged into pellets. Commercial pellet mills and other pelletizing equipment are widely available across the globe.[54] "Pelletization of biomass facilitates easy and cost-effective handling, and the pellets can be burned with very high combustion efficiency. Notably, however, in Mexico, the biomass pelletization industry is incipient, this due, among other circumstances, to the few credit alternatives, the lack of knowledge of its advantages, and the variability of biomass sources."

In southeast Asia, there are numerous sugar factories in the sugarcane industry that use sugarcane bagasse and other byproducts for energy generation, among other

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[53] BE ATEX. "Producing Energy with Biomass and Sugar Cane." www.be-atex.com, December 21, 2021. https://www.be-atex.com/en/node/150#:~:text=The%20use%20of%20sugar%20cane&text=The%20bagasse%20is%20the%20remaining.

[54] Zafar, Salman. "Biomass Pelletization Process." *BioEnergy Consult* (blog), September 3, 2021. https://www.bioenergyconsult.com/biomass-pelletization/.

uses. While there are limited studies that demonstrate the implications of this process in the Mexican context, this report analyzes studies from Southeast Asia to estimate impacts within Mexico. Typically, for every 10 tons of sugarcane crushed, a sugar factory produces around 3 tons of wet bagasse. Some factories choose to burn the bagasse fiber as fuel, as it produces heat energy that can meet the energy needs of a typical sugar factory when burned in large quantities. The remaining bagasse can be processed into biomass pellets, which can be exported as fuel to other countries or used as raw materials for making sugarcane bagasse pulp. Additionally, bagasse can be turned into activated carbon - a form of carbon derived from environmental wastes that contain high levels of carbon that is commonly used to filter contaminants from water and air. Due to its large surface area, microporous properties, and complex external area chemistry, activated carbon is well-suited for adsorbing heavy metals. Sugarcane's renewable nature makes it a more sustainable energy source. Its high calorific value of 3,400 to 4,200 kilocalorie and low ash content make sugarcane bagasse pellets a smart choice for energy fuel.[55] While there is no large-scale infrastructure for efficient sugarcane bioenergy production in Mexico, this system could be established to use residual biomass wastes from sugar production.

Orange Peels

In a typical orange juice production facility, once the fresh oranges are harvested, they are transported to a facility for industrial processing, which includes a peeling process. Once the peels are extracted from the fruit, they are pressed for press liquor, which can be used to produce components for citrus liquor or animal feed.[56] This process also produces a considerable amount of wastewater that can be high in organic matter.[57] Once pressed, the peels are often disposed of and the process is finished. However, it is feasible to harvest energy from peels through an additional drying and combustion process. To do so, once the peels are pressed, they can be

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[55] Jack Huang, "Pellets Made from Sugarcane Can Make Giant Profits," *GEMCO Energy - from Biomass to Biofuel* (blog), January 18, 2016, http://www.biofuelmachines.com/make-pellets-from-sugarcane-and-make-giant-profits.html#:~:text=Production%20of%20sugarcane%20bagasse%20pellets&text=Pelletizing%3A%20The%20bagasse%20powder%20materials,of%20rollers%20inside%20the%20mill..

[56] Martinez-Hernandez, E., Magdaleno Molina, M., Melgarejo Flores, L.A. Palmerín Ruiz, E. Zermeno Eguia-Lis, J.A. Rosas, A., Aburto, J. and Amezcua-Allieri, M. A. 2019. "Energy-water nexus strategies for the energetic valorization of orange peels based on techno-economic and environmental impact assessment." Food and Bioproducts Processing 117:380–387.

[57] ibid

sent through a series of drying chambers after which they are burned in a furnace, and energy is harnessed from steam that is produced in a boiler.[58]

Orange peels are not recommended for large-scale utility energy production because of the large amount of peels that would be needed for the operation to be financially feasible and the high associated transportation costs. However, orange peels are an option as a cheap solid biofuel for industrial juice factories with a modest caloric value range of 10.9 - 19.3 MJ/kg.[59] At a larger scale, other fruit-based residues (coconuts, limes, lemons, etc.) have the potential to be transformed into solid biofuels and used as energy feedstock for their respective facilities. However, further research is needed to determine the caloric values and economic feasibility of other peeled and processed fruits to be transformed into solid biofuels Mexico.

Environmental Considerations

Greenhouse Gas (GHG) Emissions

Emitting significantly less greenhouse gasses than conventional fuel, biomass energy should be viewed as a strategic priority as part of Mexico's Paris Agreement and National Climate Change Law commitments to reduce its emissions. According to a study from Instituto Mexicano del Petróleo, biomass energy produced from orange peels on site has a global warming potential that is 94% less than that of conventional oil due to reduced transportation needs and the elimination of fossil fuel combustion.[60] For similar reasons, the carbon dioxide emissions resulting from bagasse combustion are significantly lower than those produced by fossil fuel combustion.[61]

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[58] Ibid

[59] Carolina Monteiro Santos a, Jo Dweck b, Renata Silva Viotto a, André Henrique Rosa a, Leandro Cardoso de Morais. 2015. "Application of orange peel waste in the production of solid biofuels and biosorbents."

https://www.sciencedirect.com/science/article/pii/S0960852415010858

[60] Martínez-Hernández, E., Magdaleno Molina, M., Melgarejo Flores, L.A. Palmerín Ruiz, E. Zermeno Eguia-Lis, J.A. Rosas, A., Aburto, J. and Amezcua-Allieri, M. A. 2019. "Energy-water nexus strategies for the energetic valorization of orange peels based on techno-economic and environmental impact assessment." Food and Bioproducts Processing 117:380–387.

[61] BE ATEX, "Producing Energy with Biomass and Sugar Cane," www.be-atex.com, December 21, 2021, https://www.be-

Consequently, a critical factor to consider for emissions reduction is the source of the residues. While it can be challenging to find sufficient raw material to entirely fuel thermal power plants, transporting biomass pellets from foreign countries to meet demand can exacerbate the greenhouse gas emissions of these operations.[62] Additionally, crop production methodology has the potential to emit significant GHG emissions through deforestation, tillage, and other unsustainable agricultural practices. Therefore, it is crucial that Mexico's regulatory framework around biomass requires companies to examine emissions impacts of the use of biomass that is not a residue from their own facilities.

Wastewater

As mentioned above, the orange peel production process results in the generation of wastewater that is high in organic matter. If not properly managed and treated, this organic matter increases the risk of aquatic and terrestrial ecotoxicity and eutrophication in regions where the water is dumped, which poses a risk to the productive capacity of local ecosystems and agricultural systems.[63] The legal framework for wastewater management in Mexico is extensive. However, the OECD identified compliance and enforcement as areas of needed improvement.[64] Further, there is a need to define specific roles for government organizations that are responsible for wastewater management - especially wastewater that is produced from agricultural practices.[65] As more orange peels are being used for bioenergy, it will be critical to ensure these recommendations are implemented to ensure energy

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atex.com/en/node/150#:~:text=The%20use%20of%20sugar%20cane&text=The%20bagasse%20is%20the%20remaining.

[62] BE ATEX, "Producing Energy with Biomass and Sugar Cane," www.be-atex.com, December 21, 2021, https://www.be-atex.com/en/node/150#:~:text=The%20use%20of%20sugar%20cane&text=The%20bagasse%20is%20the%20remaining.

[63] Martinez-Hernandez, E., Magdaleno Molina, M., Melgarejo Flores, L.A. Palmerín Ruiz, E. Zermeno Eguia-Lis, J.A. Rosas, A., Aburto, J. and Amezcua-Allieri, M. A. 2019. "Energy-water nexus strategies for the energetic valorization of orange peels based on techno-economic and environmental impact assessment." Food and Bioproducts Processing 117:380–387.

[64]Valdivia Alvarado, Ana Teresa, Alba E. Gamez, Luis Felipe Beltrán Morales, and Alfredo Ortega-Rubio. 2020. "Mexico's Legal Framework Regarding Wastewater Management: A Case Study of Baja California Sur." SciELO México. https://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S1870-05782021000100115.

[65] ibid.

generation through this process does not inadvertently contribute to further environmental harm.

Air Quality

While we expect the technology used for biomass to energy generation to be more sophisticated and efficient than traditional agricultural byproduct burning for cooking fuel and warmth, the air quality impacts of biomass energy production are important to consider. For example, there is a possibility of toxic gas release during the production process, including carbon dioxide (CO_2) and sulfur dioxide (SO_2), which can lead to health risks such as intoxication. The use of formaldehyde to prevent or correct bacterial contamination in sweet juices is also a potential chemical risk as a volatile compound that releases vapors responsible for respiratory symptoms like asthma, especially when used as a surface disinfectant.[66]

Mexico has implemented several air quality laws and regulations to address pollution and protect public health. Some key measures include:[67]

- General Law for Ecological Balance and Environmental Protection (Ley General del Equilibrio Ecológico y la Protección al Ambiente): This law serves as the primary environmental legislation in Mexico and includes provisions for air pollution control and management.
- Official Mexican Standards (Normas Oficiales Mexicanas or NOMs): NOMs are technical regulations issued by the Mexican government to establish air quality standards and emissions limits for various pollutants, including particulate matter, ozone, sulfur dioxide, nitrogen dioxide, and others.
- Air Quality Monitoring and Reporting: Mexico has established a network of air quality monitoring stations to assess pollution levels in different regions. The data

[66] BE ATEX, "Producing Energy with Biomass and Sugar Cane," www.be-atex.com, December 21, 2021, https://www.be-atex.com/en/node/150#:~:text=The%20use%20of%20sugar%20cane&text=The%20bagasse%20is%20the%20remaining.

[67] Transport Policy. "Mexico: Air Quality Standards | Transport Policy." Transport Policy, 2018. https://www.transportpolicy.net/standard/mexico-air-quality-standards/.

collected is used to inform decision-making and the implementation of control measures.

These policies could serve as the foundation of a regulatory framework around biomass valorization in Mexico.

Climate Change

One of the main environmental concerns for agricultural production is climate change, leading to increased prevalence and intensity of extreme weather events such as droughts, fires, frost and flooding.[68] This poses a risk for agro-industrial biomass energy production because a changing climate has the potential to severely decrease the amount of waste available for use as feedstock. Additionally, higher temperatures are conducive for spreading new diseases for wildlife, such as the citrus greening disease (HLB).[69]

An example of environmental impacts due to climate change is identified at the state of Veracruz, Mexico. Veracruz, the region that produces much of Mexico's sugarcane and oranges, has a climate with mildly high temperatures, consistent humidity, and nutrient rich soils that make this region suitable for crop production. Any disruption to these conditions might prove to have negative economic impacts on the commodity crop market and could limit the supply of feedstock for biomass energy production. Already, for the 2022-2023 growing season, increased drought prevalence threatens the crop yield of oranges in the Veracruz region and warmer weather conditions increase the risk of HLB disease spread.[70] Due to these risk

[68] J. Amador Honorato-Salazar, Jhuma Sadhukhan. "Annual biomass variation of agriculture crops and forestry residues, and seasonality of crop residues for energy production in Mexico". Food and Bioproducts Processing, Volume 119, 2020. https://doi.org/10.1016/j.fbp.2019.10.005.

[69] DeMuth Sullivan, Kathryn. "How temperature affects citrus-greening disease". https://www.labroots.com/trending/earth-and-the-environment/15236/temperature-affects-citrus-greening-disease

[70] BMT Foods. "Mexican Citrus: 2022-2023 Crop Overview and Orange Juice Outlook". https://www.bmtfoods.com/mexican-citrus-2022-2023-crop-overview-and-orange-juice-outlook/?utm_source=rss&utm_medium=rss&utm_campaign=mexican-citrus-2022-2023-crop-overview-and-orange-juice-outlook

factors, the estimated crop available for orange juice processing is expected to decrease as much as 46% since the previous season.[71]

It is important to consider the future of agricultural production in Mexico when exploring the potential of utilizing agro-industrial waste for biomass energy production. It is possible that feedstock availability might become more limited and uncertain. Therefore, it is necessary to research projected changes in agricultural yields within the regions where these facilities operate and perform feasibility studies on biomass energy systems based on these projections.

Social Considerations

Job Potential

While the sugar sector in Mexico has the potential to generate employment and income, its efficiency is limited by low productivity, lack of crop diversification, and vulnerability to climate change. Small-scale farmers contribute 61% of total sugarcane production but face barriers in planting, cultivation, and harvest due to a communal land tenure structure.[72] Sugarcane workers and growers are well-organized into unions, but the education level of farmers and the broader workforce is low.

Therefore, it is recommended the administrative and regulatory agencies responsible for biomass energy management create a workforce development plan in order to identify communities and facilities where these projects would be built and provide training to manage biomass energy systems as an alternate form of employment for local communities. Mexico's National Institute for Forestry, Agriculture and Livestock Research (INIFAP) has a community engagement methodology for implementing new agriculture technologies that can be replicated for the purpose of biomass energy training. Further studies will need to be conducted in order to determine the numeric job increase potential that would

[71] ibid.

[72] Aguilar-Rivera, N., D. A. Rodríguez L., V. Enríquez R., A. Castillo M., and A. Herrera S. “The Mexican Sugarcane Industry: Overview, Constraints, Current Status and Long-Term Trends.” *Sugar Tech* 14, no. 3 (July 3, 2012): 207–22. https://doi.org/10.1007/s12355-012-0151-3.

result from valorizing Mexico’s biomass industry. In later sections, we discuss the application of a Community-Based Participatory Action Research (CBPAR) framework for researching community health impacts of biomass valorization. In our discussions, we found that INIFAP already engages principles of CBPAR in their research which should be elaborated upon and used in other ministries and organizations.

Energy Security

Rural communities in Mexico have lower access to reliable energy, which is often correlated with higher economic constraints and food insecurity.[73] Enhancing energy security for rural communities can contribute to greater food security and economic mobility in a development context. Utilizing agricultural waste for biomass energy has several benefits for enhancing the energy security of rural communities and industrial facilities. First, both sugarcane and oranges are resources that are grown near their respective processing facilities, so there is less supply chain risk associated with biomass energy inputs. Additionally, by reducing their reliance on fossil fuels, communities and facilities also reduce exposure to volatile energy prices in the international oil and gas markets. By efficiently harnessing Mexico’s vast domestic resources, biomass energy effectively reduces Mexico’s reliance on foreign energy sources, thereby enhancing the country’s energy security.

Alternative Use of Biomass Feedstocks

When planning to expand the productivity of a specific industry, it is especially important to be mindful of the competitive nature of the free market. Mexico’s legal and regulatory framework must implement stringent preventative measures to ensure that the crops used for biomass production do not compromise the country’s food security. Biomass, including waste produced from citrus and sugarcane, are natural resources that require meaningful change of land use to produce and therefore, if change of land use for biomass input production is needed, it must be within a level that considers environmental issues and maintains Mexico’s food

[73] García Ochoa, Rigoberto, Daniel Itzamna Avila-Ortega, and Jordi Cravioto. 2022. “Energy services' access deprivation in Mexico: A geographic, climatic and social perspective.” Energy Policy 164 (May). https://doi.org/10.1016/j.enpol.2022.112822.

security.[74] This requires that the agricultural crops used for biomass energy not be a majority of those commonly used as livestock feed or for direct human consumption such as corn and other feedstock crop waste. This might be difficult to monitor and enforce due to the laborious task of collecting data on the lifecycle of all agricultural products within a facility; therefore, a clear and robust policy that is supported by a strong regulatory framework is necessary to ensure there is no concern with the use of agricultural crop residues for biomass energy production. Maintaining Mexico's food security is important, especially with climate uncertainty that is expected to limit the country's crop yields.[75] Therefore, it is critical that the use of agricultural residues for biomass energy does not impact the availability of food for human consumption.

Economic Considerations

The regulatory framework for the Mexican sugar industry lacks flexibility, efficiency, and financial opportunities for identifying opportunities in the international market due to poor integration of the Research, Development, & Extension (RD&E) effort. The 2005 Ley de Desarrollo Sustentable de la Caña de Azúcar (Law of Sustainable Development of Sugarcane) and El Programa Nacional de la Agroindustria de la Caña de Azúcar (National Program of the Sugarcane Agroindustry) establish a framework for sugarcane supply and marketing without a competitive environment. Legal issues related to pesticides, herbicides, irrigation, fertilizers, air pollution, and burning are not considered. Moreover, there has not been a formal institute for RD&E in sugarcane since 1990, and research is carried out marginally by universities and sugar groups.[76]

The lack of competitiveness in the Mexican sugarcane industry can be attributed to several key factors. Firstly, there has been stagnation in sugarcane and sucrose yield,

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[74] Art 1.(I) of Bioenergetics Law provides that the development of bioenergy shall not give rise to externalities particularly with respect to harmful effects to biodiversity and food security. The Bioenergetics Law requires SAGARPA, as the agriculture and food authority, to periodically monitor the implication of biomass development and make it publicly available.

[75] Estrada, F., Mendoza-Ponce, A., Calderón-Bustamante, O. et al. Impacts and economic costs of climate change on Mexican agriculture. Reg Environ Change 22, 126 (2022). https://doi.org/10.1007/s10113-022-01986-0

[76] Aguilar-Rivera, N., D. A. Rodríguez L., V. Enríquez R., A. Castillo M., and A. Herrera S. "The Mexican Sugarcane Industry: Overview, Constraints, Current Status and Long-Term Trends." *Sugar Tech* 14, no. 3 (July 3, 2012): 207–22. https://doi.org/10.1007/s12355-012-0151-3.

with low productivity and high fiber content in stalks per hectare. Average yields of sugarcane and sucrose have remained relatively low, resulting in limited output over the past decade.

A major issue contributing to the industry's lack of competitiveness is the decline in sugarcane agriculture yield, primarily caused by the loss of productive capacity in soils due to long-term monoculture practices. This phenomenon is particularly prevalent in distinct landscapes along the Pacific and Gulf of Mexico coasts, as well as in high mountain river valleys in central Mexico.

The sugar mills in Mexico exhibit a dichotomy, characterized by varying sizes, ages, and technologies. Many mills are medium to small in scale and employ outdated and inefficient technologies, which significantly increases the cost of sugar production compared to countries with advanced technology and support systems. Consequently, Mexico is considered a medium-to-low-cost producer of sugar.

These factors have had adverse effects on both sugarcane growers and the sugar industry as a whole, eroding their sustainability and profitability. Moreover, the sugar industry has acquired a status akin to "political goods," where political considerations play a significant role, similar to the petroleum industry.

The Mexican sugar industry faces multiple challenges, including high crushing capacities, environmental impacts, high domestic demand, and low productivity and capacity to supply sufficient sugar cane from the fields. These challenges pose ongoing obstacles to the industry's competitiveness and overall success.

In summary, the Mexican sugarcane industry's lack of competitiveness can be attributed to stagnant yields, low productivity, outdated technologies, and the erosion of sustainability and profitability. Addressing these challenges would require modernizing technologies, implementing sustainable practices, and finding solutions to enhance productivity and supply capacity in order to improve the industry's competitiveness in the global market.

More financing opportunities are necessary for companies to assess the financial feasibility of a potential biomass energy project. This is particularly important as there is a high initial capital expenditure to retrofit and build the appropriate infrastructure. Further, financing will be determined based partially on assessment of whether the steam, heat, and power production capabilities are enough to offset the utility consumption from both factory operations and biomass energy production processes. Initial studies are promising, proving that orange peels and sugarcane are economically feasible as a biomass feedstock if efficient drying and combustion processes exist that minimize the energy intensity of biomass energy production.[77]

Additionally, as agricultural crop production is seasonal, companies should prepare for intermittent supply of residues and ensure they invest in alternative energy sources. While it is more economically advantageous to use residues that are already present or nearby the processing and combustion facilities as producers can minimize or eliminate costs of transportation, the local supply of residues may at times be reduced to a point where biomass energy production is no longer economically feasible. To mediate these situations, there should be subsidies for companies that generate biomass energy to procure alternative sources of energy for the months where biomass feedstock supply will likely be low. This can also be mediated through further studies to identify the lifetime of agricultural residues and determine how long these pellets can be stored.

One final important economic consideration is the competitiveness of the agricultural sector in Mexico. Industrial food production in Mexico is very competitive and factories are constantly searching for ways to increase their competitive advantage. While a biomass energy system might be a long-term cost savings tool, many might find the initial capital expenditures too high when focusing on mitigating short-term costs. Therefore, it is necessary to provide financial incentives to increase the uptake of industrial biomass energy consumption and stimulate investment. We will elaborate more on these financial incentives later in this report.

[77] Martinez-Hernandez, E., Magdaleno Molina, M., Melgarejo Flores, L.A. Palmerín Ruiz, E. Zermeno Eguia-Lis, J.A. Rosas, A., Aburto, J. and Amezcua-Allieri, M. A. 2019. "Energy-water nexus strategies for the energetic valorization of orange peels based on techno-economic and environmental impact assessment." Food and Bioproducts Processing 117:380–387.

