Mexico-U.S. Cross-Border Electricity Hubs:

Limitations and Opportunities for Decarbonization

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KEY FINDINGS:

1. Policies on both sides of the border determine how markets and infrastructure work under three cross-border electricity hubs.
2. Three policy factors apply to the three cases:
   a. Policy differences regarding centralization and decentralization of energy.
   b. The lock-in of cross-border trade into fossil fuels due to Mexico's dependency on U.S. oil and gas and Texas historical fuels production.
   c. The small size of the cross-border electricity market.
3. Due to national and state policies, all three hubs run in different directions regarding renewables.
4. Even with renewable deployment on both sides of the border and the political will to integrate them into cross-border trade, the limited and ill-maintained infrastructure is an obstacle to overcome in the three hubs.

INTRODUCTION

The Mexico-U.S. cross-border integration of the oil-and-gas sector is profound, contrasting with electricity trade and renewables. Policies on both sides do not prioritize the decarbonization of the energy trade.

Puzzling enough, U.S. and Mexican border states develop their own renewable electricity for domestic use, but not all states align their renewables deployment to decarbonization and climate goals. Why is there such a contradiction between states' decarbonization trends, renewables deployment, and cross-border fossil-fuel trade? This paper assumes that policies drive how the cross-border electricity market works, impacting infrastructure development. These electricity policies are supported by each state's energy mix, resulting in U.S. and Mexican states having different levels of decarbonization. Despite bi and trinational environmental institutions awarding funds to deploy renewable energy for electricity generation, it seems there are scarce incentives to incorporate it into cross-border trade; only California has followed this strategy to comply with its ambitious goals.

To examine this contradiction, this paper explores three policy factors. First, energy policies in Mexico have historically depended on cross-border fossil-fuel trade since the beginning of the 20th century, and even more so in the 21st to meet the country's electricity demand (EIA 2021c; Wood and Ramiro 2021). Texas has also depended on fuel production. Mexico exports crude oil to the U.S., and the U.S., in return, exports refined oil products and gas to Mexico (EIA 2019). Secondly, as the energy sector is centralized in Mexico, states have very limited room for designing policies toward decarbonization (López-Vallejo 2017). In contrast, U.S. states can develop climate policies based on their energy matrix. In both cases, states relying on fossil-fuel markets for domestic consumption and trade tend not to be ambitious regarding decarbonization.

A third factor is the little exchange in cross-border electricity trade and the lack of infrastructure for transmission (Cabrera-Colorado 2018; GNEB 2019; Wood and Ramiro 2021). There are only three cross-border interconnecting regions that operate as electricity hubs, providing power to only a small number of cities both sides of the border. There is little investment in cross-border electricity transmission lines, and infrastructure is old and ill-performing on the Mexican side. Cross-border trade of renewable electricity between both countries, although it dates back to 1905 and then to collaboration on geothermal energy in the 1970s in the area of Baja California-California (Wood 2010:3), has not been part of the integration agenda despite the prices of renewables (especially solar and wind energy) being low and competitive with fossil fuels. This contrasts with the prosperous fossil-fuel market accounting for a dense network of pipelines and facilities. This infrastructure reaches a wide territory in both countries and accounts for various sub-networks of pipelines and road-and-sea transportation. Under these conditions, there seems to be no incentive for states to include renewable sources for cross-border electricity trade.

The goal of this paper is to examine these factors by comparing the three electricity Mexico-U.S. cross-border hubs: the CFE-CAISO, the CFE-EPE, and the CFE-ERCOT. CFE-CAISO is integrated by the Baja California-California electricity region, which is operated by the Mexican state power company, Federal Commission of Electricity (CFE), and the California Independent System Operator (CAISO). The CFE-EPE includes the Chihuahua-New Mexico and Texas interconnection, operated by CFE and Electricity El Paso Electric (EPE). Thirdly there is the Coahuila, Nuevo León, Tamaulipas, and the state of Texas hub, operated by CFE and the Electric Reliability Council of Texas (ERCOT). The three cases suggest three stages of renewable electricity deployment determined by national and state policies. CFE-CAISO does integrate renewables into trade, but California consumes most of the resulting electricity. California imports solar and wind electricity generated in Baja California to meet its climate targets, and Baja California imports gas from California and Texas

to operate power plants locally and provide electricity to its population. The CFE-EPE hub has the potential to incorporate renewables into the little electricity exchange it has, but policies and the small size of the electricity market have been obstacles to its development. CFE-ERCOT is the most contradictory case as Texas has increased its renewables deployment for local consumption, but it is still heavily integrated with Mexico in the fossil-fuel sector; little electricity is exchanged.

The first section of this paper discusses how hubs are conceived as regional spaces of electricity interconnection and how they can take the road toward an energy-green transition. The second section presents an overview of policies and institutions managing energy in both countries. This section also discusses how energy policies impact markets, infrastructure, and decarbonization trends. The third section discusses the CFE-EPE and CFE-ERCOT cases, followed by a fourth section underscoring the CFE-CAISO case as it is the only region partially promoting decarbonization through renewables deployment as part of the hub's electricity market. To systematize the comparison, all cases will be examined under a policy analysis highlighting their impact on infrastructure and markets. Each case also underscores the three factors presented above: Mexico's energy dependency from the U.S., the different levels of centralization of the energy sector in cross-border partners, and the small size of the electricity trade. The conclusions present the main findings.

1. ELECTRICITY HUBS AS TERRITORIAL CROSS-BORDER SPACES

In contrast to U.S.-Canada energy relations, where electricity networks are dispersed throughout the border, along the Mexico-U.S. border, electricity integration is localized in "hubs." Originally, energy hubs were conceived as technological "units," combining different sources (inputs) and interconnectors (infrastructure) to provide energy loads (outputs). For Geidl and others (2007:3), an energy hub generally includes a transformer, a micro turbine, a heat exchanger, a furnace, an absorption cooler, a battery, and hot water storage to produce electricity, heating, and cooling. Other experts transcended the technological explanation to define hubs as spaces where there is a coupling of energy sources and infrastructure to produce, convert, store, and supply electricity either from primary-use fossil fuels (gasolines, diesel, gas) or renewables (Mohammadi et al. 2017; Zhang et al. 2015). Under this renewed definition, hubs must be conceived not only as technical devices, but as embedded within social, market, and political relations (Goldthau 2014).

Adapting energy hubs to the energy transition literature (O'Connor 2010; Smil 2017; Takács-Sánta 2004) and to the energy regionalization approach (Guler, Çelebi, and Nathwani 2018; Herman and Ariel 2021; López-Vallejo 2014; Mildenberger and Stokes 2021; Pastor 2011; Wood and Ramiro 2021), this paper assumes that energy hubs are socio-political territorial spaces that can be "greened" when supported on renewables, or at least when including some percentage of them into the sources, thus decreasing the use of primary-use fossil fuels in time. Green electricity hubs become the path toward decarbonization and meeting climate-change goals (López-Vallejo 2014). The inclusion of renewables into the hub speaks of the territorialization of resources as they are regionally localized. In other words, green electricity hubs depend on the deployment of local renewable sources and their incorporation into the energy mix. As Goldthau (2014:134) argues, "low-carbon infrastructure solutions are highly localized, both in terms of energy supply and demand patterns."

The three hubs analyzed in this paper are regions conformed by cross-border energy trade. Geographically contiguity can optimize cross-border partners' energy supply since they have interconnected grids and variability of resources (Guler et al. 2018). For an efficient electricity trade (green or not), transmission infrastructure is fundamental as it interconnects localized energy resources (Gothau 2014). Most of the time, the electricity market is as limited as transmission lines are (Guler et al. 2018; Wood and Ramiro 2021). Policies play a key role as they establish ownership of resources and the way to manage them in domestic or international markets (Muñoz-Meléndez and López-Vallejo 2017).

2. POLICIES AND THEIR IMPACT ON MARKETS AND INFRASTRUCTURE IN CROSS-BORDER ELECTRICITY HUBS

Mexico's dependency on U.S. fuels, centralized and decentralized energy policies in Mexico and the U.S., and the minimal electricity trade are factors that impact the type of cross-border electricity trade. They also explain the apparent inconsistency of having border states with climate goals and local deployment of renewables that do not bring these into cross-border trade.

Policies, Institutions, and Decarbonization

The Mexico-U.S. electricity hubs work under several sets of policies at different levels. In the U.S., it is the Federal Energy Regulatory Commission (FERC), an agency under the U.S. Department of Energy (DOE), the regulator of electricity transmission and interstate commerce (renewables, hydropower, oil, and natural gas). The DOE grants authorization to export electricity abroad, and FERC regulates this exchange. However, there is no licensing requirement to import electricity to the U.S. (DOE 2015). FERC has a wide territorial scope, having jurisdiction over almost all transmission lines in the U.S; it delineates prices and authorizes construction and operation of facilities (GNEB 2019:21–22). The one exception is ERCOT, as it performs only within Texas (ERCOT 2021). In 2006, FERC appointed the North American Electric Reliability Corporation (NERC) as the electrical reliability organization of the federal government. It oversees six regional reliability agencies and covers the U.S., Canada, and the northern part of Baja California in Mexico. NERC also covers six independent system operators (ISO) and four regional operators (RTO), as summarized in Table 1.

These agencies are generally nonprofit corporations under supervision by state and federal governments (EIA 2016). Some of them have more than one function. For example, ERCOT is a reliability council for the Texas Regional Electricity, as well as an operator. Others are both operators and regional organizations, such as the ISO for New England. These utilities can be private companies, public utilities, and cooperatives, each with a capacity to own transmission lines (EIA 2019). Besides regional agencies, each state has transmission owners, operators, and distribution companies. State regulations on electricity have aimed toward including a percentage of renewable sources into their energy mix. Although different targets and instruments were put in place, most U.S. states are committed to decarbonization.

Table 1. U.S. Regional Electricity Agencies

Regional Reliability Coordinators	Independent Systems Operators	Regional Transmission Organizations
WECC—Western Electricity Coordinating Council	CAISO—California ISO*	PJM—PJM Interconnection
TRE-ERCOT—Texas Reliability Entity	ERCOT—Electric Reliability Council of Texas; also a Regional Reliability Council	MISO—Midcontinent Independent System Operator; also an RTO
MRO—Midwest Reliability Organization	NYISO—New York ISO	SPP—Southwest Power Pool; also a Regional Reliability Council
SPP—Southwest Power Pool	MISO—Midcontinent Independent System Operator	ISONE—ISO New England
SERC—State Electricity Regulatory Corporation	ISONE—ISO New England	
FRCC—Florida Reliability Coordinating Council	AESO—Alberta Electric System Operator	
RFC—Reliability First Corporation	IESO—Independent Electricity System Operator	
NPCC—Northeast Power Coordinating Council		

*The Mexican State of Baja California is part of CAISO. Source: DOE 2015.

At the state level, border states have their own way of managing their energy sectors, renewables, and decarbonization goals. Tables 2 and 3 show the decarbonization policy instruments (especially for electricity) and the energy mix of cross-border U.S. states.

Energy policies get more complex when rules change with incoming governments. On the Mexican side, regulations are designed and enforced by the federal government, currently aiming to re-centralize decisions energy sector decisions. Mexican cross-border states do not have much say in energy policies today. In Mexico, most of the energy sector was entirely in the hands of the federal government until 2013, when reforms took place. Their goal was to open up the sector to private and foreign investment while transforming the two national companies, CFE and PEMEX, into competitive state companies. This aimed to put an end to monopolies and attract other sources of investment. The new way to operate energy required new institutional regulators. The reforms created the Energy Regulatory Commission (CRE), which is a federal agency focused on industry

Table 2. U.S. Policy Instruments for Decarbonizing Electricity in Cross-Border States