Development Roadmap

Agricultural waste has the potential to provide rural communities and agro-industrial processing facilities with a generous supply of biomass energy. Due to the resistance to implementing new technologies with subsistence farmers in southern Mexico, it is recommended that the government first focus its efforts on larger agriculture industries located in the northern and eastern regions of the country. In particular, focus on regions with high energy potential from crop production including Tamaulipas where levels can reach as high as 15,000 TJ/year and in Veracruz where levels can reach 5,000 TJ/year.[78]

As stated previously, beyond the sugarcane industry, the agricultural sector is very competitive, and financial returns are considered by various stakeholders to be the most important factor in determining agriculture operations. The high upfront costs to implement biomass energy production will likely deter companies from investing. Additionally, the government of Mexico heavily advocates for oil and many within the general population have the mindset that fossil fuel energy is the best energy option. Therefore, it is recommended that government agencies responsible for biomass energy research pilot several biomass energy projects using different waste sources to use as examples for industries to follow to show how biomass energy can be financially, socially, and environmentally beneficial for these industrial processes. This way, more research on the financial feasibility of these operations can be analyzed to improve technology, operational efficiency, and eventually, lower overall costs.

Additionally, to alleviate expenses, the Mexican government should implement economic incentives for these industries to invest in biomass energy. This can take either the form of a low-carbon tax break for companies that have implemented clean energy technologies or a subsidy for those that wish to invest but are unable to front the costs. It is recommended that the government does not implement taxes on companies that continue to use a majority of fossil fuel energy because the burden of the tax will likely fall on consumers and workers, resulting in higher costs for consumers and/or lower wages. This energy transition within the agriculture

[78] Honorato-Salazar, J. Amador, and Jhuma Sadhukhan. 2019. "Annual biomass variation of agriculture crops and forestry residues, and seasonality of crop residues for energy production in Mexico." *Food and Bioproducts Processing* 119 (October): 1-19.

industry should be done through positive financial incentive and reinforcement rather than enforced additional costs.

Furthermore, these businesses can begin to take advantage of the new cap and trade carbon market that will be established in Mexico in 2023 by SEMARNAT for the industry and energy sectors.[79] As agricultural processing facilities limit their greenhouse gas emissions, they can sell carbon credits for the amount of carbon they saved that is below the established cap. This can provide financial resources for the company to more quickly pay off the capital expenditures from biomass energy infrastructure and provide higher long-term economic benefits. More studies are needed to determine the savings and potential profitability associated with the newly established carbon markets for sustainably minded companies.

Another method of reducing upfront costs associated with biomass energy implementation is to increase research and development into biomass energy technologies and more energy efficient pelletization. This would help lower initial capital expenditures and decrease financial barriers to entry. Further, it would be beneficial to research the possibility of using the same industrial processes and machinery for multiple sources of agricultural waste. This way, in a situation when residue supply is low, it is easy for a company to purchase alternative dry biomass as a replacement. Additionally, it is important to contribute further research into the lifetime of different biomass pellets and residues to determine the amount of time that these residues can be stored.

Finally, it would be beneficial for industries within localized regions to form a waste marketplace to buy and sell waste from their facilities. Qualifying companies that do not utilize their waste for alternative purposes can sell their residues, which can act as a way to diversify their revenue streams. Alternatively, companies that have a varied biomass supply throughout the year can purchase waste from other facilities to replace the original sources.

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[79] International Carbon Action Partnership. 2023. “Mexico.” International Carbon Action Partnership. https://icapcarbonaction.com/en/ets/mexico.

To address the lack of competitiveness in the Mexican sugarcane industry, several strategies can be considered:

1. Enhancing Research and Development: Investing in research and development is crucial to improve sugarcane and sucrose yields. This includes developing new sugarcane varieties that are more productive and disease-resistant, as well as conducting research on sustainable farming practices and soil management techniques.
2. Upgrading Technology and Infrastructure: Modernizing the sugar mills with advanced technology and machinery can improve efficiency and reduce production costs. Additionally, upgrading infrastructure such as irrigation systems and transportation networks can enhance the overall productivity of the industry.
3. Promoting Sustainable Practices: Implementing sustainable agricultural practices can contribute to increased productivity and environmental conservation. This includes promoting crop rotation, diversifying agricultural activities, and adopting efficient water management techniques to mitigate the negative impact of monoculture and protect soil health.
4. Strengthening Support Systems: Enhancing support systems for sugarcane growers, such as providing access to affordable credit, agricultural extension services, and technical assistance, can help improve their productivity and profitability. Additionally, providing incentives for farmers to adopt sustainable practices and invest in modern technologies can contribute to their long-term success.
5. Encouraging Collaboration and Knowledge Sharing: Facilitating collaboration among industry stakeholders, including farmers, sugar mills, research institutions, and government agencies, can foster knowledge sharing and innovation. This collaboration can lead to the development and adoption of best practices, improvement in production techniques, and the sharing of technological advancements.
6. Addressing Policy and Trade Barriers: Advocating for policies that support the competitiveness of the sugarcane industry, including fair trade agreements, reduced trade barriers, and targeted subsidies, can improve market access and enhance the industry's competitiveness.
7. Diversifying Revenue Streams: Exploring opportunities for diversification beyond sugar production, such as bioenergy, ethanol, or value-added products derived from sugarcane, can help generate additional revenue streams and increase the industry's overall competitiveness.
8. Implementing these strategies would require collaboration between the government, industry stakeholders, and research institutions. A

comprehensive approach that addresses productivity, sustainability, technology, and market access can help overcome the challenges and enhance the competitiveness of the Mexican sugarcane industry.

To proliferate the agro-industrial waste biomass industry in Mexico, policies must be implemented to lower capital expenditures and operational costs, and maximize financial returns for participating companies. This can help minimize risks of high upfront capital costs and long-term payouts to incentivize companies to implement agro-industrial biomass energy systems within their facilities. Without significant financial incentives, it will be difficult for agriculture companies to adopt sustainable energy systems due to the competitive nature of the industry.

Forestry

As the looming threat of climate change continues to increase pressure on countries to decarbonize, there is a global shift underway towards renewable energy sources as a strategic tool for both developed and developing economies alike. Biomass energy has risen in popularity as an alternative energy solution that is both cost-effective and efficient in areas where it can offer small scale decentralized generation to overcome the limitations of obsolete and expanding distribution networks found in many developing countries.[80] Forestry biomass– including wood and wood processing wastes such as firewood, pellets, wood chips, lumber, furniture mill sawdust and waste, and pulp from paper mills–is a popular source for biomass across the world and is looking to be developed further in Mexico.

This section will provide a landscape analysis of Mexico's forestry sector and identify targeted regions where there is the significant potential for biomass energy valorization. It will further provide an analysis of the environmental, social, and economic considerations that need to be taken into account for development. It will conclude by addressing the gaps found within the analysis and provide a

[80] Mehmet Eker, Raffaele Spinelli, Nevzat Gürlevik. "Recovering energy biomass from sustainable forestry using local labor resources". Journal of Cleaner Production, Volume 157, 2017.

https://doi.org/10.1016/j.jclepro.2017.04.134.

development roadmap on how to responsibly roll-out biomass energy production via the forestry sector.

Mexico context and industry overview

According to the World Bank, 33 percent (about 65 million hectares) of Mexico's land composition was considered to be forest area in 2020.[81] Of this, nearly 53 percent (34,300,000) is classified as primary or natural forests while 3,200,000 ha are planted forests.[82] Primary or natural forests are the most biodiverse and carbon-dense form of forest, meaning they have the highest potential to sequester carbon dioxide whereas planted or plantation forests lack this same ability to capture carbon. It has been estimated that total forest land captured 188 million tons of carbon dioxide (CO2).[83] Reflected in Mexico's Nationally Determined Contribution, there has been a push to take an ecosystem-based approach through the conservation, restoration, and sustainable management of forests to increase resilience and reduce vulnerability to climate risks, while mitigating GHG emissions.

Mexico has a wide variety of forest ecosystems, including tropical rainforests in the south and temperate forests in the center and north of the country. This paper will not address the exploration of biomass development within tropical forests because these ecosystems harbor significant amounts of biodiversity, sequester large amounts of carbon dioxide, reduce erosion, increase soil fertility, among other benefits, and, given such benefits, they should not be compromised and interfered with.

Spatial distribution of available forest residues and bioenergy potential are localized in forest harvesting areas in municipalities where temperate forests grow. Therefore, focusing specifically on temperate forests located in the Central and North of Mexico, these forests can be both primary and planted forests. 93 percent of timber

81 Trading Economics. "Mexico - Forest Area (% of Land Area). https://tradingeconomics.com/mexico/forest-area-percent-of-land-area-wb-data.html

82 Mongabay.com. "Mexico Forest Information and Data" https://rainforests.mongabay.com/deforestation/2000/Mexico.htm

83 Gobierno de México. "Principales indicadores del sector forestal en México" https://databosques.cnf.gob.mx/inicio/

production comes from these forests, mainly from the pine and oak species.[84] This is important as the logging industry acts as a catalyst for the forestry biomass energy valorization as they have the resources and the bioproduct to produce the corresponding energy. Accordingly, it is useful to focus specifically at the industry level rather than the household level because biomass energy valorization would grant industry the ability to become self-sufficient with the option to also sell the excess energy they produce. However, there is little literature and data available regarding country-specific biomass use for industrial purposes. Therefore, engaging with experts and research institutions that specialize in forestry, energy, and biomass utilization could help provide literature and data. In addition, conducting field surveys and case studies, and making them public, will assist as well.

In Mexico, there is an estimated energy potential of 1135 to 1923 PJ/year and 472 PJ/year from forestry biomass and agricultural waste, respectively.[85] However, while forestry residues (including wood-based bioproducts collected from forests and the waste generated from the industry itself) are estimated to produce 700,000 tons of dry matter per year, agriculture crop residues are estimated at 87.94 million tons of dry matter per year.[86] This discrepancy in ratios signifies a crucial potential for the forestry industry to maximize its energy potential in terms of biomass energy valorization given its high productivity compared to that of the agriculture sector.

Timber production has ranged from 1905 kt DM/yr to 4773 kt DM/yr, with an overall average of 2899 kt DM/yr between 2007 to 2017.[87] The average value of timber production in Mexico reached a monetary value of 40,568 million pesos; production levels remain well below the existing potential for exploitation, transformation and

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[84] Honorato-Salazar, J. Amador, and Jhuma Sadhukhan. "Annual Biomass Variation of Agriculture Crops and Forestry Residues, and Seasonality of Crop Residues for Energy Production in Mexico." *Food and Bioproducts Processing*119 (2020): 1–19. https://doi.org/10.1016/j.fbp.2019.10.005.

[85] Musule, Ricardo, José Núñez, Joel Bonales-Revuelta, Carlos. A. García-Bustamante, Juan C. Vázquez-Tinoco, Omar R. Masera-Cerutti, and Víctor M. Ruiz-García. "Cradle to Grave Life Cycle Assessment of Mexican Forest Pellets for Residential Heating." *BioEnergy Research* 15, no. 4 (2021): 1733–46. https://doi.org/10.1007/s12155-021-10337-6.

[86] Amezcua-Allieri MA, Torres E, Eguía-Lis JAZ et al (2018) Valorization of residues from forest industry for the generation of energy. Int J Energy Environ Eng 12:390–393. https://doi-org.ezproxy.cul.columbia.edu/10.5281/zenodo.1316768

[87] "Principales Indicadores Del Sector Forestal En México." DataBosques. Accessed March 20, 2023. https://databosques.cnf.gob.mx/inicio/.

commercialization due to numerous barriers that will be addressed later in the paper.[88]

During harvesting operations, several residues are generated, including stumps, roots, leaves, off-cut, branches, and sawdust, also known as logging residues. Pine species contribute to 56.3 percent of the total logging residues. Oak species are the second group that accounts for about 21.2 percent of the logging residues. [89] Logging residues hold great potential for energy production as they are often left in the forest fields without being utilized. The availability of logging residues varies between 348.4 kt DM/yr and 1022.6 kt DM/yr with an average of 574.5 kt DM/yr.[90] Yet, these figures significantly vary by states. For example, Durango is one of the largest timber producers in the country, showing a higher availability of forest residues at 26.4 percent, followed by Chihuahua state at 15.0 percent.[91]

Within the forestry sector, sawmilling is the most important industrial activity. Large scale sawmills are located in the states with high timber production. Sawmill residues consist of bark, sawmill rejects, edgings, slabs, trimmings, and sawdust. Sawmilling processing output of dry matter ranges between 1428.8 kt DM/yr and 3046.3 kt DM/yr with an average of 2037.4 kt DM/yr, contributing to 72 percent of the national timber production. Durango and Chihuahua states are the major sawmilling producers, in which 29 percent and 18 percent of sawmill residue waste is supplied, respectively.[92]

However, the commercial forestry industry in Mexico has encountered numerous obstacles, such as wood production costs being 35 to 40 percent higher than the

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[88] "Principales Indicadores Del Sector Forestal En México." DataBosques. Accessed March 20, 2023. https://databosques.cnf.gob.mx/inicio/.

[89] Honorato-Salazar, J. Amador, and Jhuma Sadhukhan. "Annual Biomass Variation of Agriculture Crops and Forestry Residues, and Seasonality of Crop Residues for Energy Production in Mexico." *Food and Bioproducts Processing*119 (2020): 1–19. https://doi.org/10.1016/j.fbp.2019.10.005.

[90] Ibid.

[91] Ibid.

[92] Ibid.

world average[93]. As a result, Mexico imports cheaper softwoods from the United States, thus further lowering Mexico's domestic lumber production. According to CONAFOR, [94] only 8.3 million cubic meters of wood were legally produced in 2018. This represents a marginal 24 percent of national consumption, leading the rest of the national demand to be satisfied with imports or illegally extracted wood. To further the situation, the growing dependency on imported wood is reflected in the national deficit, amounting to nearly 6.990 million dollars.[95]

Environmental Considerations

The utilization of forestry waste for bioenergy has the potential to significantly reduce greenhouse gas emissions and primary energy use. Forestry waste could prevent the emission of 6 kilo tons of CO_2 equivalent and 74 terajoules of primary energy annually, which can curb up to 90% of greenhouse gas emissions and primary energy use; in addition, bioenergy production can reduce water consumption, acidification, and eutrophication by 87-53%, and urban smog and ecotoxicity by 29-18 percent.[96] A life cycle assessment compared the environmental impact of using biomass from forestry waste and fuel oil; the results indicated that biomass is environmentally a better option as it showed negative mitigation of -107.8% in the category of eutrophication potential. An environmental index was also calculated, the index was 0.064 PEI/MJ for forestry waste and 0.156 PEI/MJ for fossil fuel. The life-cycle assessment also concluded that waste from the forestry industry can be used for heat generation for a lesser environmental impact.[97]

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[93] "Mexico's Forests and Notable Trees." Planetacom. Accessed June 1, 2023. https://www.planeta.com/mexico-forests/.

[94] "Principales Indicadores Del Sector Forestal En México." DataBosques. Accessed March 20, 2023. https://databosques.cnf.gob.mx/inicio/.

[95] "Principales Indicadores Del Sector Forestal En México." DataBosques. Accessed March 20, 2023. https://databosques.cnf.gob.mx/inicio/.

[96] Martinez-Hernandez, Elias, Jhuma Sadhukhan, Jorge Aburto, Myriam A. Amezcua-Allieri, Stephen Morse, and Richard Murphy. "Modelling to Analyse the Process and Sustainability Performance of Forestry-Based Bioenergy Systems." Clean Technologies and Environmental Policy 24, no. 6 (2022): 1709–25. https://doi.org/10.1007/s10098-022-02278-1.

[97] Anaya-Reza, Omar, Juan A. Eguía-Lis, Jorge Aburto, and Myriam A. Amezcua-Allieri. "Environmental Impact Assessment of Heat Generation from Residues: A Forest-Based Industry Case Study." BioEnergy Research 15, no. 4 (2021): 1787–96. https://doi.org/10.1007/s12155-021-10356-3.

Using forestry waste for energy generation has environmental benefits, such as reducing water consumption, acidification, eutrophication, urban smog, and ecotoxicity.[98] The mitigation benefit from using forestry waste for energy generation occurs in the terrestrial ecotoxicity and marine aquatic ecotoxicity categories. Forest sites with higher yields produce fewer greenhouse gas emissions per ton of forest residues.[99] However, emissions per hectare are higher when more biomass is extracted. Despite this, extracting greater quantities of biomass has the potential to displace conventional fuels and reduce greenhouse gas emissions more significantly, resulting in greater potential for greenhouse gas mitigation.[100]

Deforestation–the permanent loss of forest cover due to livestock, agriculture, infrastructure, and real estate development activities– is a critical problem in Mexico and poses a significant threat to environmental security. Not only does it put the environment at risk, it also is detrimental to the social and economic well-being of communities within these boundaries. From 2000 to 2020, Mexico has experienced a net change of -1.2 percent in total tree cover; in 2021 alone, it was reported that Mexico lost 186kha of primary forest, resulting in the equivalent release of 82.1Mt of CO2e emissions.[101] This should be taken into account when promoting biomass energy production via the forestry sector as it could further exacerbate deforestation activities.

Additionally, promoting timber plantations may have negative impacts on biodiversity, as highlighted by Anaya-Reza's 2021 study. The Mexican government has been promoting investments in commercial plantations to increase production of pulp and paper products. However, these areas are currently used for marginal

[98] Martinez-Hernandez, Elias, Jhuma Sadhukhan, Jorge Aburto, Myriam A. Amezcua-Allieri, Stephen Morse, and Richard Murphy. "Modelling to Analyse the Process and Sustainability Performance of Forestry-Based Bioenergy Systems." Clean Technologies and Environmental Policy 24, no. 6 (2022): 1709–25. https://doi.org/10.1007/s10098-022-02278-1.

[99] Whittaker, Carly, Nigel Mortimer, Richard Murphy, and Robert Matthews. "Energy and Greenhouse Gas Balance of the Use of Forest Residues for Bioenergy Production in the UK." Biomass and Bioenergy 35, no. 11 (2011): 4581–94. https://doi.org/10.1016/j.biombioe.2011.07.001.

[100] Martinez-Hernandez, Elias, Jhuma Sadhukhan, Jorge Aburto, Myriam A. Amezcua-Allieri, Stephen Morse, and Richard Murphy. "Modelling to Analyse the Process and Sustainability Performance of Forestry-Based Bioenergy Systems." Clean Technologies and Environmental Policy 24, no. 6 (2022): 1709–25. https://doi.org/10.1007/s10098-022-02278-1.

[101] "Mexico Deforestation Rates & Statistics: GFW." Global Forest Watch. Accessed March 20, 2023. https://www.globalforestwatch.org/dashboards/country/MEX/.

agricultural and livestock practices. More than 8.1 million hectares have been identified as having appropriate soils and climate conditions for commercial plantations, with the regions with the largest potential located in northern, central western, and southeastern parts of Mexico.[102] However, it is essential to consider the potential negative impact of promoting timber plantations on biodiversity.

In conclusion, to promote sustainable utilization of forestry waste for bioenergy, it is important to implement responsible forest management practices to prevent deforestation. Investing in technology can optimize energy conversion processes and help mitigate negative environmental impact.

Social Considerations

Social considerations associated with the development of forestry biomass energy should be taken into account throughout the development roadmap of the industry. There is a great potential for job creation as it relates to the recovery of forest residues via manual techniques. Because labor costs are still low and the availability of excess capital remains scarce for more technical recovery manners, employing ejidos or other disadvantaged rural communities could provide employment to numerous people.[103]

Furthermore, Mexico's forests are primarily stewarded by ejidos or community forestry enterprises (CFE). Currently, about 500 forest communities across Mexico have formed CFEs with diverse business models which hold the capacity to collect and utilize both forest and sawmill residues for biomass energy production. Communal producers of forest biomass provide biomass to sawmills. The sawmill then uses wood residues to generate bioenergy for self-sufficiency of the local community. The CFRs and ejidos would therefore be the beneficiaries of the newly founded energy access and could cut costs by being self-sufficient or could even increase their profits from the sale of any excess energy generated. While most CFEs

[102] Anaya-Reza, Omar, Juan A. Eguía-Lis, Jorge Aburto, and Myriam A. Amezcua-Allieri. "Environmental Impact Assessment of Heat Generation from Residues: A Forest-Based Industry Case Study." BioEnergy Research 15, no. 4 (2021): 1787–96. https://doi.org/10.1007/s12155-021-10356-3.