	Energy Efficiency	Renewable Portfolio Standard	State Climate Law with Regulations & GHG Reduction Targets	Distributed Generation	Clean Energy and Climate Fund	Carbon Pricing (ETS)
California	Decoupling gas and electricity.	33% from eligible renewables by 2020. 50% from eligible renewables by 2026. 60% from eligible renewables by 2030. 100% from eligible renewables by 2045.	Global Warming Solutions Act of 2006. Goals: net zero for 2045 and reduction to 40% below 1990 levels by 2030.	62,019 MW/h	Budget of $15 billion for climate risks.	Authorized the California Air Resources Board (CARB) Cap-and-Trade Program for GHG emissions. Regional ETS: Cap-and-trade with Quebec and soon with New Scotia.
New Mexico	Decoupling profit gains from quantity of power sold.	Clean Energy Standard— 100% of electricity states to come from renewable sources by 2045.	The Climate Solutions Act. Goals: 45% below 2005 levels by 2030 and 50% reduction by 2030.	8,965 MW/h	The initiative also includes $5.8 million in state investment for clean-energy and emissions-monitoring companies and job creation.	ETS under consideration.
Texas	State loans for energy efficiency.	5,000 MW of new renewable energy capacity by 2015. Voluntary target of 10,000 MW by 2025 (surpassed in 2019).	No state climate law.	102,267 MW/h	No funding for climate change.	Market for offset credits.
Arizona*	Energy-efficiency measures by 2030 to equal 35% of their 2020 peak.	15% of the electricity load needs to come from renewable sources by 2025. A growing % of renewables from distributed generation.	Western Regional Climate Action Initiative. Goals: 80% reduction by 2050 and 100% reduction by 2070.	6,858 MW/h	No funding for climate change.	No ETS.

*Although Arizona is not part of the three electricity cross-border hubs, it is included to have data of all border states.
Sources: Adapted from C2ES 2020; ClimateXchange 2021; EIA 2020; NCSL 2017; and USCA 2020.

effectiveness, equal competition, non-discriminatory practices, protection of consumers, reliability, and stability of the energy system in Mexico. CRE is in charge of oil, petroleum products, natural gas, LNG, biofuels, and electricity (CRE 2021a). The gas sector is in the hands of the National Commission for Gas (CENAGAS); the National Center for Electricity Control (CENACE) regulates electricity. CENACE operates domestic interconnections, as well as transmission of the National Electricity System (SEN). The reform also included the Energy Transition Law, which addressed different mechanisms to deploy and promote clean energy.[1] It was the necessary piece missing to implement mitigation strategies already mandated in the General Law on Climate Change (López-Vallejo 2017).

These reforms also promoted auctions for oil and gas exploration and exploitation for the electricity sector. Eleven auctions for adjudicating hydrocarbon projects took place where PEMEX and other investors participated in direct or joint contracts. For electricity, there were three long-term auctions between 2013 and 2018; all of them with the goal of promoting contracts of renewable projects. The renewable sector was prospering and receiving important renewable investment. In the second auction in 2017, Mexico received investment from France, Italy, the U.S., Canada, Spain, and Japan, and the projects were developed in the northern states of Mexico. In the 2018 auction, the prices of solar and wind were the lowest worldwide, making Mexico very attractive to new investment (CENACE 2018). Under these policies, the commitments under the Paris Agreement were to be reached and the General Law on Climate Change (2012) was to be complied with.

In 2018, a new administration took office and tried to overrule these reforms, and hydrocarbon and electricity auctions were suspended. The third electricity auction of 2018, which had already adjudicated projects, was suspended and then canceled by presidential mandate (CENACE 2020). Today, the federal policy intends to bring back the two state monopolies, preventing foreign or private investment, and focusing on fossil fuels, especially on oil products. Energy sovereignty is the premise supporting these strategies. Several pieces of legislation have been sent to Congress in this sense, which, with a clear majority of the President's party, have passed all these counter-reforms.

Several social groups, NGOs, and Mexican and foreign companies have fought against these laws in the courts through protection petitions ("amparos"). These petitions protect any citizen against acts, rules, and abuses of government. For example, some NGOs asked for a protection petition to suspend the construction of the Dos Bocas Refinery, arguing forest destruction and lack of compliance with the Paris Agreements and the country's Nationally Determined Contribution (CEMDA 2019). Another reform sent by the Executive was that PEMEX could suspend operation permissions to private gasoline stations already working (ONEXPO 2021). Another example is the petition granted to private renewable companies over legislation that intended to 1) give clear priority to PEMEX as the main provider for electricity plants no matter the price this company offered to CFE, and 2) establish a 500–800% increase in prices of electricity transmission services by CFE to private providers (Energía a Debate 2020a). There was also the proposal to prohibit new renewable companies from entering into the Mexican electricity market (Energía a Debate 2020b). And the last reform sent by the Executive addressed electricity. It would only grant 46% of the market to private companies and the rest to CFE. This reform also cancels some renewable projects already working and it is being discussed in Congress at the time of writing. These federal decisions are based on the poor competitiveness of CFE and PEMEX when compared to private companies. In 2020, CFE accounted for 32.9% of clean energy deployment, and PEMEX accounted for 39.9% versus 59.3% of private companies (SENER 2020:182).

At the state level, before López Obrador's energy plan, the Mexican states in the electricity hubs (Baja California, Chihuahua, Coahuila, Nuevo León, and Tamaulipas) were developing their own energy programs based on participation in renewable-project auctions and distributed generation, as shown in Table 3. Coahuila, Nuevo León, and Tamaulipas had even designed individual energy clusters with the participation of private companies and local governmental authorities. They intend to link them in the near future to create a wider regional energy hub (Clúster Energía Coahuila 2021; Clúster Energético NL 2021; Clúster Energético de Tamaulipas 2021).

1 In Mexico, clean energy includes hydro, wind, solar, geothermal, biomass, as well as nuclear and co-generation.

Table 3. Mexico Policy Instruments for Decarbonizing Electricity in Cross-Border States