[103] Eker, Mehmet, Raffaele Spinelli, and Nevzat Gürlevik. "Recovering Energy Biomass from Sustainable Forestry Using Local Labor Resources." *Journal of Cleaner Production* 157 (2017): 57–64. https://doi.org/10.1016/j.jclepro.2017.04.134.

own small to medium-sized sawmills, about 200 are operating at an industrial scale and can compete in international markets.[104]

Negative implications to consider, however, are the emissions and resulting impacts on air quality from burning biomass for energy. A study conducted on emissions from burning switchgrass and hardwood biomass pellets in a biomass boiler, for example, found that emissions contain relatively high levels of oxygenated compounds, and levoglucosan is the predominant individual semivolatile organic compound (SVOC) constituent. Further, organic matter emissions increase at lower loads due to less-than-optimal combustion performance. While the study found that burning pellets in boilers lowers PM emissions by nearly an order of magnitude compared to other types of residential wood combustion studies, further toxicological evaluation is required to understand the risks posed by the emissions. This raises concerns regarding the potential health implications that would be imposed on the populations working within the sector and those in surrounding communities.[105]

Economic Considerations

Using forest residue to generate energy has the potential to provide affordable and sustainable clean energy to marginalized communities. A study found that 1 MWe can be generated from 12.47 kt/year of forestry residue, with low-pressure steam generation of 50 kt/year, at a cost of production of $0.023/kWh.[106] This can have a significant economic impact on communities, as it can generate jobs and income while promoting sustainability. In addition, creating community forest enterprises (CFEs) can also generate employment and improve social welfare, with La Trinidad CFE offering employment to 40 households a day. The lack of funds from Mexico's National Forestry Commission has suspended operations at UNECOFAEZ nursery, which could impact the sustainable management of almost a million hectares of

[104] Mongabay.com. "Mexico Forest Information and Data" https://rainforests.mongabay.com/deforestation/2000/Mexico.htm

[105] Hays, Michael, John Kinsey, Ingrid George, William Preston, Carl Singer, and Bakul Patel. "Carbonaceous Particulate Matter Emitted from a Pellet-Fired Biomass Boiler." Atmosphere 10, no. 9 (2019): 536. https://doi.org/10.3390/atmos10090536.

[106] Martinez-Hernandez, Elias, Jhuma Sadhukhan, Jorge Aburto, Myriam A. Amezcua-Allieri, Stephen Morse, and Richard Murphy. "Modelling to Analyse the Process and Sustainability Performance of Forestry-Based Bioenergy Systems." *Clean Technologies and Environmental Policy* 24, no. 6 (2022): 1709–25. https://doi.org/10.1007/s10098-022-02278-1.

forests owned by 76 forest communities and ejidos.[107] Poor road infrastructure and inadequate installed capacity of timber industries limit states like Durango and Oaxaca to consume only a fraction of their local production, while states like Chihuahua process only 45% of their local industrial capacity, leading to underuse or import of round wood from other regions. Addressing forest fires is crucial, with 60 forest fires registered in Durango alone in 2023,[108] leading to significant economic consequences and the need for more resources and funds to stop the fires. Adopting better forest practices and investing in fire prevention can have significant economic benefits by preventing the destruction of valuable forest resources, protecting water supplies, and promoting sustainability.

Development Roadmap

Forestry waste has the potential to provide rural communities, ejidos or CFEs, and forest industry producers– specifically in northern regions of the country– with a generous supply of biomass energy. It is recommended that the government first focus its efforts on larger pre-established forestry industries located in the northern and eastern regions of the country due to their high productivity and clear organization of forest enterprises. Additionally, the composition of these forests in the north and east can be harvested easier than that of southern Mexico and impose less environmental concerns as it relates to loss of biodiversity in the primary and tropical forests of the Yucatan region.

Financial returns are considered by various stakeholders to be the most important factor in determining forestry operations. The electricity generation cost from forest biomass is higher than most other sources of energy, primarily due to factors such as high transportation cost of a low density and cumbersome material in which the supply chain has not yet been optimized. Effective supply chain design, from the planting of the trees to its product, is essential to the valorization of energy from forestry waste to usable and productive electricity. The seasonality of supply and geographic distribution make collection, storage, and transportation complex and expensive. This is due in part to its physical properties such as high moisture content

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[107] Hernández T., Marco A. "Mexico: Four Decades of Community Lessons from the Forests of Durango." Mongabay Environmental News, October 13, 2020. https://news.mongabay.com/2020/10/mexico-four-decades-of-community-lessons-from-the-forests-of-durango/.

[108] Newsroom, MDP. "In Durango, 60 Forest Fires Have Been Registered so Far in 2023 - the Durango Post." Mexico Daily Post,April 5, 2023. https://mexicodailypost.com/2023/04/05/60-forest-fires-have-been-registered-so-far-in-2023

and low energy density which hinders technology selection. Supply chain design and logistics integrated in a whole system perspective can positively contribute to achieve greater performance of bioenergy production systems across Mexico's forestry sectors.[109]

Additionally, the high upfront costs to implement biomass energy production will likely deter CFEs or companies from investing in the technology needed to transform their sawmills to be operated on biomass energy. By refining and improving supply chains as it relates to procurement, storage, energy production, and ash management in an integrated framework at a tactical level, using forest biomass in direct combustion power plants to provide a less expensive source of electricity to increase renewable energy production without major capital investment to electricity generation can be achieved.

Moreover, to alleviate upfront capital expenses, the Mexican government should implement economic incentives for these industries to invest in the transition to biomass energy. As mentioned in the previous development roadmap found in the agriculture section, solutions to dissuade economic deterrence associated with the biomass transition can take the form of both low-carbon tax breaks for companies that have implemented clean energy technologies or a subsidy for those that wish to invest but are unable to for a variety of reasons. Varying tax incentives can act as a catalyst to drive the transition to biomass energy consumption at an industrial level. The energy transition within the forestry industry should be done through positive financial incentive and reinforcement rather than enforced additional costs to punish those who do not choose to transition.

Furthermore, these businesses can begin to take advantage of the new cap and trade carbon market that will be established in Mexico in 2023 by SEMARNAT for the industry and energy sectors.[110] As forestry processing facilities, primarily sawmills, limit their greenhouse gas emissions, they can sell carbon credits for the amount of carbon they save below the established cap to help offset initial upfront capital costs.

Another method of reducing costs associated with biomass energy production is to increase research and development into pelletization facilities. The most energy efficient way to utilize forestry waste for energy production is through pelletization

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[109] Helena Paulo, Xavier Azcue, Ana P. Barbosa-Póvoa, Susana Relvas. "Supply chain optimization of residual forestry biomass for bioenergy production: The case study of Portugal." Biomass and Bioenergy, Volume 83, 2015. https://doi.org/10.1016/j.biombioe.2015.09.020.

[110] International Carbon Action Partnership. 2023. "Mexico." International Carbon Action Partnership. https://icapcarbonaction.com/en/ets/mexico.

as it facilitates cost-effective handling, including making transportation and storage less burdensome, and the pellets can be burned with very high combustion efficiency. Yet in Mexico, the biomass pelletization industry is nascent due to the few credit alternatives, the lack of technology, and the wide variability of biomass sources. To date, commercial pellet mills and other pelletizing equipment are widely available across the globe and should be utilized if the government has the ability to invest.[111]

Several strategies can be applied to maximize the transition and valorization of biomass energy from forestry waste:

1. Upgrading Technology and Infrastructure: Modernizing the sawmills with advanced technology and machinery can improve efficiency and reduce production costs.
2. Supply Chain Design Optimization: Entire system design upgrade would benefit the efficiency of the industry as a whole. Improved collection practices and transportation networks can enhance the overall productivity of the industry.
3. Deterrence of illegal logging: To safeguard forests, the government can introduce more rigorous regulations to tackle illegal logging. Illegal logging can lead to economic losses, displacement of land, significant damage to forests, and ultimately affect the biomass energy industry as it relates to forestry waste.[112] Stricter measures against illegal logging can guarantee the safety of the forests and the communities that manage them.
4. Strengthening Support Systems and legal framework for CFEs: Enhancing support systems for forest producers, such as providing access to affordable credit, extension services, and technical assistance, can help improve their productivity and profitability. Additionally, many of the forests in Mexico are managed by local communities, who, with state support, have created CFEs. However, a more detailed framework is needed to ensure the survival of CFEs, especially by enacting laws to provide a clear framework for land tenure and to simplify its complexity.
5. Encouraging Collaboration and Knowledge Sharing: Facilitating collaboration among industry stakeholders, including forest owners, sawmills, research institutions, and government agencies, can foster knowledge sharing and innovation. This collaboration can lead to the development and adoption of

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[111] Zafar, Salman. "Biomass Pelletization Process." *BioEnergy Consult* (blog), September 3, 2021. https://www.bioenergyconsult.com/biomass-pelletization/.

[112] Greentumble. "The Negative Effects of Illegal Logging." Greentumble, December 29, 2020. https://greentumble.com/the-negative-effects-of-illegal-logging.

best practices, improvement in production techniques, and the sharing of technological advancements.

6. Addressing Policy and Trade Barriers: Advocating for policies that support the competitiveness of the forestry industry, including investments into pelletization, reduced trade barriers, targeted subsidies, and tax incentives can improve market access and enhance the industry's competitiveness.

To maximize the potential of forestry biomass valorization in Mexico, policies should be implemented to lower entry costs as well as long term operational costs. To do so, incentives to increase participation, such as tax incentives, legal protections, knowledge sharing, and upgrading technology, can act as a catalyst as mentioned above.

PART II: RURAL AND COMMUNITY DEVELOPMENT

Biomass energy is poised to constitute a minor fraction of Mexico's expanding portfolio of green energy. This report's preceding sections elucidate the application of biomass in a cyclic fashion to power processing plants. However, an additional potential area for biomass implementation lies in the arena of rural development.

Biomass utilization for rural development in Mexico presents an opportunity not only to advance sustainable energy practices but also to stimulate economic growth within rural communities. Given that a significant proportion of Mexico's population resides in rural areas without access to dependable electricity, biomass energy derived from agricultural and forestry residue as well as purpose-grown energy crops may function as a decentralized energy source for these communities.

Access to basic services, including clean water and reliable electricity, is a critical factor for the development of biomass energy in rural communities in Mexico.[113] Particularly in mountainous regions, where biomass energy holds significant potential, the lack of access to such services poses a significant challenge. Biomass energy, therefore, can be a sustainable energy solution.

The Community-Owned Energy Business Model

A potential solution for sustainable energy production is the community-owned energy business model, which involves utilizing locally-sourced biomass residue and waste as inputs. The successful implementation of this approach has been demonstrated in the Adjuntas microgrid project in Puerto Rico.[114] The community-owned energy business model demonstrated by the successful Adjuntas microgrid project in Puerto Rico, which uses locally-sourced biomass residue and waste as inputs, serves as a valuable model for other communities seeking sustainable energy solutions. Mexico has been working on developing its rural biomass resources to create sustainable energy solutions in its rural areas and could particularly benefit from this model in its efforts to address its energy challenges and promote local, environmentally-friendly energy sources.

The establishment of community-owned microgrids, exemplified by the Adjuntas project, has the potential to contribute substantially to this endeavor. The project was launched in response to the devastation caused by Hurricane Maria in 2017. The hurricane left the island without power for months, and many communities were left in the dark. The Adjuntas community recognized the need for a more resilient and reliable energy system and began exploring the possibility of a community-led microgrid. The project was developed in collaboration with local organizations, including Casa Pueblo, a community-based environmental organization that has been advocating for sustainable energy solutions for decades.

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[113] Andries, A., Morse, S., Murphy, R. J., Sadhukhan, J., Martínez-Hernandez, E., Amezcua-Allieri, M. A., Aburto, J. 2023. Potential of using night-time light to proxy social indicators for sustainable development. Remote Sens. 15, 1209. https://doi.org/10.3390/rs15051209

[114] Gallucci, Maria. "Puerto Rico's first community-led microgrid is ready to launch." Canary Media, 16 March 2023, https://www.canarymedia.com/articles/clean-energy/puerto-ricos-first-community-led-microgrid-is-ready-to-launch/

The Adjuntas microgrid project has several benefits for the community.[115] First and foremost, it provides reliable energy to the community, which is particularly important in the aftermath of natural disasters. The microgrid is designed to operate independently of the main electricity grid, which means that it can continue to provide power even if the grid goes down. This is a significant advantage in a place like Puerto Rico, where the grid is often unreliable. The project also creates local jobs and supports the local economy. The microgrid is owned and operated by the community, which means that the profits generated by the project are reinvested back into the system thereby creating a sustainable economic model that benefits the community. The project also provides opportunities for training and education in renewable energy technologies, which can help to build local expertise in this area. Finally, the project reduces carbon emissions and helps to mitigate the effects of climate change. The biomass used to power the microgrid is locally sourced, which means that it does not have to be transported long distances. This reduces the carbon footprint of the project and helps to reduce greenhouse gas emissions. The collaboration between local organizations and the community, as seen in the Adjuntas microgrid project, can be key to the success of efforts to provide reliable and sustainable energy, create local jobs and support the economy, offer training and education in renewable energy technologies, reduce carbon emissions, and mitigate the effects of climate change.

Capacity Building

Part of investing in rural infrastructure includes educating and building capacity among locals to ensure that their communities can maintain the energy plant. A substantial number of staff at all technical levels would be needed to serve the existing and future upkeep needs. Building capacity for microgrids in Mexico will look similar to building capacity for other projects in developing countries, such as desalination projects in Algeria.[116] As stated in the article, "Capacity building

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[115] Gallucci, Maria. "Puerto Rico's first community-led microgrid is ready to launch." Canary Media, 16 March 2023, https://www.canarymedia.com/articles/clean-energy/puerto-ricos-first-community-led-microgrid-is-ready-to-launch/

[116] Hacene Mahmoudi, Ouagued Abdellah, Noreddine Ghaffour. "Capacity building strategies and policy for desalination using renewable energies in Algeria". Renewable and Sustainable Energy Reviews, Volume 13, Issue 4, 2009, Pages 921-926, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2008.02.001.

strategies and policy for desalination using renewable energies in Algeria," the establishment of reliable education and training programs is crucial to the success of these types of community-owned utilities.[117]

> "The most important recommendation in this respect is to establish a training and education center or in the Universities to train the staff working in the sector. Desirable energy education programs should include all renewable energy sources and technologies, with particular emphasis on some specific ones depending upon the local needs and characteristics of the country. It should be flexible and allow for improvement in future. The program should be taught in an understandable language to avoid lack of knowledge and meet the needs of the large public. The program should start from primary and high school level for better acceptance and effectiveness. Energy education programs should also ensure employment of local people and the students."[118]

Therefore, investment into capacity building in developing countries like Mexico is essential to ensuring that these types of locally-owned and operated programs are able to survive and thrive.

Learning from Mexico's neighbor to the north

In addition to universities providing training and education programs, federal, state, and local governments can provide similar types of capacity building programs. Many rural communities all over the world face similar key barriers – namely, a lack of capacity; funding inaccessibility resulting from the complexity and cost of existing government grant programs; compounding social vulnerabilities; and a historical

[117] Hacene Mahmoudi, Ouagued Abdellah, Noreddine Ghaffour. "Capacity building strategies and policy for desalination using renewable energies in Algeria". Renewable and Sustainable Energy Reviews, Volume 13, Issue 4, 2009, Pages 921-926, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2008.02.001.

[118] Hacene Mahmoudi, Ouagued Abdellah, Noreddine Ghaffour. "Capacity building strategies and policy for desalination using renewable energies in Algeria". Renewable and Sustainable Energy Reviews, Volume 13, Issue 4, 2009, Pages 921-926, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2008.02.001.

lack of trust in government agencies.[119] To begin to fill these gaps, the United States has hundreds of programs and opportunities specifically devoted to rural communities.[120] For example, today, the majority of the rural United States is powered by electrical cooperatives. These co-ops serve 42 million people, including 92% of persistent poverty counties.[121] The cooperative model–whereby energy is distributed by partially, if not fully, community-owned utilities– would not have been possible without preliminary legislative investment in technology and capacity, such as in the Tennessee Valley Authority Act.

The United States can be used as a learning lesson for how to invest federal funds directly into communities. By passing widespread legislation that directly invests in communities –such as the Tennessee Valley Authority Act— Mexico can continue to make progress towards ensuring that rural communities have access to reliable sources of energy.

Mexico as an Environmental Justice Leader

Environmental justice (EJ) promotes diverse movements oriented to avoid discriminatory environmental policies, by considering their impact in traditionally relegated groups and including communities in the policy-making process[122]. When regional components of environmental justice are also considered, promoting Mexico's potential biomass development project focused on rural communities may be a significant next step in providing environmental justice while developing local communities in a sustainable way.

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[119] Garcia-George, Sofia; Mark Haggerty, Center for American Progress. "How To Improve Community Wildfire Defense Grants To Build Rural Resilience" https://www.americanprogress.org/article/how-to-improve-community-wildfire-defense-grants-to-build-rural-resilience/

[120] U.S. Department of Agriculture: Rural Development. "All Programs" https://www.rd.usda.gov/programs-services/all-programs

[121] NRECA, America's Electrical Cooperatives. "Electric Co-op Facts & Figures". https://www.electric.coop/electric-cooperative-fact-sheet

[122] The Environment Protection Agency (EPA) defines Environmental Justice as "*the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies*."

In Mexico and in Latin America, EJ has evolved into a broader term that embraces access to information and justice and indigenous self-determination. Emergent from the Rio Declaration and other environmental and indigenous rights' treaties, the Escazú Agreement provides a regional framework for Latin America and the Caribbean to ensure that their states provide with enough information and protection to environmental rights defenders.

However, besides general guidelines on a national level, impact is focused on local governments' policies to reduce exposure to hazardous waste. In the US, Executive Order 12898 provides guidelines to articulate EJ policies on the federal level, and EPA promotes good practices and collaborative problem-solving observed in local projects around the country.

Since rural equity issues are part of the larger umbrella of environmental justice efforts, by investing in rural energy access, Mexico could become a global environmental and energy justice leader.

Community Interview

To build an environmentally justice project requires three main pillars: procedural, distributive and recognition justice.[123] In order to achieve these, the communities directly and indirectly impacted by a project(s) need to be included in the decision-making and roll out processes.

To gain further insights into these challenges, interviews were conducted with rural communities in Santiago Papasquiaro and Victoria de Durango.[124] Our findings indicate that access to clean water remains a major challenge for some communities, with existing dams and pumping systems proving inadequate to meet

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[123] José Vega-Araújo, Raphael J. Heffron. "Assessing elements of energy justice in Colombia: A case study on transmission infrastructure in La Guajira". Energy Research & Social Science, Volume 91, 2022. https://doi.org/10.1016/j.erss.2022.102688.

[124] Community interview, Santiago Papasquiaro and Victoria de Durango, April 2023

their needs. In addition, high electricity prices and frequent power outages during the rainy season further exacerbate the challenge. Communities emphasized the need for government support in improving infrastructure and promoting productive activities in their region.

Durango is rich in biomass sources, including forest waste from pine and oak timber harvesting, as well as industrial waste from sawmills, pellet factories, and plywood factories. Urban waste with the potential to be used as biomass is also available. Currently, the region is using its own and the surrounding area's biomass to operate a 1 MW plant through combustion. However, challenges such as a lack of knowledge, policies that incentivize the use of biomass, and difficulties in collection and transportation pose significant obstacles to the region's ability to fully leverage its biomass potential. Additionally, the waste that remains in the forest contributes to forest fires that affect large areas and damage ecosystems, making compliance with current legal frameworks related to forest harvesting and environmental regulations crucial.

In addition to promoting the development of biomass energy projects, it is crucial to invest in improving the infrastructure of rural communities in Durango. Restricted accessibility to basic services, such as electricity and potable water, has been a persistent challenge for these communities. Augmenting infrastructural resources like dams and pumping systems can help establish a dependable water supply for both household and agricultural purposes and alleviate energy poverty, improving health, wellness, economic development, and overall quality of life.

Furthermore, some communities face an additional obstacle of inadequate drainage infrastructure. Therefore, it is important to allocate investments towards the development of infrastructure that is tailored to meet the unique requirements of each rural community, as they are not uniformly equipped to handle the same technological apparatus.

Investing in biomass energy projects without addressing these fundamental infrastructure challenges could lead to suboptimal outcomes. Thus, alongside incentivizing investment in sustainable energy infrastructure, the Mexican government must also invest in improving drainage infrastructure and water quality to ensure that rural communities can benefit from the biomass projects and that the projects can function seamlessly. By taking a comprehensive approach to rural development in Durango, the government can support the sustainable and inclusive development of rural communities, improving their access to basic services and promoting economic growth and environmental stewardship.

In summary, the challenges faced by rural communities in Durango underscore the urgent need for sustainable and inclusive solutions to improve access to basic services, reduce energy poverty, and promote rural development. Biomass energy can play a significant role in addressing these challenges by providing a reliable and cost-effective source of renewable energy for rural communities. However, realizing the potential of biomass energy requires increased knowledge and investment.