	Energy Efficiency KW/h	Renewable Portfolio Standard	State Climate Law, Regulations & GHG Targets	Distributed Generation (MW/h)	Clean Energy Law and Climate Fund	Carbon Pricing (ETS & Taxes**)	Renewable Projects from Auctions (MW/h) P= In Process O= In Operation 1,2,3= Auction Number
Baja California	2,505.028	35% to 2021 (includes renewables and nuclear). More than 30,000 MW of installed capacity expected in 2026. Supply 25% of energy consumption in the public sector with renewable generation sources.	Law for Renewable Energy.	28	Climate Change Fund mandated by Climate Change Mitigation and Adaptation Law for Baja California.	ETS (pilot) Federal Tax: between 7-17MXN per liter and 20-52MXN per tCO2e. Local Carbon Tax: 170MXN per tCO2e. Gasoline: 2.196 kg CO_2/liter Diesel: 2.471 kg CO_2/liter Natural Gas: 2.690 kg CO_2/ kilogram LP Gas: 3.000 kg CO_2/kilogram	41 (O-2)
Chihuahua	1,570.924	Renewable energy cluster in formation, 100% of the energy it consumes by the year 2025.	Law to Promote Energy Efficiency and Deploy Renewable Energy (reduction of 30% GHG by 2020).	63	Climate Fund at the Climate Change Law for Chihuahua.	ETS (pilot) Federal Tax: between 7-17MXN per liter and 20-52MXN per tCO2e.	329 (O-2) 150 (P-3)
Coahuila	1,706.284	Electricity generation goals from clean sources: 2018, 25%; 2021, 30%; 2024, 35%.	Law of Rational Use of Energy.	40	Environmental Fund for Climate Change (Law for Adaptation and Mitigation for Climate Change Impacts).	ETS (pilot) Federal Tax: between 7-17MXN per liter and 20-52MXN per tCO2e.	1,710 (O-1) 82 (O-2) 593 (P-3)
Nuevo León	2,221.951	Increase in renewable electricity generating capacity by 21,089 MW to 2027 (wind and hydro energy will have the largest share, 52% and 25%, respectively).	Climate Change Law for Nuevo León Goal: GHG reduction goal of 0.4658 MtCO2e to 2030.	111	Climate Change Fund (Climate Change Law for Nuevo León)	ETS (pilot) Federal Tax: between 7-17MXN per liter and 20-52MXN per tCO2e. Local Tax under consideration	249 (O-2)
Tamaulipas	2,580.704	Capacity generation capacity of 1,710 MW. Additionally, installed capacity of 2,025 MW.	Law for Renewable Energy.	11	Climate change Fund for Tamaulipas (Climate change Law for Tamaulipas)	ETS (pilot) Federal Tax: between 7-17MXN per liter and 20-52MXN per tCO2e. Local Carbon Tax: 250MXN per tCO2e.	585 (O-1) 537 (O-2)
Sonora*	2,997.248	35% to 2024 (includes clean energy) 37.7% to 2030 (includes clean energy)	Law to Promote Renewable Energy and Energy Efficiency.	36	State Environmental Fund (in the Sonora Climate Change Law)	ETS (pilot) Federal Tax: between 7-17MXN per liter and 20-52MXN per tCO2e.	395 (O-2) 498 (P-3)

* Sonora is the only Mexican State not part of the cross-border electricity hubs.

** Federal Taxes refer to the Secial Tax over Production and Services for Fossil Fuels (IEPS Carbono) for 2021. Fuels measured liters are: propane, butane, gasolines, aviation gas, diesel, heavy oil. Fules measured in tCO2e are petroleum coke, coal coke, mineral coal, and other fuels.DOF 2020.

Sources: Adapted from CENACE 2020; CONUEE 2016; CRE 2020; INECC 2020; DOF 2020; and information from all states' environmental and energy webpages.

Apart from the national and state levels of policy design, we find cross-border and trilateral regional initiatives and policies regarding renewable energy. Cross-border cooperation mechanisms, such as technical groups or task forces, have been working for decades to deal with energy trade. There was the *Bilateral Framework on Clean Energy and Climate Change (CEBA)* in 2009, which appointed the *US-Mexico Cross-border Electricity Task Force (CETAF)*. CETAF did not find the political will and the transmission infrastructure necessary to consolidate cross-border integration or a regional renewables market (López-Vallejo 2017; Wood 2012). USAID also developed decarbonization programs, such as *Mexico's Global Climate Change Program* and the *Low Emissions Development Program* (López-Vallejo 2017; USAID 2014). Additionally, there are some important environmental projects under the U.S.-Mexico Border 2025 Program (the updated version of Border 2020). However, most of the projects approved in 2021 addressed water quality, wastewater, waste management, air quality, and emergency preparedness (NADBANK 2021a).

Another important bilateral institution aiding environmental issues has been the Border Environmental Commission (BECC). In November 2017, the North American Development Bank (NADBANK) absorbed BECC, giving more strength to the bank's environmental agenda. NADBANK had been fundamental to the development of renewable energy in border states—and for other types of cross-border environmental projects, such as air quality, water, and waste management. From 2011 to 2019, the bank financed several renewable projects in border states, as Table 4 shows.

Table 4. Number of Renewables Projects Funded by NADBANK (2011–2019)

	Solar	Wind	Biogas	Other renewables
California	7			
New Mexico				
Texas	2			1 (biodiesel)
Arizona*	3			
Baja California		1		
Chihuahua	2			1 (wastewater- cogeneration)
Coahuila		1	1	
Nuevo León		2		
Tamaulipas		4		
Sonora*	3			

*Arizona and Sonora are not part of any hub. They are included to present data from all border states.
Source: NADBANK 2021b.

There have also been meaningful meetings at a bilateral inter-agency level. Meetings between CFE, border Mexican states, and EPE, WECC, CAISO, and ERCOT took place in the years of the Mexican energy reform (2013–2015). There were even cooperation mechanisms put in place, such as the Memorandum of Understanding between the nascent Mexican carbon market with the California emissions trading scheme. In the case of the CFE-EPE meetings, for example, their goal was to promote a more diversified energy hub for New Mexico, Texas, and Chihuahua (Kolenc 2017). In 2017, NERC signed a Memorandum of Understanding with CRE and CENACE to enhance the reliability of cross-border systems (GNEB 2020:46).

At the trinational level, the USMCA frames the electricity (and energy) trade not in an individual chapter (as it was in Chapter 6 of NAFTA), but as part of several chapters regarding competitiveness and investor-state dispute settlement mechanisms. Only in the Tariff Schedules for Mexico and the U.S., under Chapter 2 in Annexes 2-A and 2-B, does the USMCA establish that for electricity, natural gas, crude oil, gasoline, or diesel, neither country can charge import duties. The zero tariff is reinforced in Chapter 27 (OUSTR 2020). Chapter 8 also addresses energy issues. It is not a technical chapter regulating specific trade norms, but a political chapter where energy sovereignty is underscored. Under this chapter, Mexico reserves its right to change rules regarding the energy sector and reform its Constitution regarding energy, highlighting its ownership of energy resources.