The Mexican government can support the development of the biomass energy sector in Durango by creating policies and providing targeted financial support that incentivizes investment in sustainable energy infrastructure. This could include establishing favorable tax and regulatory frameworks, offering subsidies for the development of biomass projects, and investing in research and development initiatives aimed at improving the efficiency and effectiveness of biomass technologies.

By prioritizing investments in biomass energy infrastructure, the government can help to foster a more sustainable and inclusive energy sector, while also promoting economic development and environmental stewardship in rural communities throughout the state of Durango. Local communities must be involved in decision-making processes, ensuring that their voices are heard and that biomass projects are developed in a way that is procedurally, distribution-, and recognition-just.

In conclusion, the Mexican government has a crucial role to play in supporting the development of the biomass energy sector in Durango. By doing so, it can help rural communities to achieve greater energy security, reduce energy poverty, and promote sustainable development. Ultimately, investing in biomass energy can improve the lives of rural communities, while also contributing to Mexico's broader environmental and economic goals.

PART III: IMPLEMENTATION

This section of the report will analyze recommended enablers for implementing the development and production of biomass in Mexico. In order to foster biomass production, Mexico needs to build capabilities in four key areas: operational, legal, financial, and community collaboration.

Operational

Information sharing is an essential building block in operational capacity building. The International Monetary Fund advises that “the Mexican authorities should strengthen data collection and conduct further analysis to understand the potential impact of climate risks."[125] Interviews conducted in March 2023 with organizations such as IMP, INECC and Grupo BAL illustrated there are multiple information gaps that must be addressed to valorize biomass production in Mexico. As a result, facilitating information sharing between different groups within an organization and across organizations is critical.

IMP[126] has noted there is a misconception that biomass production, especially when it uses agricultural inputs, will require the choice of growing food to feed families versus energy creation. This is not the case because Mexico has legislation that states you cannot use agricultural products intended for human consumption in energy production.[127] As a result, there is no tradeoff between feeding families versus biomass production. Nevertheless, if communication lines between organizations remain underdeveloped, it is possible that certain stakeholders will be unaware of this rule.

Additionally, INECC identified further gaps in the information sharing processes between organizations. In an interview with Dr. Ulises Ruiz Saucedo and Tania Ramirez,[128] both spoke about two operational barriers to biomass development in Mexico. The first is the lack of mapping of big biomass sources indicating where each source would be the most financially and logistically acceptable. The second operational barrier is a lack of publicly available data for research and policymaking. As a result, there are limited inter-institutional data sharing mechanisms. Currently, there are no laws in place that require organizations to collect, register, and share data. This means there is a lack of information sharing and management between organizations. Additionally, there is limited existing foundational information that could be used to create biomass policies. Private sector companies also described

[125] International Monetary Fund. "Mexico: Financial Sector Assessment Program-Technical Note on Climate Risk Analysis". https://www.imf.org/en/Publications/CR/Issues/2022/12/08/Mexico-Financial-Sector-Assessment-Program-Technical-Note-on-Climate-Risk-Analysis-526754

[126] Dr. Myriam Adela Amezcua Allieri, Interview with Instituto Mexicano del Petróleo, March 13, 2023.

[127] J. Amador Honorato-Salazar and Jhuma Sadhukhan, "Annual Biomass Variation of Agriculture Crops and Forestry Residues, and Seasonality of Crop Residues for Energy Production in Mexico," *Food and Bioproducts Processing* 119 (January 1, 2020): 1–19, https://doi.org/10.1016/j.fbp.2019.10.005.

[128] Roberto Ulises Ruiz Saucedo and Tania Ramirez, Interview with Instituto Nacional de Ecología y Cambio Climático, March 15, 2023.

similar challenges.

An interview with Grupo BAL's[129] Director General Jorge Armando Gutierrez Vera,[130] reiterated the same issue about a lack of information sharing both between organizations and also within individual organizations. More information sharing through formal and informal public-private partnerships would allow Mexico to accelerate its renewable energy development.

Similarly, across interviews it was noted that there is no central data platform to refer to for many of the key data-points needed for the development of the biomass industry. Whilst Mexico already has established geospatial tools that could feed into this sort of platform like the Atlas Nacional de Biomasa (geospatial mapping tool laying out the various regions of Mexico and their respective types of biomass), the Atlas of Climate Vulnerability (a tool analyzing climate-related problems, identifies vulnerable regions, sectors, and populations, and issues specific recommendations to strengthen public policy for adaptation to climate change), as well as geospatial data from INEM and SINAICA, it is crucial that this data be made available to all government agencies. Currently, the data is outdated and not shared across the relevant agencies.

A useful case study to examine here may be the U.S. Environmental Protection Agency's (EPA) geospatial (country based) platform EJScreen is a tool developed for mapping and screening environmental justice phenomena within specific geographic contexts. It uses a consistent dataset and approach to combine environmental and socioeconomic indicators. Users can select a geographic area and view publicly-available information on environmental and demographic socioeconomic factors. EJScreen includes 12 environmental indicators, 7 socioeconomic indicators, and 24 indexes which combine these factors. The tool offers color-coded mapping, standard report generation, and comparison capabilities. While there is uncertainty in demographic and environmental data, limitations of the tool's ability to provide a comprehensive risk assessment, a lack of

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[129] Grupo BAL is one of the largest companies in Latin America, standing as one of the largest producers of refined silver in the world and with additional holdings spanning from insurance and retail to renewable energy"Grupo BAL," World Economic Forum, accessed April 14, 2023, https://www.weforum.org/organizations/grupo-bal/.https://www.weforum.org/organizations/grupo-bal/"Grupo BAL."

[130] Jorge Armando Gutierrez Vera, Interview with Grupo BAL's Director General, March 15, 2023.

contextualizing information and local knowledge, the tool is effective at geospatially representing the disproportionate impacts of environmental and energy justice issues on marginalized communities[131]. While there is a need for improved data collection, especially in rural areas, the development of a comparable platform would help policy makers better assess the impacts of their energy and environmental policies, and facilitate the standardization of government data, improving interagency collaboration and producing more consistent programs and policies.

Legal duties and challenges

In Mexico, energy generation and natural resources are matters that fall under the nation's administration and ownership.[132] Thus, their development and valorization are regulated by public law, specifically, the Mexican Constitution, general and organic laws, and federal law. In order for the implementation of biomass in rural development to be successful, the legal framework must be clear in the regulation of the actions of the state and its public servants and efficient in terms of implementation.

Mexico's environmental and energy legal framework is strong, but the lack of specific and up-to-date regulation on forestry biomass poses a challenge to the valorization of biomass in the country. The following subsections will examine problems and challenges within the current legal framework on renewable energy, biomass, and forestry. In addition, two strategic case studies will shed light on how other countries (Chile and Indonesia) have dealt with their own energy transitions and the use of bioenergy from forest biomass, with the aim to illustrate ways in which Mexico can be a leader of bioenergy development in Latin America.

A brief overview of the Mexican legal framework for environmental protection and for energy transition can be found on the Appendix I to this Report.

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[131] US EPA, OECA. "What Is EJSCREEN?" US EPA. US Environmental Protection Agency, October 20, 2014. https://www.epa.gov/ejscreen/what-ejscreen.

[132] Article 27 of the Mexican Constitution.

Legal challenges to biomass valorization in Mexico

a) Regulation of the bioenergetic sector has not been revisited in 15 years

The Bioenergetics Law was published on February 1, 2008 to promote the production and use of bioenergy in order to contribute to sustainable development and energy diversification Specifically, the Bioenergetics Law seeks to promote the production of inputs for bioenergy, from agricultural, forestry, algae, biotechnological and enzymatic processes in the Mexican countryside, without jeopardizing the country's food security and sovereignty, in accordance with the articles 178 and 179 of the Sustainable Rural Development Law.

With the enactment of the Bioenergetics Law, a first step was taken to assure predictability of the legal framework for the bioenergy market, by contributing to the country's rural development through energy diversification.[133] However, no further progress has been made since its publication.

In 2015, the Mexican Government adopted the Energy Transition Law with the aim to gradually increase the share of renewable energies in Mexico's electric industry. While the law includes bioenergetics in its definition of renewable energies,[134] the sustainable utilization of bioenergetics for the production of electric power must be done in accordance with the "applicable legal provisions."[135] After this reform to the energy sector, no changes or revisions have been made to the Bioenergetics Law.

This is problematic because Mexico has an enormous potential for the creation of a bioenergetic industry from forest residue biomass[136]; however, the use and management of forest products for biomass is not thoroughly regulated. For example, in interviews with SENER and INECC, it was underscored that there are no quality standards for these products and the current industry is mostly informal. The bioenergetics regime needs to be updated in order to reflect the goals and aims of

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[133] Article 1(II) of the Bioenergetics Law.

[134] Article 3(XVI)(f) of the Energy Transition Law.

[135] Article 32 of the Energy Transition Law.

[136] Neydeli Ayala-Mendivil and Georgina Sandoval, 2018. "Bioenergía a partir de residuos forestales y de madera" Madera y Bosques, vol. 24. https://www.scielo.org.mx/pdf/mb/v24nspe/2448-7597-mb-24-spe-e2401877.pdf

the energy transition, by including, specifically, provisions for the utilization of residues in a sustainable manner that also takes into account economic viability.

b) Lack of specific regulation about solid bioenergy from forest residue

Besides absence of up-to-date regulations, the Mexican energy framework lacks specific norms about solid bioenergy from forest waste and residue, even though the forestry industry is substantial. According to the Forestry Production Statistical Yearbook, in 2018 more than 14.000 pieces of land were authorized for forest use.[137] This deficit has resulted in a weak market that hinders the development of bioenergy from forestry waste as foreseen by the Bioenergetics Law and the Energy Transition Law.

Nevertheless, the absence of necessary laws and regulations should not prevent an investment in this area. For instance, the City of San Francisco has embraced the precautionary principle as a guiding rule in purchasing and developing its environmental programs and is a good illustration of the precautionary principle in action.[138] The precautionary principle is an attempt to give the notion of precaution—understood as a form of addressing risk—legal status. Its core elements are the need for environmental protection, the presence of threat or risk of serious damage, and the notion that a lack of scientific certainty should not be used to avoid taking action to prevent that damage.[139] Thus, as new scientific data becomes available, the City of San Francisco will review its decisions and make adjustments when warranted. Where there are reasonable grounds for concern, the precautionary approach to decision making is meant to help reduce harm by triggering a process to select the least potential threat.[140]

In Mexico, the ruling of the Supreme Court of Justice, *Amparo de Revisión Número 307-2016*, had previously also signaled the manner in which the principle was to be

[137] SEMARNAT, 2018. "Anuario Estadístico de la Producción Forestal" https://dsiappsdev.semarnat.gob.mx/datos/portal/publicaciones/2021/2018.pdf

[138] Hanson, Jaydee. Precautionary Principle: Current Understandings in Law and Society. (2017, December 31).

[139] Sands, P. & Peel, J. (Eds). (2012). Principles of international environmental law, third edition. Cambridge University Press.

[140] Hanson, Jaydee. Precautionary Principle: Current Understandings in Law and Society.

effectuated.[141] This assessment is quite ubiquitous; for example, the European Commission has also declared that it would be its policy to use the precautionary principle "where preliminary objective scientific evaluation indicates that there are reasonable grounds for concern that the potentially dangerous effects on the environment, human, animal, or plant health may be inconsistent with the high level of protection chosen for the community".[142] Based on the best available science, the precautionary principle requires the selection of the alternative that presents the least potential threat to human health and the natural systems. Public participation and an open and transparent decision-making process are critical to finding and selecting alternatives. Where threats of serious or irreversible damage to people or nature exist, lack of full scientific certainty about cause and effect shall not be viewed as sufficient reason to postpone cost effective measures to prevent the degradation of the environment or protect the health of its citizens.

Consequently, in light of the lack of clear and robust laws and regulations including scientific data should not be considered as a barrier to valorize biomass in Mexico as long as there is a "reasonable belief" that a particular action is harmless to the environment and will provide benefits to the greater public. Mexico should thus consider the application of the precautionary principle in the context of biomass valorization.

c) Absence of Bioenergy Commission's Actions

The Bioenergetics Law was enacted to create a regulatory framework on the use of bioenergy in Mexico. One of its main features is the formation of the Inter-Ministerial Commission for the Development of Bioenergy Products (the "Bioenergy Commission"), which consists of the heads of Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA), Secretariat of Energy (SENER), Ministry of Environment and Natural Resources (SEMARNAT), the Ministry of Economy (SECON) and the Ministry of Tax Collection and Administration (SHCP). The responsibility of these governmental institutions includes, among others, production and commercialization of inputs, and production, storage, transport, distribution, commercialization and efficient use of bioenergy.

[141] Zapata, Jose. Law and the Precautionary Principle: Wild Card for Courts in Latin America? (2001). https://www.hklaw.com/es/insights/publications/2021/03/law-and-the-precautionary-principle-wild-card-for-courts-in-latam. Accessed in May 2023.

[142] European Commission (2000). The Commission adopts communication on precautionary principle. http://europa.eu/rapid/press-release_IP-00-96_en.htm. Accessed in April 2023.

The Bioenergy Commission must elaborate and implement, where appropriate, actions necessary for the promotion of sustainable production of inputs,[143] collaborating with various governmental institutions to make valorization of biomass plausible in Mexico. The establishment of the Bioenergy Commission is essential. Based on discussion with several Mexico Government officials, up to this date, the Bioenergy Commission has not yet taken any action as mandated by the Bioenergetics Law to enhance the valorization of biomass in Mexico.

This poses a challenge in regard to intergovernmental coordination, which refers to the way that different governmental agencies interact with each other[144] to come up with strategies and instruments to coordinate its programs.[145] Based on discussions with various governmental institutions, there is an indication that the intergovernmental coordination is low in Mexico. As a result, some secretariats are not even aware of the existence of Bioenergetics Law.

Intergovernmental coordination is essential to address deficiencies in institutional capacities and intergovernmental coordination for biomass valorization. It is equally important that transparency and public participation can improve an effective community engagement and address knowledge management gaps that can influence access to biomass on a local scale. In addition, discussion between with private and public sectors may increase the possibility of biomass valorization and strengthen the intersectoral coordination by establishing synergies with related projects which can be done by way of, among others, hiring personnel with experience in key positions, and commencing project cooperation with potential community and consumers such as industrial, agricultural, and community level.

d) Delays in renewable energy permits and authorizations

In February 2021, the administration of President Lopez Obrador submitted a bill with several amendments to the 2014 Energy Industry Law to the Mexican Congress.

[143] Art. 17(1) of Bioenergetics Law.

[144] Behnke Nathalie, Mueller Sean. The purpose of intergovernmental councils: A framework for analysis and comparison. Regional & Federal Studies.

[145] Bouckaert Geert, Peters B. Guy, As new scientific data become available, the City of San Francisco will review its decisions and make adjustments when warranted. Where there are reasonable grounds for concern, the precautionary approach to decision making is meant to help reduce harm by triggering a process to select the least potential threat; Verhoest Koen. The coordination of public sector organizations. Shifting patterns of public management. Houndmills, Basingstoke, Hampshire, New York: Palgrave Macmillan.

These proposed amendments significantly altered the legal and regulatory framework in place for the electricity sector, favoring the state-owned enterprise, CFE, over the private sector. As a result, the power contracts and permits of private companies have been limited due to policies that increase CFE's market share. The amendments prioritize energy produced by CFE over that produced by the private sector, both for international and domestic companies.[146] The amendments include:

1. The economic dispatch method has been modified by the 2021 LIE Amendments which has resulted in the CFE's power plants being prioritized to be dispatched first, irrespective of cost-efficiency and sustainability factors. A study predicts this will increase annual electricity production costs by 32-54% and increase Mexico's CO2 emissions by 26-65%. The modification may also impair the operation and profitability of existing power generation projects, leading to obstacles in revenue generation and legal uncertainty.[147]

2. Clean Energy Certificates (CEL) were introduced as part of the 2013 Energy Reform to incentivize electricity generators to use clean energy sources and invest in clean power plants. Prior to the 2021 LIE Amendments, only new renewable energy plants built after August 2014 were eligible to obtain CELs in Mexico. This meant that most of the state-owned CFE's older renewable power plants were unable to obtain CELs and had to purchase them from other clean energy sources to meet the annual clean energy requirements. A CEL market was established to facilitate the buying and selling of these certificates. However, the rules have now changed, and all clean energy sources, including CFE's older renewable power plants, can obtain CELs. As a result, there will be an oversupply of CELs in the market, causing their value to decrease, which could discourage future investments in clean energy projects in Mexico.[148]

3. The 2021 LIE changed the conditions for obtaining power generation permits in Mexico. Instead of meeting certain requirements, new permits are now subject to planning criteria established by the National Electric System issued by the Ministry of Energy. The new regulation sets out further requirements and establishes new obligations in connection with generation permits,

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[146] Llano, Rafael, Francisco de Rosenzweig, Jonathan C. Hamilton, and Marièle Coulet-Diaz. “Energy Investors Face Mexico Risks in the Electricity and Lithium Sectors.” White & Case LLP, July 19, 2022.

[147] Ibid.

[148] Ibid.

including legal, technical, and financial aspects. These changes may reduce new private generation projects in Mexico. Still, transparency in planning criteria and reduced regulatory burden will be crucial to attract new investments.[149]

The amendments introduced by the Mexican government have raised concerns in the international community, especially from the United States and Canada, as the two countries have an agreement with Mexico, specifically the United States-Mexico-Canada Agreement (USMCA). The USMCA includes provisions related to energy, which ensure non-discriminatory treatment. However, the Mexican government's actions in favor of CFE, which disadvantage private companies, can be interpreted as a violation of these provisions.

In July 2022, the United States requested dispute settlement consultations with Mexico under the United States-Mexico-Canada Agreement, stating that the country had violated the terms of the agreement.[150] The US government claims that these sections are violating the trade agreement because Mexico has failed to accord to US investors and their investments treatments that are no less favorable than it accords, in like circumstances, to Mexican investors and their investments[151] and that articles 2.3, 2.11, 13.3, 22.5, 29.3 are all being violated as they are less favorable to US goods, companies and investments. In addition, the government is not administering its laws consistently and impartially.

A 2020 report by S&P found hundreds of projects are on hold due to the denial of permits for building and operating energy projects, which include wind, solar, midstream, and natural gas pipelines.[152] The report found that the delays were caused by CFE and Pemex, both state-owned. During August 2022, Reuters also reported that at least nine major projects, amounting to more than 1,000 megawatts (MW) by large developers like German company BayWa and Italy's Enel Green Power

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[149] Ibid.

[150] "United States Requests Consultations under the USMCA over Mexico's Energy Policies." United States Trade Representative. Accessed May 2, 2023. https://ustr.gov/about-us/policy-offices/press-office/press-releases/2022/july/united-states-requests-consultations-under-usmca-over-mexicos-energy-policies-0.

[151] Bond, David E., and Francisco de Rosenzweig. "United States and Canada Request Consultations over Mexico's Energy Policies under USMCA." White & Case LLP, July 21, 2022. https://www.whitecase.com/insight-alert/united-states-and-canada-request-consultations-over-mexicos-energy-policies-under.

[152] Espejo, Sheky. "Mexico Energy Project Permit Delays Seen as Blocking Growth." S&P Global Commodity Insights, February 14, 2020. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/oil/021420-mexico-energy-project-permit-delays-seen-as-blocking-growth.

are currently stalled as they await permits from the state power regulator. The Enel Green Power project is said to be worth $507 million and is already built and ready to enter operation; however, due to the continuing issues that arise from receiving an electricity generation permit from the CRE, the operation has been stalled.[153] Furthermore, Spain's Iberdrola has an already-built 100 MW wind farm that was denied its generation permit.[154]

The denial of permits for projects that have already been completed may precipitate legal disputes of considerable magnitude. An administrative policy to deny permits could benefit state-owned companies, but it could also be viewed as prioritizing state-owned companies while negatively affecting the private sector. Additionally, in November 2021, Francisco Garza, the Chief Executive of General Motors Mexico, expressed concerns about Mexico's investment in the renewable energy sector.[155] Francisco Garza emphasized, "We're evaluating that if the necessary conditions are not met, the dollar that was going to be invested in Mexico will go to the United States, Brazil, China, or Europe, and Mexico will no longer be a key destination."

Additionally, lawyers who have dealt with permit delays have stated that permits are also delayed due to the lack of technical competence among some government officials. This could hinder growth in general for the entire country as it could be perceived that Mexico lacks competent officials to handle important projects. This perception could result in foreign investors losing confidence in the country's ability to carry out large-scale projects, leading to a decrease in foreign investment.

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[153] Solís, Arturo. "Exclusive: Mexico Withholding Permits for ENEL Renewable Projects Worth $500M." Bloomberg Línea, July 11, 2022. https://www.bloomberglinea.com/english/exclusive-mexico-withholding-permits-for-enel-renewable-projects-worth-500m/.