Despite these cross-border and regional initiatives, the NADBANK projects, and the USMCA, Mildenberger and Stokes (2021) assert that energy policy remains under national or subnational jurisdiction because there are no strong North American institutions to regulate and manage energy. Policies in the region are subject to national sovereignty, and each of the three countries accounts for its own regulatory framework, which complicates cross-border energy relations.

Energy exchange is subject to different policies at national and local levels (Hunt Institute for Global Competitiveness 2016). Attempts to include a climate and decarbonization approach into regional energy integration were developed in the two North American Leaders' Summits in 2016 and 2021. Both meetings reinforced the commitment to establish a regional renewables market in North America. Among other socio-environmental issues, in the last meeting the three executives agreed to 1) accelerate renewable energy deployment in the region; 2) design a North American Pledge for Methane and Black Carbon to reduce emissions from oil and gas by 60–75% to 2030; and 3) promote more electric vehicles and cleaner fuels for road, rail, and maritime transportation, and aviation (Prime Minister of Canada 2021).

Under Mexican president López-Obrador, these programs, plans, initiatives, and cooperation groups need to be considered carefully given that the Mexican federal goals for the energy sector aim toward a fossil-fuel future with centralized decision making. The exploitation of the oil industry by PEMEX, and the electrification of the country through gas and fuel-oil run by the CFE, are priorities for this administration. Basing the decision on a nationalistic approach, refining oil products became a prime goal. The construction of the Dos Bocas Refinery, the modernization of other refineries in the country, and the acquisition of the Deer Park refinery facility by PEMEX are pieces of the strategy. At the time of writing, an electricity reform designed by the Executive is being discussed in Congress. This reform would leave 56% of electricity provision to CFE and the rest for private companies (national or foreign). This reform also threatens to suspend contracts for renewable energy projects already performing. The federal government argues that with these steps, PEMEX would decrease its dependency on refined gasolines from U.S. providers and become self-sufficient to meet Mexico's energy demand. Under these reforms, CFE intends to regain control of most of the electricity generation and link it to PEMEX production of fossil fuels.

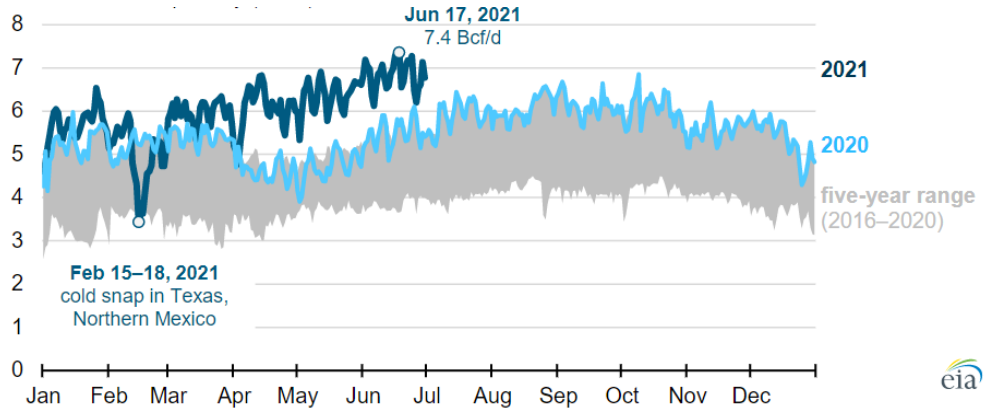
Impact of Policies on Markets and Infrastructure

Energy policies are linked to market decisions. Between 1998–2018 in Mexico, the percentage of coal for electric generation declined substantially and was substituted by a growing natural gas sector; to 2020, 60% of electricity has been generated with natural gas. Nuclear energy has been steady, and renewable sources (solar and wind) registered an important increase (GNEB 2020:18). Mexico's intended transition relies on electrifying the country through gas. However, Mexico is not a big gas producer and fracking is not allowed. The need for electrification increases the dependency that Mexico has on Texas gas, as portrayed in the following figure.

The rationale is clear: the prices of U.S. gas are very competitive. From 2015 to 2019, the price of Texas gas fluctuated from 2 to 4 USD/BTU. In 2020, there were prices under 2 USD/BTU (EIA 2021b). Mexican natural gas ranged between 3–6 USD/BTU for the years 2017–2021 (CRE 2021b). Under this context, the U.S. and Mexico debated between integrating their energy markets and acknowledging their interdependence against their intention to be self-sufficient and independent (Clarkson and Mildenberger 2011; Mildenberger and Stokes 2019).

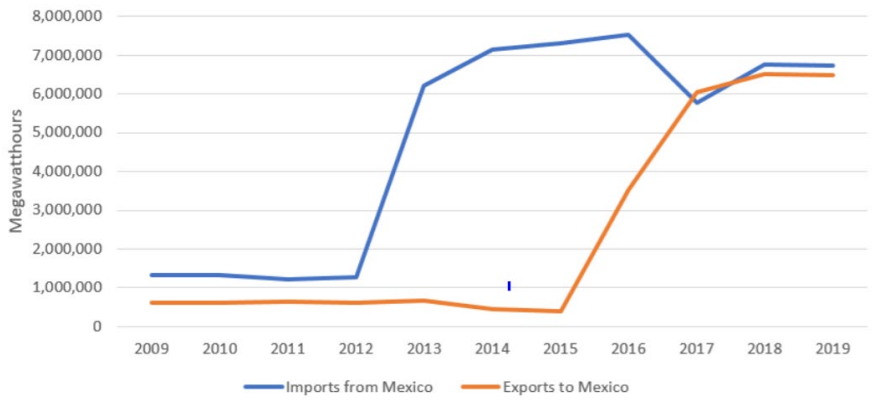
The energy reform of 2013 promoted the interdependence between both partners as private and foreign companies from the U.S. (and other countries) would be able to participate in the electricity market or deploy renewable energy. Despite the small volume, the cross-border electricity trade increased and has reached a steady point since 2017. In 2009, trade was around 2 million megawatt hours (MWh), and by 2019, it had increased to 13 million MWh (Wood and Ramiro 2021:3). The electricity balance also shifted, as shown in Figure 2.