[154] Garrison, Cassandra. "As Mexico Stalls Major Solar Projects, Companies Turn to Smaller Workarounds." Reuters. Thomson Reuters, August 22, 2022. https://www.reuters.com/world/americas/mexico-stalls-major-solar-projects-companies-turn-smaller-workarounds-2022-08-22/.

[155] Angulo, Sharay. "GM Flags Concern over Renewable Energy in Mexico, Sees Investment Risk." Reuters. Thomson Reuters, November 20, 2021. https://www.reuters.com/business/energy/gm-flags-concern-over-renewable-energy-mexico-sees-investment-risk-2021-11-20/.

In order to address these challenges, the Mexican government should consider implementing comprehensive training programs for government officials involved in the approval process for issuing permits and authorizations. This would help attract domestic and foreign talent. Additionally, the government should encourage better coordination and collaboration between government agencies involved in the authorizations for permits, as improved communication and cooperation can help address the delays. Moreover, establishing clear guidelines and simplifying the procedures could also be beneficial. Finally, if the government wants to focus on state-owned projects, another possible solution would be to encourage public-private partnerships. This would allow state-owned companies to work with private companies, benefiting the country and domestic and international private companies, while also increasing investment.

e) Conclusions

Continuing delays on permits, uncertainties regarding future amendments in Mexican laws for the energy sector, and the government's agenda to prioritize state-owned utilities could have severe legal implications for the Mexican government. Denying or delaying permits and making frequent amendments can discourage foreign investment and make it difficult for Mexico to achieve its renewable energy goals. Therefore, Mexico needs to ensure that it has a stable and predictable legal framework for the energy sector to attract foreign investment, achieve its clean energy targets, and maintain a positive international reputation.

Frequent changes to laws and regulations governing Mexico's energy sector may lead to legal challenges from companies that have invested significant resources in developing renewable energy projects and obtaining permits. If these companies face permit denials or see their investments at risk due to shifting regulatory environments, they may seek legal remedies, which could result in international legal disputes. Therefore, it is crucial for Mexico to establish a stable and predictable legal framework for the energy sector to attract foreign investment, avoid potential legal challenges, and achieve its renewable energy goals.

The USMCA can provide a legal framework for foreign investments in Mexico's energy sector. Article 14.8 of the USMCA prohibits expropriation or nationalization of a covered investment directly or indirectly through measures equivalent to expropriation or nationalization (expropriation), except: (a) for a public purpose; (b) in a non-discriminatory manner; (c) on payment of prompt, adequate, and effective compensation in accordance with paragraphs 2, 3, and 4; and (d) in accordance with due process of law.[156] Adhering to this provision can help Mexico avoid potential legal disputes with US and Canadian companies that have invested in Mexico's renewable energy projects.

Case Studies

Part of the solution to develop and valorize biomass energy in Mexico relies on overcoming the aforementioned problems within the legal framework. Other countries have faced similar challenges, and the way in which they have addressed these issues may offer different alternatives for the development of Mexico's own legal framework on bioenergy from forest residue.

The following sections focus on two countries: Chile and Indonesia. These two case studies were selected because of the Team's familiarity with these countries and because of their considerable development in forestry biomass in the last decade. In Chile, forestry biomass comprised 25% of the primary energy matrix in the country in 2020, and in November 2022, the first solid biofuels law was published. In Indonesia, there is regulatory support for the energy market, which has helped boost the bioenergy industry in rural areas.

Chile

In 2011, biomass had become a priority issue in Chile, as well as other countries in the region, due to oil price volatility[157] and the threat of climate change.[158] The main barriers at the time were the lack of concrete public policies to foment renewable energies, a shortage of experts, and the lack of investment in new technologies.[159]

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[156] "Chapter 14 Investment - United States Trade Representative." Accessed April 30, 2023. https://ustr.gov/sites/default/files/files/agreements/FTA/USMCA/Text/14-Investment.pdf.

[157] World Bank. 2014. "The nature and causes of oil price volatility." https://pubdocs.worldbank.org/en/121871461938592832/CMO-2014-January-analysis.pdf

[158] Manuel Paneque, Celián Román-Figueroa, Rodrigo Vásquez-Panizza, José Miguel Arriaza, Darío Morales, Marcela Zulantay. 2011. "Bioenergía en Chile" Organización de las Naciones Unidas para la Alimentación y la Agricultura.

[159] Ibid.

Different actors participated in the discussion to come up with policies to incentivize biofuels, including the United Nation's Food and Agriculture Organization (FAO)[160] and Office of Agricultural Studies and Policies of the Chilean Ministry of Agriculture (ODEPA).[161] Interestingly, a study that compared the different existing regulations in Latin America regarding the production of biofuels[162] concluded that legislation must include:

- A definition of "biofuel"
- An authority that applies the norms
- Requisites for biomass producers
- Requisites for biomass distributors
- A tax regime
- Timeframes to apply the new legislation
- Sanctions and penalties
- Environmental considerations
- Regulations/rules

By the end of the decade, several policies and programs were implemented through different public sectors. For example, the Ministry of Energy's Energy Policy 2050[163] and the firewood use policy for heating[164] recognize the need for market regulation of forestry-derived biofuels such as firewood, pellets, and briquettes. The specific objectives that were identified in these documents were:

a. Regulating the firewood market through a draft bill that establishes quality standards in this market.
b. Enabling residential heating alternatives different from firewood at accessible prices.

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[160] United Nations. 2006. "América Latina: Seminario trinacional debatirá desarrollo de biocombustibles." https://news.un.org/es/story/2006/07/1083601

[161] Chilean Ministry of Agriculture. 2008. "Contribución de la Polítca Agraria al Desarrollo de los Biocombustbles en Chile" Oficina de Estudios y Políticas Agrarias. https://www.odepa.gob.cl/publicaciones/articulos/contribucion-de-la-politica-agraria-al-desarrollo-de-los-biocombustibles-en-chile-2

[162] Ajilla, V.H. and B. Chiliquinga. 2007. "Análisis de legislación sobre biocombustibles en América Latina." Organización Latnoamericana de Energía (OLADE), p. 26. https://core.ac.uk/download/pdf/48029485.pdf

[163] Chilean Ministry of Energy. "Energía 2050: Política Energética de Chile." https://www.energia.gob.cl/sites/default/files/energia_2050_-_politica_energetica_de_chile.pdf

[164] Chilean Ministry of Energy. 2018. "Ruta Energética 2018-2022. Liderando la Modernización con Sello Ciudadano." https://www.cne.cl/wp-content/uploads/2018/05/rutaenergetica2018-2022.pdf

c. Coordinating with other Ministries actions and programs to retrofit equipment and buildings.
d. Promoting a just and sustainable transition that minimizes the impacts on employment and reduces the social and economic impacts of the transition.

The specific strategy within this program comprised 14 measures upon three pillars: regulation, public programs, and public-private partnerships.[165]

Regarding the first pillar, regulation, support for the bill that regulates solid biofuels was considered, along with other initiatives such as the implementation of a special electricity tariff for residential heating. The draft bill was published in November 2022, becoming Law 21.499.

Regarding public programs, they are implemented through the Energy Sustainability Agency, namely the *Leña Más Seca* Fund, which that seeks to encourage, through a competitive fund, the production and trade of dry firewood for the construction and implementation of Collection and Drying Centers of firewood in the southern Chilean regions. Meanwhile, the Integral Biomass Centers program finances the construction of infrastructure and acquisition of equipment to process larger volumes of biomass in order to increase the supply of dry firewood, pellets, fuel chips and / or briquettes with quality standards. This program seeks to address the larger-scale challenges in the production, refining and standardization of biomass and its diversification in its use in residential heating, so that economies of scale are taken advantage of and quality biofuels are offered at competitive prices.

For its part, the Firewood Quality Seal seeks that producers who have drying and dimensioning processes can ensure compliance with a quality standard of the firewood they market, taking advantage of a certification process that will grant a seal that accounts for that. This Seal relied on the experience of the National Firewood Certification System, a private initiative that certified firewood producers from 2015 to 2020, homologating and assuming the continuity of 120 marketers that

[165] Celia Iturra Molina. 2022. "Bioenergía: Oportunidades y Desafíos de la Biomasa Forestal como Combustible Regulado" Ministerio de Agricultura, Departamento de Política Sectorial y Análisis de Mercado, Chile. https://bibliotecadigital.odepa.gob.cl/bitstream/handle/20.500.12650/71520/Art_Bioenergia.pdf

are already certified, and seeking to expand the number of certified merchants. The Chilean Ministry of Energy has also implemented pilot projects for the replacement of heaters, district energy, studies and collaboration agreements with the private sector for the reduction of electricity tariffs. In the same way, it has integrated this dimension into the Long-Term Energy Planning process aligned with the climate change commitments that Chile has acquired.[166]

In Mexico, a similar regulation could help overcome the current problem of lack of quality standards and market regulation. In a few years, Chile's experience with solid biofuels regulation could inform Mexico whether these policies were sufficient to generate added value to forestry resources in order to transform biomass into a competitive form of energy.

There is a clear demand for clear rules that regulate the industry and promote the benefits and advantages of biomass as energy. Nonetheless, the Chilean experience highlights the importance of having accompanying programs aimed at overcoming competitive and formality gaps of small entrepreneurs and rural producers who, in the face of this new regulation and standard for their commercialization, will require promotion instruments that aim at formalization and value creation.

Indonesia

Similar to Mexico, Indonesia is blessed with an abundance of biomass resources. With a large forestry industry, it is one of the world's largest exporters of wood products, and a key palm oil producer and exporter of palm kernel shells to countries such as Japan and South Korea for biomass feedstock use.[167] Indonesia, as one of the biggest producers of wood products, has a huge potential to utilize its energy forestry and wood waste as a source of biomass, such as wood chips and wood

[166] Ibid.

[167] Tim Fourteau and Winifred Lu. Nikkei Asia: Biomass offers Indonesia a way out of its net-zero emissions dilemma. https://asia.nikkei.com/Opinion/Biomass-offers-Indonesia-a-way-out-of-its-net-zero-emissions-dilemma. "The Role of Biomass Supply Chains for Bioenergy in the Post-COVID-19 Economy | Bioenergy."

pellets, as well as an abundant amount of potential to use biomass as one of substitutes for fossil fuels.[168]

The Government of Indonesia successfully developed a 15 Megawatts biomass power plant using agricultural residues named the Siantan Biomass Power Plant, which is in Wajok Hulu Village, Siantan District, Mempawah Regency, West Kalimantan Province. This biomass power plant started its commercial operation on April 23, 2018, using gasification technology, namely boilers with water tube types with fuel derived from palm oil shells and wood, rice husks, corn cobs, bagasse, sawdust, and other agricultural waste. In addition to providing cleaner energy, this power plant collects its agricultural waste from the surrounding community.

The electricity generated by this power plant will later be channeled through a 20 kilo Volt (kV) network along 5.6 circuit kilometers (kms) from the Siantan Substation (GI) interconnection point to the Equator System.[169] Currently, the Equator System serves customers in Pontianak, Kubu Raya, Mempawah, Singkawang, Pemangkat, Sambas and Bengkayang, with an average capable power of 341 MW and an average peak load of 294 MW. The Power Purchase Agreement between IPP as the developer and PT PLN (Persero), a state-owned electricity enterprise, was signed on September 5, 2016. From a regulatory viewpoint, the Government of Indonesia obliges PT PLN (Persero) to purchase electricity generated from biomass power plants. The electricity purchase prices are determined under the Minister of Energy and Mineral Resources Regulation Number 50 of 2017 on Renewable Energy Utilization (as amended).

Creating a market for biomass requires regulatory support. As in Indonesia, the Government of Mexico may consider mandating the CFE to purchase biomass-based electricity. It may potentially intensify the biomass procedure, engage communities and electrify rural areas.

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[168] Muhammad Osribillal, The Jakarta Post: Promoting biomass as a source of renewable energy in Indonesia. https://asianews.network/promoting-biomass-as-a-source-of-renewable-energy-in-indonesia/#:~:text=Indonesia%2C%20as%20one%20of%20the,of%20substitutes%20for%20fossil%20fuels. accessed April 20, 2023.

[169] Ibid.

Funding

Based on desktop research and interviews with representatives from INECC and Mexico's Expert Group on Resource Management for the UNECE, lack of financing for renewable energy developments in Mexico remains a significant challenge for expanding bioenergy[170]. Further, details on the flows of climate finance in Mexico are obscure, with the last comprehensive study by INECC conducted in 2018. Despite being slightly outdated, the 2018 study reported a few key findings of note that are still relevant:

- Mexico has struggled to attract global climate finance - between 2017 and 2018 the country mobilized $9.2 billion USD from multilateral, bilateral, and national sources between 2017-2018[171], only 3% of global climate flows that flowed towards developing economies in 2017[172]
- The funds came mainly from 10 sources: 2 multilateral mechanisms (Global Environment Facility and Inter-American Development Bank), 2 bilateral institutions or initiatives (International Climate Initiative and KfW Development Bank) and 6 national sources (PEF as part of the national budget, BANOBRAS, BANORTE, NAFIN, and Fund for Energy Transition and Sustainable Energy Use (FOTEASE) and Sociedad Hipotecaria Federal, [173].
- Energy financing in specific was primarily secured via bank credits and simple credits, primarily for large-scale renewable energy infrastructure projects (+50MW projects)[174]

For an overview of the present landscape of capital sources used to fund renewable energy projects, we combined interview findings as well as secondary research to identify 6 main sources that should be leveraged to fund biomass energy projects at

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[170] Roberto Ulises Ruiz Saucedo and Tania Ramirez, Interview with Instituto Nacional de Ecología y Cambio Climático.

[171] Government of Mexico, "Call for Evidence: Information and Data for the Preparation of the 2020 Biennial Assessment and Overview of Climate Finance Flows," 2020, https://unfccc.int/sites/default/files/resource/Mexico.pdf.

[172] Padraig Oliver, Alex Clark, and Chavi Meattle, "Global Climate Finance: An Updated View 2018" (Climate Policy Initiative, November 2018), https://www.climatepolicyinitiative.org/wp-content/uploads/2018/11/Global-Climate-Finance-_-An-Updated-View-2018.pdf.https://www.climatepolicyinitiative.org/wp-content/uploads/2018/11/Global-Climate-Finance-_-An-Updated-View-2018.pdfPadraig Oliver, Alex Clark, and Chavi Meattle.

[173] Government of Mexico, "Call for Evidence: Information and Data for the Preparation of the 2020 Biennial Assessment and Overview of Climate Finance Flows."

[174] Government of Mexico.

varying stages of the industry's development: (a) government funds, (b) national development banks, (c) international development institutions, (d) research institutions, (e) private banks, (f) large corporations. The availability of funds, types of projects that have been financed, and opportunities for securing future capital for each of these sources will be analyzed below.

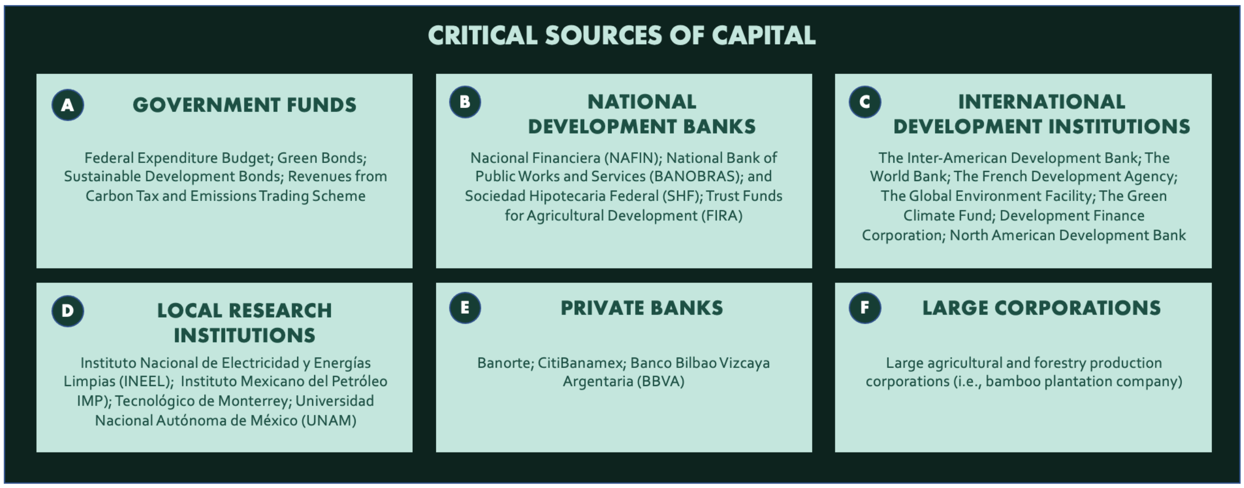

Figure 5: Critical sources of capital.

Government funds

Unlike some prior administrations in Mexico, investments in national climate finance have been increasingly scarce under President Andrés Manuel López Obrador. An analysis of the 2021 Federal Expenditure Budget finds that whilst the national climate finance budget of US $3.5 billion has reached an all-time high, more than 75% of the money was assigned to natural gas development.[175] As a result, the actual effective sustainable funding available is US $878 million - a meager 0.27% of the national budget.[176] At present, estimates suggest that based on the government's budget

[175] Center for U.S. Mexican Studies, "Briefing Paper – Paying for Climate Action: Challenges & Opportunities in U.S.- Mexico Climate Finance Cooperation" (US-Mexico Climate Change Agenda, UC San Diego), 1–32, accessed April 16, 2023, https://usmex.ucsd.edu/_files/climate-change-working-group/briefing-climate-finance-2021-08.pdf.https://usmex.ucsd.edu/_files/climate-change-working-group/briefing-climate-finance-2021-08.pdf.

[176] Center for U.S. Mexican Studies, "Briefing Paper – Paying for Climate Action: Challenges & Opportunities in U.S.- Mexico Climate Finance Cooperation."

allocation, Mexico is short approximately 6.4 billion USD a year required to meet its unconditional nationally determined contributions as part of the Paris agreement.[177]

As such, the government is looking to expand its public finance for climate initiatives. Three such initiatives of note are a carbon tax which reportedly generated USD 307 million in revenues in 2019[178], two highly successful and over-subscribed sustainable development goals bonds valued at USD 890 million and 1.48 billion respectively[179], and a pilot emissions trading scheme whose revenues are yet to be released.[180] Public information, however, does not clearly outline what percentage, if any at all, of the revenues from the carbon tax and emissions trading program will be allocated for green projects.[181] In comparison, whilst renewable energy projects are part of the potential scope of initiatives that can be financed with the SDG bonds, thus far no funds have been diverted towards this goal.[182]

Encouragingly, however, the Deputy Finance Minister Gabriel Yoro has announced that the Mexican government will be soon launching a series of green financial instruments including bonds and derivatives whose proceeds would be earmarked for environmental projects[183]. Additionally, leveraging the government-sponsored framework provided by the recently launched Mexican Green Taxonomy,[184] the

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[177] Center for U.S. Mexican Studies.

[178] Jorge Villarreal Padilla and Mariana Gutiérrez Grados, "Climate Transparency Report 2020: Mexico" (Climate Transparency, 2020), https://www.climate-transparency.org/wp-content/uploads/2020/11/Mexico-CT-2020.pdf.

[179] "Mexico's SDG Bond Allocation & Report 2022" (Secretaría de Hacienda y Crédito Público, April 16, 2023), https://www.finanzaspublicas.hacienda.gob.mx/work/models/Finanzas_Publicas/docs/ori/Espanol/SDG/Mexicos_SDG_Bond_Allocation_and_Impact_Report_2022.pdf.

[180] Jorge Villarreal Padilla and Mariana Gutiérrez Grados.

[181] "Mexico | International Carbon Action Partnership," November 29, 2019, https://icapcarbonaction.com/en/ets/mexico.

[182] "Mexico's SDG Bond Allocation & Report 2022."

[183] Reuters, "Mexico Preparing to Launch Green Finance Instruments - Deputy Finance Minister," *Reuters*, October 12, 2022, sec. Sustainable Business, https://www.reuters.com/business/sustainable-business/mexico-preparing-launch-green-finance-instruments-deputy-finance-minister-2022-10-12/.

[184] Fiona McNally, "Mexico Includes Gender Equality and Access to Services in Sustainable Finance Taxonomy," content, *Responsible Investor* (blog), March 20, 2023, https://www.responsible-investor.com/mexico-includes-gender-equality-and-access-to-services-in-sustainable-finance-taxonomy/.

barriers to structuring and seeking the right accreditations for green financial instruments will become easier. Whilst the details of the financial instruments in planning have yet to be made public, such revenues could be a useful additional funding source.