Figure 1. U.S. Daily Natural Gas Exports to Mexico—2016–2021 (Billion Cubic Feet/Day)



Source: EIA 2021c.

Figure 2. U.S.–Mexico Electricity Trade Balance (2009–2019)



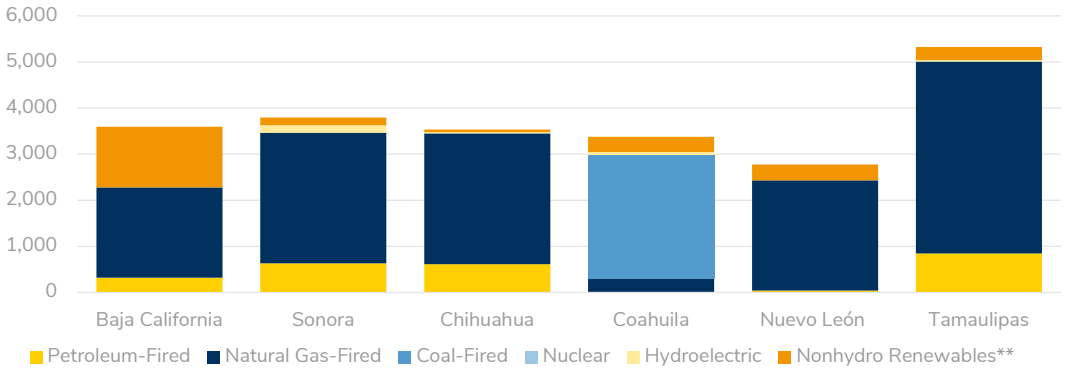
Source: Wood and Ramiro 2021:3.

The puzzling reality is that, despite border states on both sides deploying renewables, they hardly trade the outcoming electricity. Figure 3 below shows the electricity generation technology of Mexican states.

In the case of U.S. states, only Texas and California have important renewables deployment for electricity generation, as shown in Figure 4.

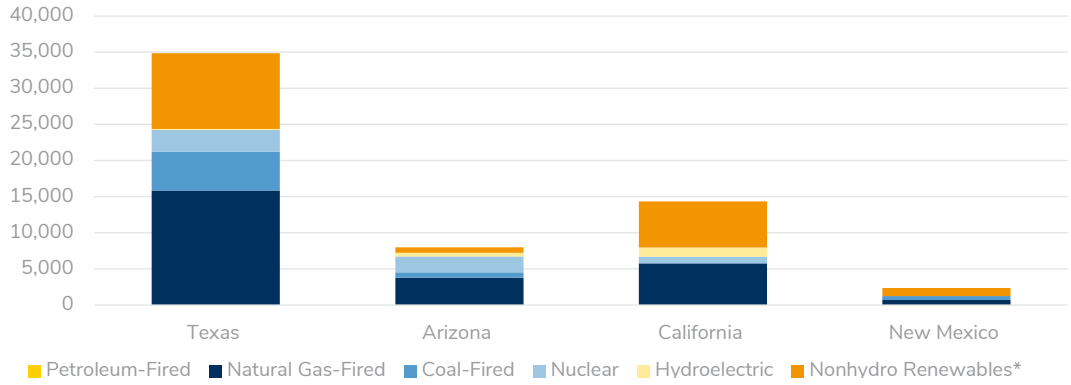
Both figures show that natural gas and non-hydro renewables are increasing rapidly within the energy mixes. Electrification through gas needs investment in infrastructure. By 2015, there were 16 gas interconnections between Mexico and the U.S. (Parfomak et al. 2017). Today, the Mexican federal government, through CFE, is building 13 new combined-cycle facilities to operate in 2025 (Expansión 2021; SENER 2020). This comes with an investment of more than 1,350 million dollars in the modernization and expansion of natural gas infrastructure, such as facilities and pipelines, to connect more regions in Mexico to the hydrocarbon network (SENER 2019:39). This infrastructure is especially destined to guarantee more and safer interconnection with Texas. The investment in transmission lines, in contrast, has been scarce. According to the Program for the Development of the National Electricity System, there will be 199 projects to modernize and expand the electricity system. The investment will reach 4.6 million dollars (SENER 2020). In the northern states with cross-border transmission lines, the projects are only to support tension and to give maintenance to the existing infrastructure.

Figure 3. Mexico Generation of Electricity by Source and State, 2020 (MW/h)



**Includes wind, solar, geothermal.
Sources: Adapted from SEMARNAT 2020; SENER 2020:182.

Figure 4. U.S. Generation of Electricity by Source and State, 2021 (MW/h).

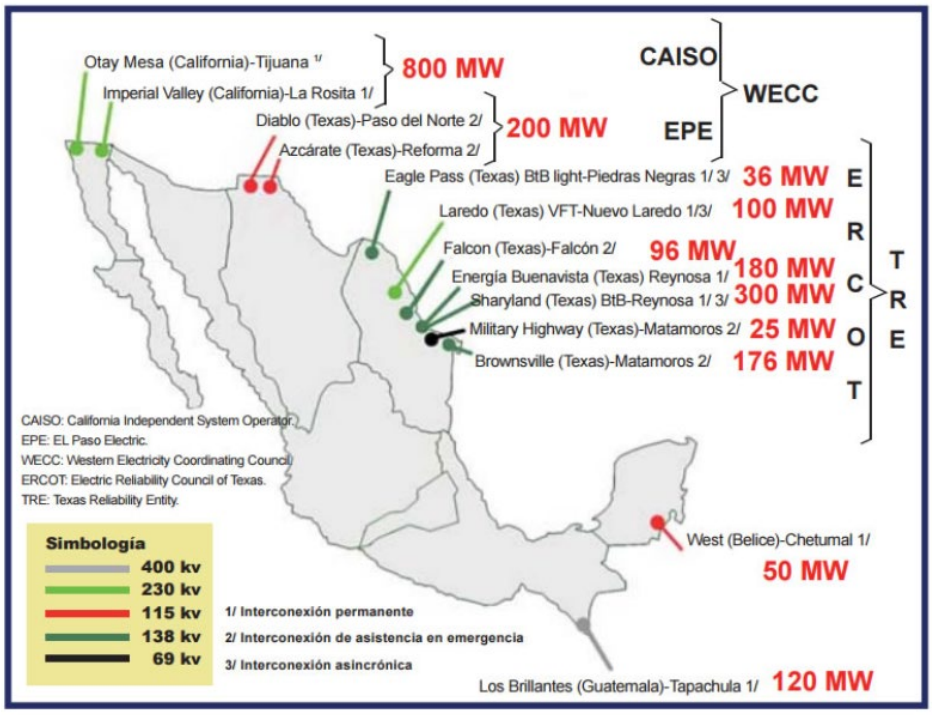


*Arizona is not part of the electricity hubs analyzed under this chapter.
Source: Adapted from EIA 2021a.