National Development Banks

National development banks are critical institutions that help mobilize climate finance in Mexico. The largest players are Nacional Financiera (NAFIN), National Bank of Public Works and Services (BANOBRAS), and Sociedad Hipotecaria Federal (SHF)[185]. The national development banks have historically played an important role in crowding in private sector support for industries that were considered 'unbankable.' For example, NAFIN was a critical early funder of the wind energy industry in Mexico. Combining its funds with the Inter-American Development Bank, the two institutions invested US $550 million to build a 250 MW wind farm in Oaxaca which produced enough energy to service half a million people and reduce annual carbon dioxide emissions by 600,000 metric tons.[186] NAFIN has since financed 13 wind farms, a solar plant and two hydroelectric plants across the country amounting to US$4 Billion in investments[187]. Another second-tier national bank of significance referenced during interviews was Trust Funds for Agricultural Development (FIRA) - a key provider of credit and guarantees, training, technical assistance and technology-transfer support to the agriculture, livestock, fishing, forestry and agribusiness sectors in Mexico.[188] In the past, FIRA has played a significant role in the issuance of green bonds related to the forestry & agriculture sectors - launching two

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[185] Government of Mexico, "Call for Evidence: Information and Data for the Preparation of the 2020 Biennial Assessment and Overview of Climate Finance Flows."

[186]"Mexico's Experience Shows That Development Banks Can Play a Key Role in Financing Transitions to Low-Carbon Economies | LSE Latin America and Caribbean," *LSE Latin America and Caribbean Blog* (blog), April 12, 2017, https://blogs.lse.ac.uk/latamcaribbean/2017/04/12/mexicos-experience-shows-that-development-banks-can-play-a-key-role-in-financing-transitions-to-low-carbon-economies/.https://blogs.lse.ac.uk/latamcaribbean/2017/04/12/mexicos-experience-shows-that-development-banks-can-play-a-key-role-in-financing-transitions-to-low-carbon-economies/"Mexico's Experience Shows That Development Banks Can Play a Key Role in Financing Transitions to Low-Carbon Economies | LSE Latin America and Caribbean."

[187] "Mexico's Experience Shows That Development Banks Can Play a Key Role in Financing Transitions to Low-Carbon Economies | LSE Latin America and Caribbean."

[188] "FIRA FEFA," Climate Bonds Initiative, April 26, 2019, https://www.climatebonds.net/certification/fira_fefa.

green bonds of USD 130 million in 2018 and 2019 respectively.[189] Given its history with issuing bonds related to agriculture and forestry, FIRA can be a valuable partner in securing financing for biomass using waste from these sectors.

As evidenced by the examples above, equally important, national development banks facilitate access to foreign sources of capital through working in partnership with other development banks and institutions globally. To this end, Mexico is currently supporting NAFIN and BANOBRAS to become a Green Climate Fund "Direct Accredited Entity" - a special accreditation for national banks which enables them to be able to access capital from the UNFCCC's landmark climate fund.[190] Building the capacity of National Development Banks to meet international standards and accreditations should therefore continue to be a priority to increase access to foreign sources of energy transition financing.

International Development Institutions

While more recent estimates remain difficult to obtain, a Transparency Mexico study[191] found that between 2015-2017 Mexico received USD $5.25 billion for climate change in international development finance, with the main funds coming from 3 institutions: The Inter-American Development Bank (40%), the World Bank (29%), and the French Development Agency (20%). Particularly encouraging for the development of the biomass industry, 22% of this development funding was dedicated to energy and renewables development and 13% towards energy efficiency projects[192]. Aside from these three institutions, Mexico has also managed to draw smaller amounts of international capital (with approximately less than USD $50 million a year) from The Global Environment Facility (GEF), The Green Climate Fund, USAID as well as non-profits like The Nature Conservancy and Rainforest

[189] "FIRA FEFA."

[190] Government of Mexico, "Call for Evidence: Information and Data for the Preparation of the 2020 Biennial Assessment and Overview of Climate Finance Flows."

[191] Transparencia Mexicana, "Origen y destino del financiamiento climático en México, una ruta por trazar," *Transparencia Mexicana* (blog), June 12, 2018, https://www.tm.org.mx/origen-y-destino-del-financiamiento-climatico-en-mexico-una-ruta-por-trazar/.https://www.tm.org.mx/origen-y-destino-del-financiamiento-climatico-en-mexico-una-ruta-por-trazar

[192] Mexicana.

Alliance.[193][194] Whilst most of the projects funded using the GEF funds have been coastal wetland and water projects, funding from the other organizations has largely been focused on sustainable agricultural and forestry projects among small industrial owners which can be directly leveraged for securing financing for the biomass use cases detailed above.[195]

An under-utilized source of capital that can be further explored is grants from major development philanthropies. For example, Mexico could look to join the Rockefeller Foundation's Global Energy Alliance for People and the Planet (GEAPP) - a program aimed to expand energy access and development in low-middle income countries through green energy and jobs[196]. In specific, expanding biomass energy to increase rural energy access can be directly funded as part of the GEAPP's focus on distributed energy systems.

An additional critical resource which has emerged as part of the North American Free Trade Agreement is American development assistance. The American Development Finance Corporation (DFC), for example, in 2020 provided a loan guarantee of US$241 million to IENEVO, a Mexican energy developer, for constructing solar power assets in Mexico. Additionally, the North American Development Bank (NADB) is another critical funder of renewable energy projects. Whilst the NADB is restricted to only funding projects located in the border region[197], the bank already has financed USD $120 million in loans for wind energy projects in large parts of

[193] Government of Mexico, "Call for Evidence: Information and Data for the Preparation of the 2020 Biennial Assessment and Overview of Climate Finance Flows."

[194] "Mexico Climate Change Country Profile | Fact Sheet | Latin America & the Caribbean," U.S. Agency for International Development, March 17, 2023, https://www.usaid.gov/climate/country-profiles/mexico.https://www.usaid.gov/climate/country-profiles/mexico"Mexico Climate Change Country Profile | Fact Sheet | Latin America & the Caribbean."

[195] Center for U.S. Mexican Studies, "Briefing Paper – Paying for Climate Action: Challenges & Opportunities in U.S.- Mexico Climate Finance Cooperation."

[196] The Rockefeller Foundation Energy Alliance, "Global Energy Alliance for People and Planet (GEAPP):FAQ," Global Energy Alliance for People and Planet (GEAPP), accessed April 16, 2023, https://www.energyalliance.org/about-us/faq/.

[197] The applicable "Border region," is delineated as within 100 kilometers (about 62 miles) north of the international boundary and within 300 kilometers (about 186 miles) south of the border

northern Mexico (Mina, Nuevo Leon, Reynosa, Tamaulipas) - areas where biomass energy may be developed as part of agricultural and industrial operations.[198]

Whilst international development institutions offer a valuable source of capital, interviews with INECC suggest that securing meaningful international climate financing is challenging due to these institutions having a poor understanding of Mexico's socio-political landscape therefore resulting in the imposition of solutions which may not be suitable for the local context.[199] INECC's concerns have been similarly voiced by many other low-middle income countries. To address this gap, further engagement with international development institutions needs to be coordinated to ensure that they are partnering with local institutions.

Research Institutions

Based on interviews with INEEL, local research institutions have been influential players in funding the research and development of biomass projects in Mexico. Firstly, government research institutions like IMP have already been lead financiers of biomass energy studies, utilizing their existing facilities as well as scientific expertise to conduct research on the efficacy of biomass energy production using different inputs and industrial facilities[200]. Whilst most of INEEL's research in this space has been focused on biofuels as well as biomass gasification, INEEL intends to finance an extension to its gasification study to understand the electricity generation potential from converting gas generated from biomass into electricity[201]. Based on interviews with INEEL, universities such as the Tecnológico de Monterrey as well as Universidad Nacional Autónoma de México (UNAM) have also historically funded biofuel research and therefore are well placed to fund biomass energy research projects in the future due to the proximity of these research areas[202].

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[198] Government of Mexico, "Call for Evidence: Information and Data for the Preparation of the 2020 Biennial Assessment and Overview of Climate Finance Flows."

[199] Roberto Ulises Ruiz Saucedo and Tania Ramirez, Interview with Instituto Nacional de Ecología y Cambio Climático.

[200] Dr. Abigail González, Interview with Instituto Nacional de Electricidad y Energías Limpias, March 15, 2023.

[201] Dr. Abigail González.

[202] Dr. Abigail González.

Private Banks

Major private banks in Mexico have begun to play an increasing role in financing the renewable energy industry. The most important players are Banorte, CitiBanamex and BBVA - all of whom have sustainable finance divisions and finance renewable energy projects.[203] Critically, however, these institutions are focused largely on financing low-risk, large scale, high return renewable energy projects - hence the popularity of private banks in Mexico financing solar which experts suggest has high scalability, a proven technology and the same cost competitiveness as traditional fossil-fuel powered combined heat and power systems.[204] Securing financing for biomass projects from private banks therefore poses a challenge in the short term as there is not enough available data on the inputs available, the generation potential of biomass projects, as well as the proficiency of the technology for the sector to quantify the risk and therefore the return it needs to see from these projects to be considered 'bankable.' However, it is important to note that with an increasing push towards Environmental Social Governance (ESG) investing amongst banks - investing in projects which are more socially minded - there is scope for future financing to open up for such projects. With social benefits of projects to be considered in the risk/return calculation of banks, a project like rural biomass energy for expanding energy access can, for example, feasibly be funded as part of an ESG portfolio. Additionally, with the recent launch of Mexico's Green Taxonomy, in the long term there will be clearer frameworks to help categorize and therefore direct capital towards 'green projects' as the taxonomy becomes more deeply embedded in the market frameworks.[205]

Corporations

Another source of funding that can be explored for developing the biomass energy industry is corporations. Based on interviews with INEEL and INEEC, particularly for industrial use cases, large companies operating in these industries can finance early research of biomass energy to help mitigate their emissions and improve their waste

[203] Government of Mexico, "Call for Evidence: Information and Data for the Preparation of the 2020 Biennial Assessment and Overview of Climate Finance Flows."

[204] Roberto Ulises Ruiz Saucedo and Tania Ramirez, Interview with Instituto Nacional de Ecología y Cambio Climático.

[205] McNally, "Mexico Includes Gender Equality and Access to Services in Sustainable Finance Taxonomy."https://www.responsible-investor.com/mexico-includes-gender-equality-and-access-to-services-in-sustainable-finance-taxonomy/

management practices.[206] Interviews with INECC suggest that this may be increasingly appealing to large local corporations who may have to refine their production practices to maintain competitiveness in international markets, particularly with the introduction of new policies like the EU Carbon Border Adjustment Mechanism which will impose an import tax based on the carbon content of goods entering the EU that are produced abroad.[207] The EU's new import tax will therefore reduce the cost competitiveness of goods produced by large corporations in Mexico where the production process may not be as emissions efficient, thereby providing an incentive for these corporations to invest in research and development of technologies which may reduce emissions and waste from their production processes.

Importantly, corporate funding has already been used to finance critical research close to this space. INEEL's research on the utility of bamboo as a biomass input for gasification, for example, was co-sponsored by a private bamboo plantation corporation that was looking to better manage its waste.[208] With the corporation helping to fund the high upfront capital costs of building a processing facility, INEEL now intends to use the machinery to test different biomass inputs and can do so at a substantially lower cost using the existing machinery.[209] This case study provides an example of a similar model which can be replicated for other bioenergy research going forward.

Capital Sources to Leverage Across the Development of the Biomass Energy Industry

Understanding the differing risk appetites and the availability of capital for each financial partner is key to securing financing for the end-to-end development of the biomass energy industry. A high-risk appetite can be defined as the willingness to take on projects with a high level of uncertainty in outcomes and return on investment. A high availability of capital can be defined as having large sums of

[206] Roberto Ulises Ruiz Saucedo and Tania Ramirez, Interview with Instituto Nacional de Ecología y Cambio Climático.

[207] Roberto Ulises Ruiz Saucedo and Tania Ramirez, Interview with Instituto Nacional de Ecología y Cambio Climático.

[208] Dr. Abigail González, Interview with Instituto Nacional de Electricidad y Energías Limpias.

[209] Dr. Abigail González.

capital (approx. 1 Billion USD or more) to invest in projects. In Figure 1, the 2x2 matrix places all the key financial partners analyzed above on two sliding scales for risk appetite and availability of capital to help outline how these organizations may perceive investing in different stages of development for the biomass energy industry.

Figure 6

Broadly, as shown in Figure 6, the different stages of development for the biomass energy industry can be categorized into 4 phases: (a) research and development - conducting studies to collect more data on the potential of the industry, (b) pilot projects - testing research in live settings, (c) small scale applications - scaling the projects to small communities or businesses, (d) industrial applications - applying the bioenergy technology to large industrial operations.

With a budget in excess of USD $500M, the government has a moderately high availability of capital. With government funds entailing the use of public money the government's risk appetite is necessarily partially conservative, requiring that funds are directed to projects that are credible, but also is more flexible due to their mission orientation of serving the broader social good. This enables the government funds to be the most flexible source of capital in that it can be delivered as grants or direct investment across all stages in the biomass energy industry's development, with the primary restriction being its limited availability of resources.

Similarly, national development banks have a moderately high availability of capital, but a higher risk appetite than the government having financed projects in Mexico that were considered 'unbankable' and served as a key mobilizer that has de-risked projects and brought in private capital. Typically, however, national development banks make large investments and as such likely they would be a financier of small and industrial applications of bioenergy.

	RESEARCH & DEVELOPMENT	PILOT PROJECTS	SMALL SCALE APPLICATIONS	INDUSTRIAL APPLICATIONS
A GOVERNMENT FUNDS	✓	✓	✓	✓
B NATIONAL DEVELOPMENT BANKS			✓	✓
C.1 INTERNATIONAL DEVELOPMENT BANKS		✓	✓	✓
C.2 INTERNATIONAL DEVELOPMENT NON-PROFITS & PHILANTHROPIES	✓	✓	✓	
D LOCAL RESEARCH INSTITUTIONS	✓	✓		
E PRIVATE BANKS				✓
F LARGE CORPORATIONS	✓	✓		✓

Figure 7

While international development banks draw on international capital and therefore have outsized availability of capital when compared to national development banks and government funds, they have a comparatively low risk appetite as they are looking for market, or at minimum slightly below market returns, and are often less familiar with local context. Hence, while international development banks are a promising source of capital, they are largely reserved for highly vetted projects via concessional loans and credit and are most likely to finance pilot projects, small scale applications and industrial applications to crowd in spending from private banks. In comparison, international development nonprofits and philanthropies have lower availability of resources, but a much higher risk appetite as they are more focused on financing projects with a high impact, even if the returns are not as abundant. As such, international development nonprofits are best suited to fund lower budget projects in the earlier stages of development such as research and development, pilot projects and small-scale applications.

Local research institutions likely have a higher risk appetite to invest in more experimental projects with unknown outcomes than most other potential funders as they are built to be innovation centers conducting research on new and untested ideas, but have a low availability of capital and hence are most likely to fund lower budget projects in earlier stages of development such as research & development and pilot projects. Additionally, research institutions are best placed as they have high levels of credibility with the public and trusted officials coupled with the right expertise and facilities to launch innovative research projects.

Whilst private banks have the highest availability of capital amongst all financial partners, they also have the lowest risk appetite as they are primarily looking to invest in proven technologies that are scalable and have high investment returns. In short, private bank financing may be most suitable to be deployed for biomass energy projects at a later stage in the industry's development where the goal is scaling industrial applications as the private banking sector will likely have both more information to quantify the risks and returns of these investments.

Similarly, large corporations involved in agricultural and forestry activities have high availability of capital, however a higher risk appetite than private banks as biomass energy using waste from these sectors may be directly beneficial to the efficiency and competitiveness of their operations. As such, large corporations can be investors that fund early research and pilot projects to create technologies that are beneficial for them. Additionally, they can be financiers for industrial applications as large contracts can be secured for the development and implementation of biomass projects across their facilities.

In conclusion, securing financing for the development and expansion of the biomass energy industry will require maximizing a mix of public and private resources. At each stage in the industry's development, different financial partners should be leveraged based on their risk and capital availability to provide the critical capital required to move the industry forward.

Constraints

It is important to acknowledge the financial constraints that must be considered during Mexico's transition to renewable energy, and ultimately biomass production. Mexico is still highly dependent on oil and gas.[210] The figure below shows how the

[210] "Mexico: Financial Sector Assessment Program-Technical Note on Climate Risk Analysis," accessed April 16, 2023, https://www.imf.org/en/Publications/CR/Issues/2022/12/08/Mexico-Financial-Sector-Assessment-Program-Technical-Note-on-Climate-Risk-Analysis-526754.

majority of carbon dioxide emissions come from utilities and manufacturing.[211] However, the bottom chart shows that approximately 37%[212] of the commercial banking system's credit exposure is concentrated in emission intensive industries such as manufacturing, construction, mining, and utilities. As a result commercial banks will have to be careful when reorienting their investments from fossil fuels to renewable energy because this transition might impact Mexico's overall financial stability.[213] However, on the other hand, "a question to analyze also is the extent to which the financial sector might be well positioned to support the transition to the low carbon economy by boosting its credit to finance green climate projects across sectors."[214] As a result, Mexico's financial sector will play an important role in the energy transition.

[211] "Mexico: Financial Sector Assessment Program-Technical Note on Climate Risk Analysis."

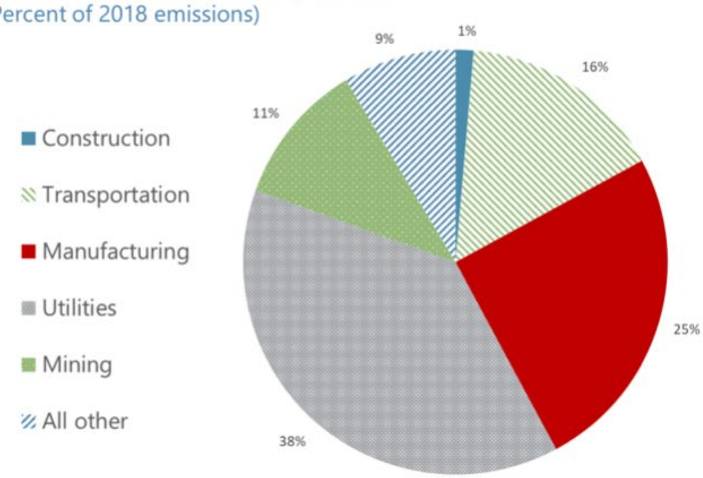
[212] Ibid.

[213] Ibid.

[214] Ibid.

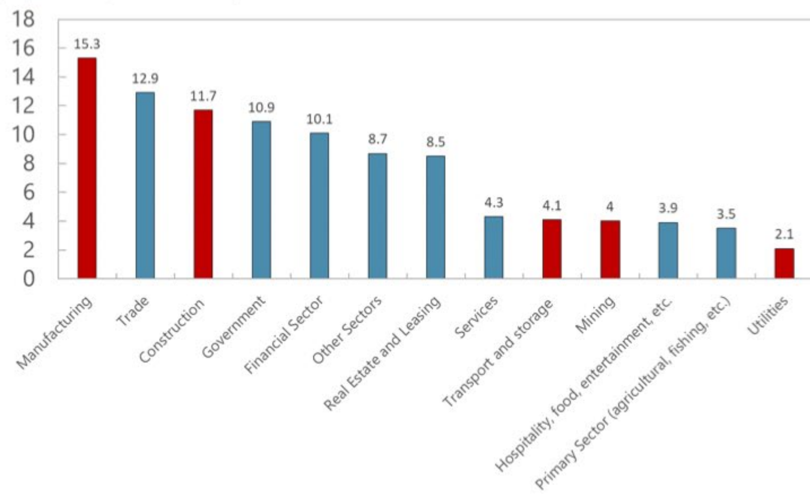
Carbon Dioxide (CO2) Emissions and Financial Sector's Sectoral Credit Exposure

Mexico CO2 Emissions by Sector
(Percent of 2018 emissions)



Sources: OECD; and IMF staff calculations.

Banking System Credit Exposure by Economic Sector
(In percent, end of 2021)

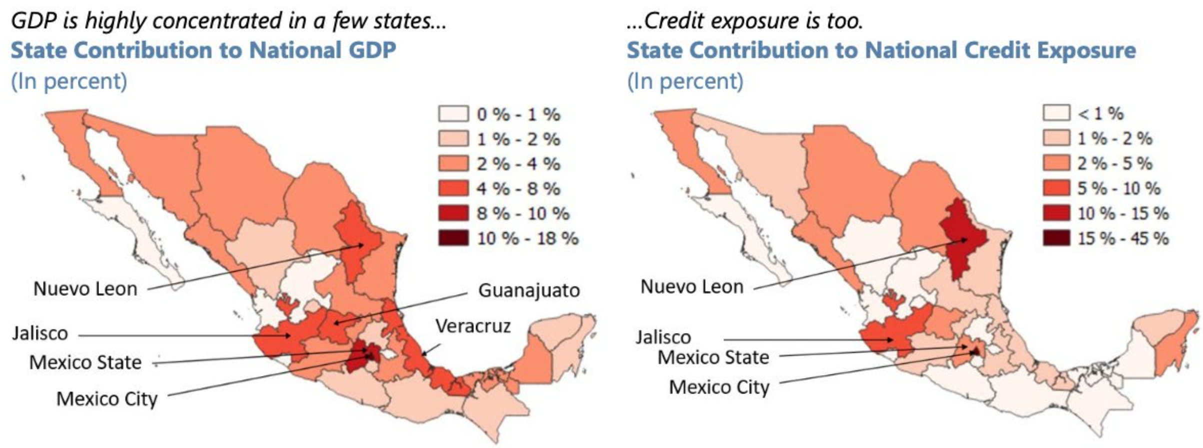


Sources: Banxico; and IMF staff calculations.

Note: The emission intense sectors are shown in red.

Figure 8

Financial stability might be further threatened in this transition to renewable energy because both credit exposure and GDP are heavily concentrated in a small number of states.[215] Per the IMF, in 2020 six states accounted for around 50 percent of Mexico's national GDP, also illustrated in the below graph. If major economic centers in Mexico do not have a well-structured plan for transitioning to renewable energy, it may put the most important economic zones in Mexico at risk and cause significant hardship. As a result, Mexico should begin taking steps to diversify industries in areas that are the largest contributors to overall GDP.



Source: WB staff calculation using GDP data from statistica.com and credit data from Banxico (end of 2021).

Figure 9

Community Collaboration and Community-Based Participatory Action Research (CBPAR)

The knowledge held within a community is invaluable and offers crucial insights that ground and contextualize administrative data.[216] The knowledge of individuals, families, and other community members is significant and should be recognized as such. Top-down research methods traditionally used in academia may not be adequate for full comprehension or resolution when dealing with intricate social

[215] Ibid.

[216] Wallerstein, Nina, Bonnie Duran, John G Oetzel, and Meredith Minkler. *Community-Based Participatory Research for Health : Advancing Social and Health Equity*. San Francisco, Ca: Jossey-Bass, A Wiley Brand, 2018.

issues. Historical evidence indicates that external interventions often fall short of expectations. As a result, communities should be involved in identifying, researching, and resolving local issues. As IMP moves forward in researching and implementing biomass to energy infrastructure, it's crucial that community health and cultural impacts are integrated into programs and policies. Community-Based Participatory Action Research (CBPAR) is a research orientation that IMP can use to inform research question, design, and methodology creation, and dissemination plans.

The Healthy City program from the Advancement Project identifies six steps to implement CBPAR.[217]

1. Project Design and Implementation: identifying the research question and project focus
2. Partner Engagement: identifying project partners and collaborators
3. Data Collection: refining the research question and choosing data collection methods
4. Data Analysis: creating and implementing an analysis plan
5. Reporting: analyzing data, disseminating the results, and taking action

IMP should plan to adapt this framework as they move forward in research, program, and policy planning and implementation. The full outline of this program can be found in the appendix.

[217] https://hc-v6-static.s3.amazonaws.com/media/resources/tmp/cbpar.pdf

CONSOLIDADED RECOMMENDATIONS

This section contains a chart outlining the policy and legal recommendations presented throughout the report, including short-, medium-, and long-term recommendations.

Section	Sub-Section	#	Recommended Action	Timeline
2. Industry	**Agriculture and Forestry**	**1**	Research and development into biomass technologies for multiple residue sources and determination of the shelf-life of various residue types	Short-term
		2	Pilot CHP biomass energy projects using different waste sources to use as leading industry examples	Short-term
		3	Provide subsidies for companies to procure alternative sources of energy between the harvesting seasons of all crops and tree species	Short-term
		4	Create tax incentive policies - tax breaks for companies that have implemented clean energy technologies or a subsidy for those that wish to invest	Short-term
		5	Utilize Mexico's carbon market as a financial incentive to implement low-carbon energy systems	Long-term
		6	Build an agro-industrial waste marketplace for companies to buy and sell residues	Long-term
3. Rural & Community Development		**1**	The government should provide financial support, through investment and funding, to improve infrastructure and promote productive activities in the regions	Short-term
		2	Allocate investments towards the development of infrastructure	Short-term

			tailored to meet the unique requirements of each rural community, especially in regards to water and drainage infrastructure	
		3	Create policies that provide financial incentives and training programs to promote investment and usage of biomass energy, which can help maximize the region's biomass potential.	Short-term
		4	Encourage the Mexican government to establish a comprehensive and sustainable plan to manage the use of biomass and reduce forest waste to minimize the damage to ecosystems	Long-term
		5	Encourage the development of affordable and sustainable renewable energy alternatives by providing financial and technical support, such as subsidies, grants, and training programs, to businesses and communities.	Long-term
		6	Promote education and training programs for the communities to increase their knowledge of renewable energy technologies and sustainable resource management practices	Long-term
4. Implement	**Operational**	1	Strengthen data collection and reporting laws about energy use in Mexico	Long-term
		2	Promote information sharing	Long-term

ation			between government agencies about the risks of climate change in Mexico by designing a centralized database	
		3	Augment existing geospatial tools, such as Atlas Nacional de Biomasa, to identify optimal areas for biomass development	Medium-term
		4	Increase stakeholder understanding of biomass, and that it does not require a tradeoff between food production and energy production	Long-term
		5	Compile foundational information on biomass that stakeholders can draw on to develop policies	Medium-term
		6	Strengthen public-private partnerships	Long-term
	Legal	**1**	Revisit the Bioenergetics Law and bring it up-to-date with the energy transition	Medium-term
		2	Promote intergovernmental coordination in matters of biomass energy by implementing the Bioenergy Commission under the Bioenergetics Law.	Short to medium-term
		3	Address the administrative policies that generate permit delays	Short-term
		4	Strengthen the quality control of forest biomass products by standardizing the firewood market	Short to medium

			through, for example, quality seals.	term
		5	Mandate CFE to purchase biomass-based energy and offer appropriate regulatory support to the industry.	Medium-term
	Funding	**1**	Lobby for greater allocation of funds in the PEF to develop and expand the biomass energy industry	Long-term
		2	Continue building the capacity of National Development Banks to meet international standards and accreditations	Medium-term
		3	Leverage National Development Banks to secure increased international and national funding for small scale and industrial applications of biomass energy	Medium-term
		4	Campaign to incorporate biomass energy projects as eligible for allocations from Mexico's SDG and green bonds	Short-term
		5	Seek increased funding from international development banks like The World Bank, French Development Agency, American Development Finance Corporation, NADB to fund pilot projects, small scale and industrial applications of bioenergy	Long-term
		6	Apply for grants from international development nonprofits like The Nature Conservancy, The	Short-term

			RainForest Alliance and The Rockefeller Foundation to fund early research and development, pilot projects and small scale applications of bioenergy	
		7	Establish partnerships with local and international research institutions (INEEL, INECC, UNAM, University of Monterrey) to fund research and development and pilot projects for bioenergy	Short-term
		8	Establish deeper partnerships with private banks like Banorte; CitiBanamex; BBVA to increase understanding of bioenergy industry and its potential to increase financing from private banks for industrial applications of bioenergy	Long-term
		9	Identify and establish partnerships with large corporations in agriculture and forestry sectors to finance early research and development, pilot projects and secure large-scale contracts for industrial applications	Short-term

CONCLUSION

Alternative forms of energy are crucial to achieving a more sustainable global energy supply. Mexico is looking to diversify their energy portfolio in a way that centers people, and with the consent of local communities impacted by the extraction, development, and/or use of various energy inputs.

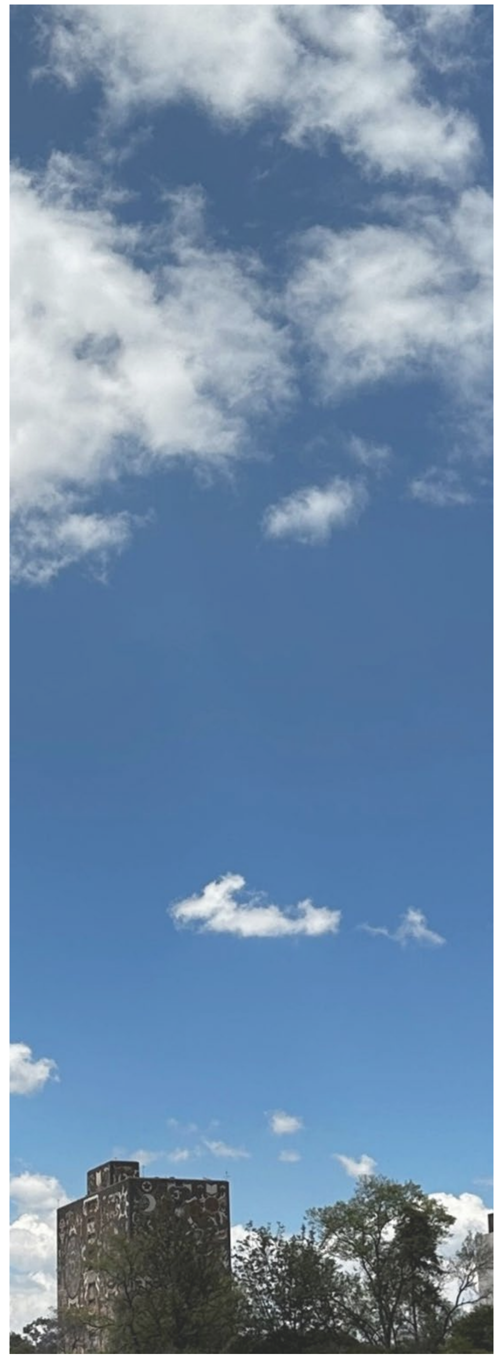
Alternative forms of energy are crucial to achieving a more sustainable global energy supply. Mexico is looking to diversify their energy portfolio in a way that centers people, and with the consent of local communities impacted by the extraction, development, and/or use of various energy inputs. For example, the Mexican Secretariat of Energy is currently researching ways of scaling up production of biomass energy to be used for low-emission household and industrial use. This report recommends ways to expand biomass production in Mexico by analyzing the opportunities and risks of this alternative energy source. Following an analysis of biomass supply chains, this report provides recommendations on implementing biomass development at the community and industrial scale taking into account the impacts on public health, environmental sustainability, gender equity, human rights, and Mexico's laws and regulations.

Mexico's agricultural and forestry industries can be greatly benefited from access to biomass energy, by using inputs from industry waste for energy, ultimately enhancing the energy security of these facilities, reducing electricity and transportation costs, and mitigating negative environmental impact. Mexico's rural and developing communities can also benefit from access to biomass energy, by using local biomass waste as an input in microgrids and distributed energy sources for low cost to increase energy access.

However, implementing said projects requires substantial effort in the country's operational, legal, financial, and community-based collaboration. Throughout the Report, we describe how, in order to foster biomass production in Mexico, the country must improve in four key areas: operational, legal, financial, and community collaboration. We end our report with recommendations for each of these subcategories in order to effectively implement our proposed policies for industry and communities.

"Mexico's rural and developing communities can also benefit from access to biomass energy, by using local biomass waste as an input in microgrids and distributed energy sources for low cost to increase energy access."

CAPSTONE TEAM BIOGRAPHIES



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Aisulu is a graduate of Kazakh Agro-Technical University with distinction, with majors in Economics and Business. She started her career in the Ministry of Oil and Gas of the Republic of Kazakhstan. In August 2019, she was working as Chief Expert of the Bilateral cooperation division of the Ministry of Energy of the Republic of Kazakhstan. Additionally, she is the recipient of the Bolashak International Scholarship. Aisulu is currently taking a sabbatical to pursue an MPA degree at Columbia University with a concentration in Energy and the Environment.

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Emma is passionate about addressing global issues and inequities at the intersection of environmental and social justice. She graduated with a Masters of Public Administration in Development Practice from Columbia University.
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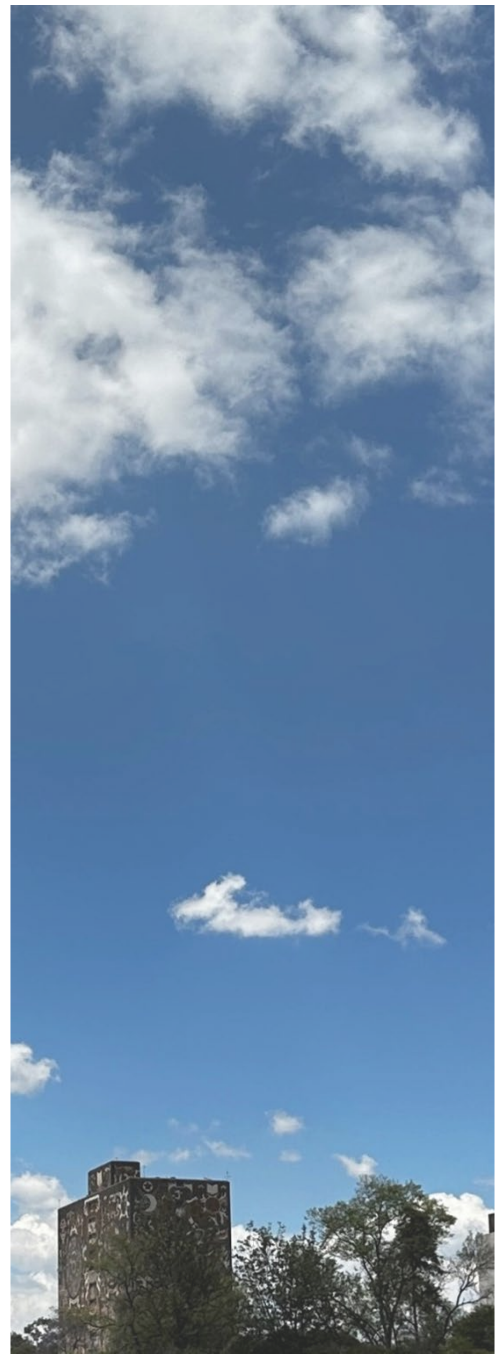

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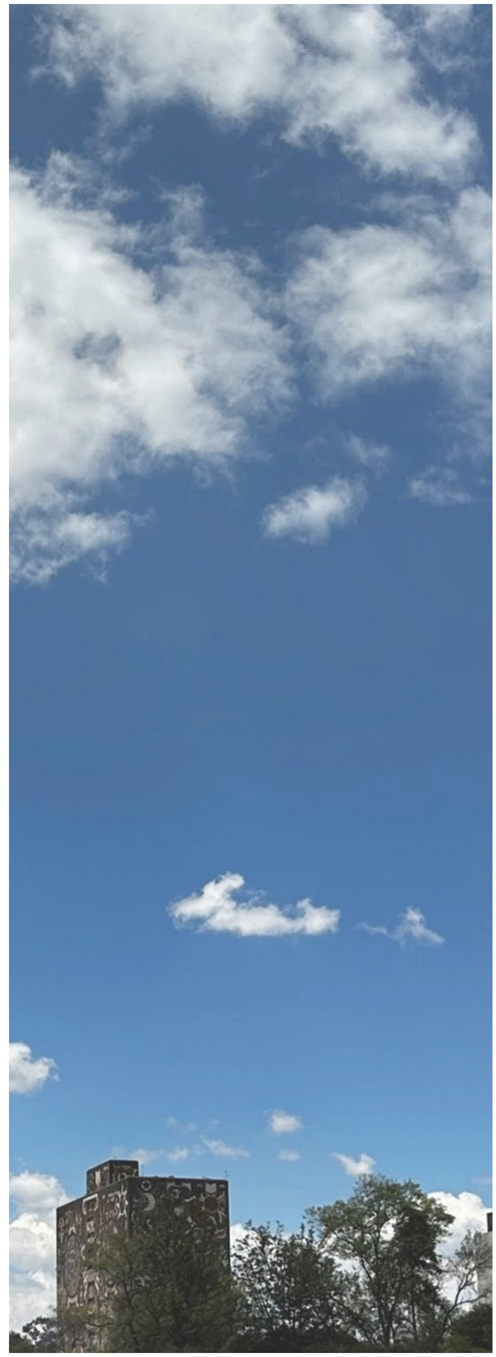

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Sofia graduated from Columbia University with a Master's of International Affairs concentrating in Energy and Environment and specializing in Latin America. A third-generation Mexican-American, Sofia grew up in Los Angeles, California, and has lived in New York City for the past six years. Most of her professional career has focused on domestic policy issues in the United States – particularly immigration, energy justice, environmental justice, and education inequity – and she's excited to bring this experience to Mexico.

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Rebecca is a second year graduate student pursuing an MPA in Energy and environment at Columbia SIPA and an MPH in Sociomedical Sciences at the Mailman School of Public Health. Prior to SIPA, she worked in water, sanitation, and hygiene infrastructure development and public health education in Northwestern Panamá. Her current work and research centers on community-based participatory research for environmental health program and policy implementation. Rebecca has her B.A. in political science and human rights from the University of Connecticut.

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Secretary

Gene graduated from Columbia Law School with Master of Laws degree. Gene worked in an Indonesian law firm which is a member of PricewaterhouseCoopers Global network before coming to New York. His practice area includes project financing, infrastructure development and energy related. He worked with both public and private clients for various transactions such as financing, and merger and acquisitions. He is keenly interested in bringing his experience and expertise into Mexico.

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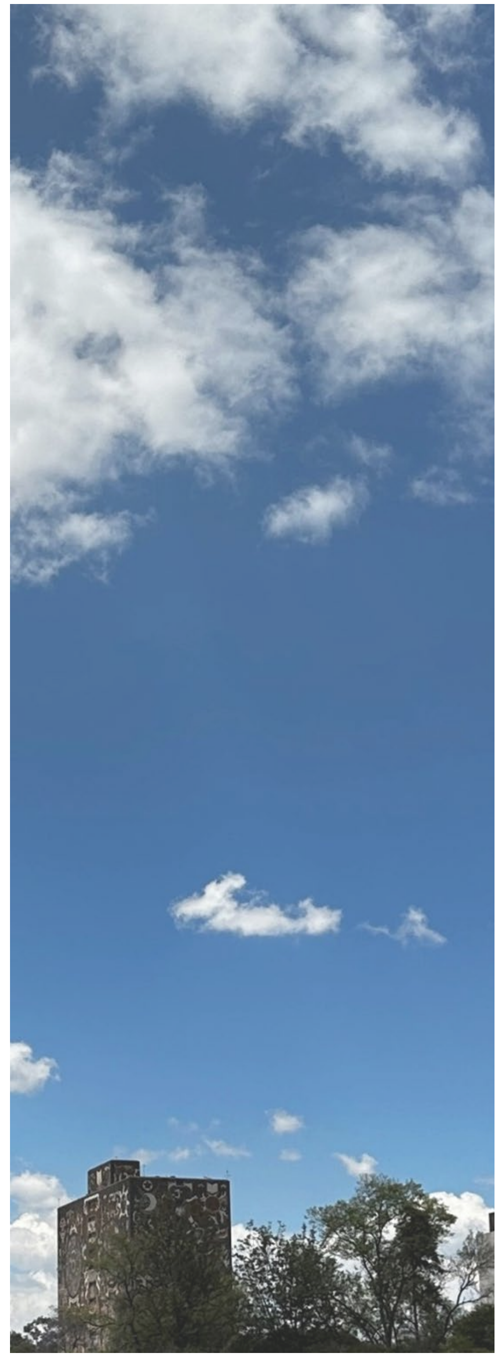

Beatriz Pais Alderete

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Beatriz graduated with a Master of Laws degree from Columbia Law School. Before coming to New York City, Beatriz worked as a lawyer for the Chilean Ministry of Foreign Affairs, where she focused on legal research and regional relations among Chile and its neighbors. She worked as a legal adviser for the Chilean delegation in the Silala case before the International Court of Justice and is currently assisting the Permanent Mission of Vanuatu to the United Nations with their initiative to request an advisory opinion from the International Court of Justice on States' obligations regarding greenhouse gas emissions and climate change.