Prioritizing gas infrastructure has resulted in leaving transmission investment aside. By 2020, there were only 11 transmission lines crossing the border. Some of them are for regular trade (e.g., CFE-CAISO), but the EPE lines and more than half of the ERCOT are for emergency only or asynchronous (they can operate independently), as shown in the figure below.

The following sections address the particularities of each of the three electricity hubs analyzed in this paper. CFE-EPE, CFE-ERCOT, and CFE-CAISO have different approaches to electricity and decarbonization, determined by energy policies. To have "green" electricity cross-border hubs, policies need to deploy renewables, not only within individual states, but policies need to incorporate them into trade. Even if this condition is met, a cross-border renewable electricity market would not be attractive to investors and decision makers if there is a lack of investment in cross-border infrastructure (e.g., transmission lines). For Mexican partners, the configuration of this type of electricity hub needs to be sustained under national policies and decarbonization goals. In the case of the U.S., each border state has already determined its decarbonization strategy.

Figure 5. Electricity Interconnections on the Mexico-U.S. Border



Source: SENER 2013.

3. CFE-EPE AND CFE-ERCOT: RENEWABLES PUT ASIDE?

With the small size of the cross-border electricity market and the intense fossil-fuel exchange, for CFE-EPE and CFE-ERCOT there is still no incentive to open an alternative market toward renewables. Despite sharing the fact of not integrating renewables to trade, the partners of these hubs have different approaches toward domestic use of renewables. In the U.S., New Mexico is still developing its renewable sector, but has established ambitious climate goals. This contrasts with the important renewable investment and deployment of Texas, which has very modest climate goals. The Mexican states of Tamaulipas, Nuevo León, Coahuila, and Chihuahua have little renewable deployment for domestic use.

The CFE-EPE Hub

The Comisión Federal de Electricidad-El Paso Electric (CFE-EPE) hub is integrated by the Mexican state of Chihuahua and the U.S. states of New Mexico and Texas; it connects the cities of Ciudad Juárez, El Paso, and Las Cruces. The energy relationship between the three cities-three states-two nations region is still in development. As explained in a report presented by the Hunt Institute of Global Competitiveness (2016:1), the three cross-border cities are interconnected through fossil-fuel infrastructure. Their economies depend on the oil and natural gas trade, while renewable sources account for a small percentage of the region's energy mix.

EPE is a regional electricity utility with generation, transmission, and distribution services covering 444,300 retail and wholesale customers in a 10,000-square mile area of the Rio Grande valley in west Texas and southern New Mexico (EPE 2021a). In electricity, the region has two transmission lines of 115 KW crossing the border. According to its 2020 Plan (EPE 2021b:1), this system aims to achieve 20% of its renewable portfolio standards based on EPE's forecasted New Mexico retail energy sales of 1,683,624 MWh. The Plan also acknowledges that when renewables are added to the energy hub, the result is larger facilities leveraging scale economies, thus reducing costs of renewables (EPE 2021b:3). Alongside the 20% goal, reducing costs suggests that electricity trade in this regional hub can promote potential decarbonization, especially with solar PV energy.

In the cross-border relationship, since 1970, EPE has provided electricity to the Mexican border city of Ciudad Juárez, Chihuahua. From 1990 to 1992, there were several amendments requested by EPE and granted by the DOE to authorize the conversion of both transmission lines from 69MW to 115MW with the purpose of exporting electricity to Mexico (DOE 1992a; DOE 1992b; EPE 2021a). There were two conditions for these permits. The first was that the maximum transmission rate was 200 MW. The second was that these lines were for emergencies only. This means that power systems can only be connected when there is a contingency or when power is scheduled to be transmitted.

To guarantee reliability and prevent overloads, when EPE exports electricity to CFE, transmission lines on both sides are disconnected from their domestic grids and operate as a cross-border closed circuit. As soon as transmission ends, they both reconnect to their power networks and switch off the cross-border connection (DOE 1992a). Agreements were signed in 2014 with CFE to provide this volume of electricity through the Diablo Substation in New Mexico to CFE's Insurgentes Substation, and EPE's Ascarate Substation in Texas to CFE's Rivereña Substation—both Mexican substations are located in Chihuahua (EPE 2014:61–62). The Ascarate substation is connected to the El Paso Refinery, and Diablo generates electricity with natural gas. Under this scenario, no renewable electricity is exported to Mexico in this hub.

The CFE-EPE hub has the potential of becoming an important cross-border hub and integrating renewables in the near future (Kolenc 2017). Some steps have been taken toward this goal. To enhance reliability and facilitate more renewable energy being integrated into the EPE network, this hub will join CAISO in 2023. This will help EPE to quickly acquire the required energy to meet the necessary load and compensate for variability from wind and solar (CAISO 2021). This might account for more renewables into the EPE grid as CAISO has high standards and goals expressed in its ambitious renewable portfolio standard for electricity. Additionally, as shown in previous data, the three states have been deploying renewable electricity for local consumption. Chihuahua and Texas have been awarded funds by NADBANK to build two solar parks each. Prices of renewable electricity are competitive (CENACE 2018). When policies address the need to decarbonize both sides of the border, they need to invest in infrastructure to either connect both solar markets or follow the model of the CFE-CAISO, explained below. Although still a small electricity market, there is potential to balance fossil-fuel electricity with solar sources.