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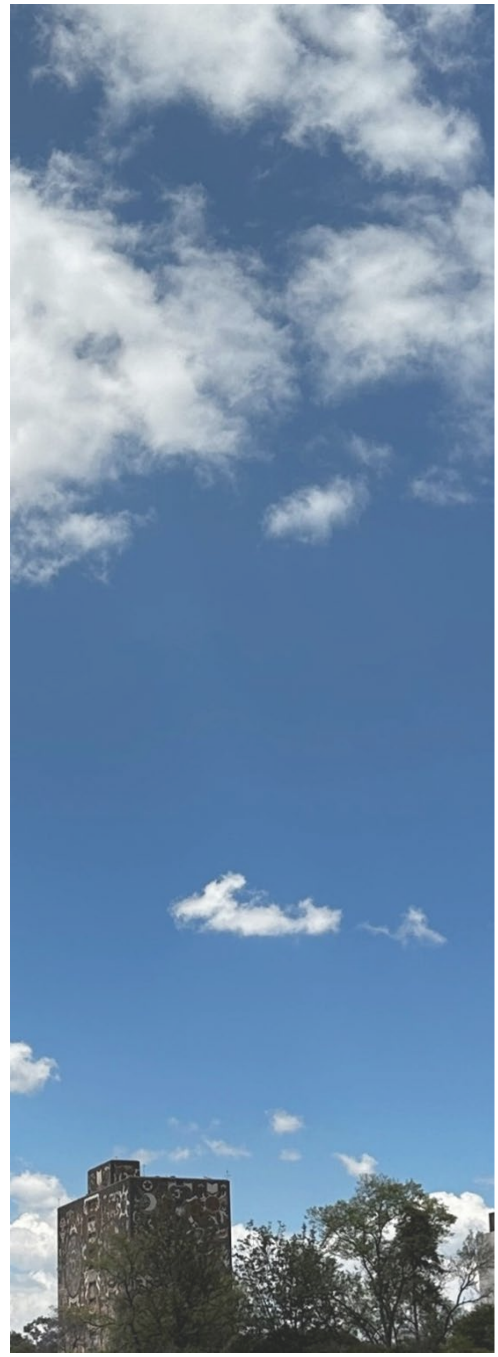
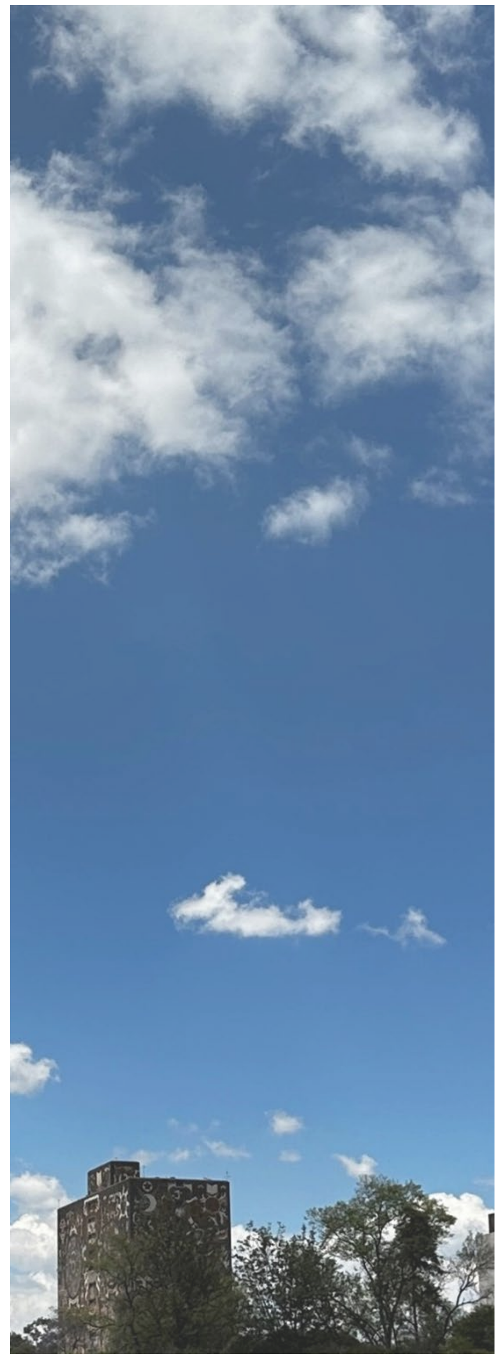
Angela graduated from Columbia University with a Masters of International Affairs in Energy and the Environment and a specialization in Latin America. Her classes at Columbia have given her insight into energy infrastructure and development, energy economics, and is familiar with biomass energy. She has previously worked in international development in Chile, Uganda, and Kenya. In her current position, Angela works in the intersection of agriculture and economic development in Sub-Saharan Africa for an International NGO based out of Nairobi.

OUR CAPSTONE TEAM



OUR CAPSTONE TEAM



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Jenik Radon is Adjunct Professor at the School of Public and International Affairs, Columbia University, where he teaches in the areas of sustainable natural resource development, small state development and corporate responsibility. In particular he focuses on risk and strategic management, sovereignty and human rights, especially environment, minority rights (including social license), transparency and anticorruption.

Professor Radon has also supervised Capstones examining the resource curse, and its impact, in Colombia, Mozambique, Namibia, Peru and Tanzania and analyzing the potential of small states, specifically Estonia, a pioneer in digitalization, and Namibia, noted for freedom of the press, to "punch above their weight" and be global leaders. He also taught at Monterrey Tech, Queretaro in Mexico, and Externado University in Bogota, Colombia.

Professor Radon has lectured and worked in over 70 (and visited over 100) countries, including Afghanistan, Argentina, Azerbaijan, Cambodia, China, Germany, India, Kazakhstan, Laos, Mexico, Mongolia, Mozambique, Nigeria, Peru, PNG, South Sudan, Turkmenistan, Uganda, UK and Viet Nam. He was honored by being invited as a non-African expert to give an address on Asset Recovery and Natural Resources, with a focus on the lack of transparency and disclosure in the beneficial ownership of companies engaged in the extractive industry, to the annual meeting of the Southern African Forum Against Corruption (SAFAC) of the Southern African Development Community.

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Appendix I

Institutional framework for environmental protection in Mexico

Constitutional provisions for the protection and management of the environment

While many constitutional provisions potentially deal with environmental protection, for practical reasons this chapter covers only the most important environmental protection and management provisions:

Article 4 of the Mexican Constitution identifies the right to health protection as a fundamental human right. “Everyone has the right to enjoy an adequate environment for their development and welfare.”

Article 26 establishes that it is the responsibility of the State to organize a democratic planning system for national development that ensures solid, dynamic, permanent and equitable economic growth. The State is constitutionally obliged to issue a national development plan that includes a section dedicated to environmental protection, which must be incorporated into all programs of the Federal Public Administration. This Article considers as a national priority the problems of environmental contamination and the economic problems derived from the exploitation of natural resources.

Article 27 establishes that the ownership of land, water and natural resources within the limits of the national territory corresponds originally to the Nation. It is the fundamental constitutional basis that empowers the federal government to impose limits on private property rights for reasons of public interest, including environmental protection. Since the promulgation of the Mexican Constitution in 1917, Article 27 has included the concept of “conservation of natural resources,” which makes evident the historical importance of the social function of property and the limitation of private property in Mexico as an absolute right.

The main Secretariat tasked with the environmental balance and sustainable development in Mexico is the Ministry of the Environment and Natural Resources (“SEMARNAT”). SEMARNAT is divided into three sub-secretariats:

- Sub-secretariat for Planning and Environmental Policy
- Undersecretary of Promotion and Environmental Regulations
- Undersecretary of Management for Environmental Protection

SEMARNAT has five decentralized administrative bodies:

- The National Water Commission ("CONAGUA")
- The National Institute of Ecology and Climate Change ("INECC")
- The Federal Attorney for Environmental Protection ("PROFEPA")
- The National Commission of Natural Protected Areas ("CONANP")
- The Agency of Security, Energy and Environment ("ASEA")
- The National Forestry Commission ("CONAFOR") is one of two of SEMARNAT's decentralized public bodies.

SEMARNAT's responsibilities include the following:

"I. Promote the protection, restoration and conservation of ecosystems and natural resources and environmental goods and services, in order to promote their use and sustainable development

II. Formulate and conduct the national policy on natural resources

III. Manage and regulate the use and promote the sustainable use of the natural resources that correspond to the Federation

IV. Establish official Mexican standards on the preservation and restoration of the quality of the environment; on natural ecosystems; on the sustainable use of natural resources and wild, terrestrial and aquatic flora and fauna; on wastewater discharges, and on mining matters; and on hazardous materials and solid and hazardous waste

[...]

XVIII. Grant contracts, concessions, licenses, permits, authorizations, assignments, and recognize rights, as appropriate, in matters of water, forestry, ecology, exploitation of wild flora and fauna, and on beaches, federal maritime land zone, and land reclaimed from the sea."

General Law for Ecological Balance and Environmental Protection

The General Law for Ecological Balance and Environmental Protection is the supreme environmental law in Mexico. The law regulates articles 4 and 26 of the Mexican Constitution, establishing a basic framework of comprehensive land and resource management.

The Law for Ecological Balance provides that ecological planning is an instrument that must be incorporated into national development planning (Article 17). It also indicates the criteria that must be considered for its formulation (Article 19), the modalities (Article 19 bis), and describes the instances and orders of government to which the formulation of the different modalities of the Ecological Ordering corresponds, as well as the scope of said programs.

The Regulation of the Law for Ecological Balance defines the competencies of SEMARNAT, as well as the participation of the agencies and entities of the Federal Public Administration in the formulation, issuance, execution, advice, evaluation, validation and monitoring of ecological regulations of federal competence; participation in the formulation of regional ecological planning programs of interest to the Federation and participation in the preparation and, where appropriate, approval of local ecological planning programs.

Agriculture

The conservation and protection of national lands, including agricultural lands, are regulated by the LGEEPA and the Sustainable Rural Development Law.

Institutions with authority over agriculture

Matters relating to agriculture fall mainly under the jurisdiction of three federal secretariats: (1) SEMARNAT; (2) Secretariat of Agriculture and Rural Development ("SADER"); and (3) Secretariat for Agrarian, Land and Urban Development ("SEDATU"). These secretariats are regulated under the Organic Law of the Federal Public Administration ("Public Administration Law").

Forest Management

Article 27 of the Mexican Constitution entrusts the federal government with promoting rural development and agricultural and forestry activities in order to achieve optimal land use. The following laws and their regulations govern the use, preservation, and control of national forests:

- General Law of Ecological Balance and Environmental Protection ("LGEEPA")
- LGEEPA Regulation on Environmental Impact ("EIA Regulation");
- General Law of Sustainable Forestry Development ("Forestry Law")
- Regulation of the Forestry Law
- Agrarian Law

SEMARNAT's forestry responsibilities include:

- Exercise the acts of authority related to the application of the policy of sustainable use, conservation, protection and restoration of forest and soil resources;
- Formulate and evaluate restoration programs for soil recovery in degraded non-forest areas, as well as evaluate the results of reforestation programs;
- Authorize, suspend, revoke, annul and nullify the change of use of forest land;
- Integrate and keep updated the soil inventory;
- Lead and technically support the implementation of sectoral programs in forestry and land matters;
- Grant, modify, suspend, revoke, annul, nullify and cancel the authorizations related to afforestation and the use of timber forest resources, in terms of forest health, and matters relating to the import and export of forest products and by-products;
- Integrate and keep updated the national forest inventory and prepare the zoning of forest lands and preferably forest aptitude and
- Establish, integrate, operate, and keep updated the National Forest Registry, among others.

There are three independent agencies that help the SEMARNAT in the development and implementation of federal forest policies:

National Forestry Commission ("CONAFOR"): CONAFOR is tasked with the development, support, and promotion of the conservation and restoration of Mexico's forests; and with the participation in the development of plans, programs, and policies for sustainable forestry development.

National Forestry Council ("CONAF"): advisory, evaluation, and supervising body tasked with the application of the forest policy and instruments provided for in the Forestry Law. Other state organs must ask for CONAF's opinion regarding forest planning and forest laws and regulations.

National Commission of Protected Natural Areas ("CONANP"): CONANP is tasked with the administration of Mexican national parks, biosphere reserves, flora and fauna protection areas, and natural resources protection areas, among others.

Legal and institutional framework for the energy transition in Mexico

In late 2015, the government of former president Enrique Peña Nieto published the Energy Transition Law ("LIE") with the object to regulate the sustainable use of energy, the obligations regarding clean energy, and the reduction of polluting emissions from the electricity industry while maintaining the competitiveness of the productive sectors.

The new law derives from a legal framework with origins in the rights enshrined in the Mexican Constitution, which are manifested through different laws, regulations, plans, and programs. In particular, the Mexican Constitution establishes that every person shall enjoy the human rights incorporated in it and in the international treaties to which Mexico is a party. Article 4 contains the fundamental right to access health, a healthy environment, water, and decent housing. Articles 25 and 26 provide that the State is responsible for national development to ensure that it is comprehensible and sustainable, and the State's plan shall guide the national economic activities.

In addition, the following specific laws define the institutional aspects that are directly related to the energy transition. Each of these is examined below.

- Public Administration Law (Ley Orgánica de la Administración Pública Federal)
- Law on Planning (Ley de Planeación)
- Electric Industry Law (Ley de la Industry Eléctrica)
- General Law on Climate Change (Ley General de Cambio Climático)
- Law of the Coordinated Regulatory Bodies in Energy Matters (Ley de los Órganos Reguladores Coordinados en Materia Energética)
- Federal Electricity Commission Law (Ley de la Comisión Federal de Electricidad)
- Geothermal Energy Law (Ley de Energía Geotérmica)
- Law for the Promotion and Development of Bioenergetics (Ley de Promoción y Desarrollo de los Bioenergéticos)

Public Administration Law

Article 33 of the Public Administration Law states that SENER is responsible for establishing, conducting, and coordinating the country's energy policy. To fulfill this duty, SENER must prioritize energy security and diversification, as well as energy saving and environmental protection. SENER is also responsible for carrying out energy planning in the medium- and long-term, taking into consideration the concepts of sovereignty and energy security, the progressive reduction of environmental impacts of production and consumption of energy, a greater participation of renewable energies, and greater efficiency in energy production and use, among others.

Law on Planning

The federal Law on Planning establishes basic norms and principles to guide National Development Planning and sets out the bases for the operation of the National System of Democratic Planning. In accordance with article 4, it corresponds to the Federal Executive to lead the planning of national development.

Bioenergetics Law

Bioenergy Law was published on February 1, 2008, to promote the production, marketing and use of bioenergy in order to contribute to sustainable development and energy diversification.

Specifically, Bioenergy Law seeks to promote the production of inputs for bioenergy, from agricultural, forestry, algae, biotechnological and enzymatic processes in the Mexican countryside, without jeopardizing the country's food security and sovereignty, in accordance with the provisions of the Article 178 and 179 of the Sustainable Rural Development Law.

General Law on Climate Change (LGCC)

The LGCC, published on 6 June 2012, aims to guarantee the right to a healthy environment, sustainable development, and the preservation and restoration of ecological balance. One of the main characteristics of the LGCC is the establishment of a set of goals in order to guide Mexico's performance towards a low carbon economy.

Regarding greenhouse gas (GHG) emissions, the Second Transitory Article of the LGCC assumes an aspirational goal of reducing them by 30% by 2020 with respect to the baseline; and a 50% reduction in emissions by 2050, in relation to those emitted in the year 2000. The Third Transitory Article of the LGCC establishes the objective of achieving at least 35% of electric power generation based on clean energy by the year 2024.

Electric Industry Law (LIE)

The LIE, published on August 11, 2014, regulates part of the changes derived from the Constitutional Reform in energy matters of 2013. The electric sector regime is modified to transition to a new model based on free competition in generation and commercialization activities, which seeks to offer citizens energy services more efficiently.

In this new model of the electricity sector, the State retains the functions of planning, regulation, control, transmission and distribution, making it possible to achieve a competitive and efficient market. Thus, the LIE, in its fourth transitory article, mandates the strict separation of the activities of the Federal Electricity Commission (CFE); Article 6 establishes the Energy Regulatory Commission (CRE) as the entity in charge of regulation and surveillance, while Article 107 establishes the National Center for Energy Control (CENACE) as the entity in charge of the operational control of the National Electric System.

The inclusion of Clean Energy Certificates (CEL) as an instrument to promote new investments in clean energy allows for the transformation of national goals for clean electricity generation into individual obligations and is essential for the energy transition. In this regard, the LIE establishes in its articles 121 and 122 that SENER will issue the obligations to acquire CEL, which will be based on the proportion of electrical energy consumed. Article 125 of the LIE establishes the creation of a CEL market, in which the surplus or shortage of Certificates will be traded by the regulated entities.

Moreover, article 126 of the LIE indicates the CRE as the body in charge of granting the CELs, as well as the one responsible for issuing the regulation to validate the ownership and verify compliance with the obligations. Therefore, the CRE must issue requirements for measurement and reporting of clean energy generation, as well as a Registry of Certificates, in order to avoid double counting.

For its part, the LIE establishes that the CENACE must operate the Wholesale Electricity Market and will determine the allocation and dispatch of the Power Plants, the Controllable Demand and the import and export programs, in order to meet the demand for electricity in the National Electric System. In addition, it will receive the offers and calculate the prices of electrical energy and will invoice, process, or collect the payments that correspond to the members of the electrical industry.

Law of the Coordinated Regulatory Bodies in Energy Matters

The Law of Coordinated Regulatory Bodies in Energy Matters lays the foundations for the organization and operation of Coordinated Regulatory Bodies, which are (1) the National Commission for Hydrocarbons (CNH) and (2) the CRE.

To promote a competitive and efficient energy sector, the State will exercise its functions of technical and economic regulation in matters of electricity and hydrocarbons through these entities.

Federal Electricity Commission Law

The Law of the Federal Electricity Commission marks the change of CFE and Petróleos Mexicanos (PEMEX) from parastatals entities to state productive companies. Under this law, the CFE transitions to a corporate governance scheme that allows the generation of economic value and profitability for the State.

Geothermal Energy Law

The Geothermal Energy Law was published together with the LIE, and its purpose is to regulate the exploration and exploitation of geothermal resources for the use of subsoil thermal energy. This law establishes the rules for the registration and recognition of exploration permits, as well as exploitation concessions.

Appendix II

1. Project Design and Implementation: identifying the research question and project focus
    1.1. Considering the community's needs, strengths, interests, mission, and ability to take action, what is the overarching issue that you aim to address?
    1.2. What is the particular problem or issue that you seek to solve?
    1.3. What are the research inquiries you wish to pursue?
    1.4. What information do you hope to acquire? What assumptions do you want to verify or challenge?
    1.5. What issue do you intend to emphasize or bring attention to that has not been adequately demonstrated or recognized?
    1.6. What are the feasible actions that you can undertake?
    1.7. What approximate geographic boundaries do you want to involve participants and take action? It is possible that the "community" may not agree with your description of the community's boundaries, so allow time for discussion and modification of these boundaries.
2. Partner Engagement: identifying project partners and collaborators
    2.1. Who are the essential stakeholders based on the overall issue and geographic location?
    2.2. Among them, with whom will you partner? If you are already collaborating, consider conducting a stakeholder analysis to identify any missing stakeholders.
    2.3. Will this group engage with various segments of the community?
    2.4. What degree of involvement is expected from the different aspects of the process?
    2.5. Will you involve some of your constituents in designing the research?
    2.6. To what extent will project partners participate in the process?
3. Data Collection: refining the research question and choosing data collection methods.
    3.1. Do you need to modify or revise your specific research inquiries based on the issue and participants?
    3.2. From whom will you collect data? Who possesses specific expertise regarding the subject matter?
    3.3. What number of participants will be involved? What is an appropriate sample size to ensure representativeness?
    3.4. What is your capacity to engage with participants?

3.5. How do you expect to apply the findings? Who is the intended audience for the research findings?
3.6. What specific data do you require to address this question? Is a combination of community knowledge and administrative data necessary? (For example, comparing the perception of safety with crime statistics)

4. Data Analysis: creating and implementing an analysis plan
   4.1. Construct data collection instruments that align with the format you have chosen to tackle your research inquiries.
   4.2. Understanding the geographic aspect of your data is crucial. Will you require addresses or zip codes?
   4.3. Will you utilize web-based tools?
   4.4. Will you need to create original forms?
   4.5. Determine the most effective participation method.
   4.6. How will you gather this data? In what form? (e.g., group discussion)
   4.7. Do you have interests that extend beyond data collection (e.g., organizing, advocacy)?
   4.8. Develop and test web-based and other instruments for data collection.
   4.9. Develop a plan for analysis.
   4.10. What is your preferred method for analysis? (e.g., geospatial, statistical analyses, qualitative)
5. Reporting: analyzing data, disseminating the results, and taking action
   5.1. Develop a plan for presenting and disseminating results and analysis
      5.1.1. What: What is the narrative you are attempting to convey? What do you want to demonstrate or what query are you trying to answer or address with this research?
      5.1.2. Who: Who is your target audience? Who will you present these findings to?
      5.1.3. When: Are you examining a persistent issue or a particular moment in time?
      5.1.4. How: In what way will you present this information and research? Will it be in a report format? On your website? At a public hearing? At a community gathering?
   5.2. Establish an Engagement Strategy for Action.
   5.3. Decide on the approach you will use to engage community members, community-based organizations (CBOs), elected officials, and other groups - strategies may vary for each group.
   5.4. Conduct interviews with residents to verify or "ground-truth" data.

5.5. Share the findings with staff and community members to build support for advocacy.