The CFE-ERCOT Hub

The CFE-ERCOT hub proves how pro-fossil fuel policies prevent renewables from being incorporated into the electricity exchange. ERCOT is a nonprofit corporation working under the jurisdiction of the Public Utility Commission of Texas. As there is no interstate commerce, ERCOT does not fall under the FERC jurisdiction (GNEB 2019). ERCOT powers 26 million customers in Texas, representing 90% of the state's electric load. ERCOT's network includes more than 46,500 miles of transmission lines and more than 710 generation units (ERCOT 2021). Partnering with CFE, this hub accounts for seven transmission lines connecting Texas and three northeastern Mexican states (Coahuila, Nuevo León, and Tamaulipas). Of the seven lines, one is 69 KW, five are 138 KW, and one is 230 KW (ERCOT 2021; SENER 2013). Three of these lines are emergency lines and they work similarly to those of EPE (Falcon-Falcón, Military Highway-Matamoros, and Brownsville-Matamoros). Buenavista is permanent, and the Laredo, Sharyland, and Eagle Pass lines are permanent and work asynchronously. Historically, Mexico has sent power to Texas when outages occur, as in 2011 when Mexico sent 300 MW (Helman 2011).

Although Texas and Northeastern Mexican states are deploying renewable sources, they are consumed in the domestic market. Bringing back data from the previous section, Texas has been awarded two solar projects by NADBANK and has important renewables deployment. Tamaulipas, Nuevo León and Coahuila have also developed wind and biogas projects under the bank's auspice. Despite these facts and that the four partners have decarbonization goals, no renewable electricity is exchanged in the cross-border energy market. The electricity exported from Texas to Mexico comes from combined cycle gas power plants. Indirectly, and through growing exports of natural gas and LNG, Texas fuels most Mexican CFE power plants. Through Texas, Mexico imports gas and refined products distributed not only to the border states but to the entire country. Mexico, with an increasing electricity demand, has become a key importer of natural gas coming from or through Texas. In 2015, 81% of gas consumed in Mexico was provided by the United States. By 2021, 60% of gas consumed in Mexico was provided by or distributed through Texas (Border Now 2021; Prud'homme 2021).

The Mexican dependency on the Texas competitive gas industry has had several consequences for cross-border energy relations. The first is that there seems to be no room for renewables in the short term in the CRE-ERCOT hub. The second consequence is that when climate disasters occur in Texas, the provision to Mexico and the prices change dramatically. This was the case of the February 2021 Texas freeze, which affected electricity generation and resulted in a two-day outage in a big part of Mexico. Apart from the suspension of electricity provision to Mexico, when the service was restored, prices had risen from 3USD/BTU to almost 600USD/BTU (Expansión 2021; Prud'homme 2021).

The CFE-ERCOT case presents a puzzling reality where the four partner states deploy renewables for their domestic consumption, Texas being the leader of the region (even surpassing California in volume), but the solid and prosperous fossil-fuel market overshadows any effort to decarbonize cross-border trade.

4. THE CFE-CAISO HUB: A RENEWABLE HUB WITH ASYMMETRIC RELATIONS

Of the three hubs, the CFE-CAISO hub is sui generis. It is the only one including renewables in cross-border trade. However, this hub cannot fully consider itself a green electricity hub, as only California consumes the renewable electricity generated in the region. There are several factors for renewable electricity being promoted in this hub.

The first deals with the special situation of Baja California. This Mexican state has a small number of cities located at the U.S. border. Because these cities are far away from the rest of the country, this state is not connected to the Mexican National Electricity System. Power is provided by an independent network linking these cities (and San Luis Río Colorado in Sonora) with the California grid through CFE and private transmission lines. In 2016, CENACE and CAISO signed an agreement to connect the Baja California independent grid to the Western Imbalance Market operated by CAISO (CENACE 2016). This aims to guarantee reliability in both directions of the cross-border interconnections.

As shown in Figure 5 above, Baja California is interconnected to California through two transmission lines of 230MW, one on the Coast (Otay Mesa), providing power to Ensenada, Tijuana, Rosarito, and Tecate, and the other in the Valley (Imperial Valley), located in Mexicali. Most of Baja California's renewable electricity comes from the Cerro Prieto Geothermal Station located near Mexicali. There are also two wind farms. First, La Rumorosa, owned by the Government of Baja California, with a capacity to export 485MW. This facility also powers the city of Mexicali. The other company, Energía Sierra Juárez, has a 1500MW capacity (DOF 2017), and it is run by U.S. companies (IENOVA and InterGen). This facility interconnects to the Southwest Powerlink in the East County substation operated by San Diego Gas and Electric (SDG&E). All of its energy is exported to California (Energía Sierra Juárez 2021).

In contrast, natural gas coming from the U.S. is key to the electrification of Baja California. By 2019, the electricity sector consumed 93% of the 340 million cubic feet provided to the state (IAmericas 2020:2). Infrastructure accounts for three gas-fired combined-cycle power plants, two belonging to U.S. companies, and the Presidente Juárez thermoelectric run by CFE (Muñoz-Meléndez and López-Vallejo 2018). Mexicali Thermoelectric has a 625MW capacity and is property of Sempra Energy; InterGen owns the thermoelectric facility La Rosita, with a 1500MW capacity (DOF 2017). Additionally, a recent re-gasification of LNG station in Ensenada is changing Baja's energy mix. The company Energía Costa Azul (operated by Sempra Energy and Ienova) provides gas to the Pacific U.S. States and connects the gas basins of Texas, New Mexico, and the producers in Wyoming and Utah; it will intend to connect these providers with Asia Pacific (Energía Costa Azul 2021). It also provides gas to the Baja California thermoelectric plants.

Summarizing Baja California's power plants, the state accounts for seven combined-cycle facilities, one turbo-gas, and one internal combustion plant, all of them using gas and representing most of the sources to generate electricity. Renewables are generated by two wind parks and one solar facility (IAmericas 2020:11–12).

The Baja California Energy Outlook (IAmericas 2020:2) acknowledges that the exports to California leave Baja with a very scarce installed capacity that is not sufficient to meet peak load and the projected increase in demand. As evidenced, Baja California provides renewable electricity to California, while most of Baja's electricity comes from fossil fuels. The renewable market in Baja seems to be directed to fulfill the decarbonization goals and climate commitments of California (Muñoz-Meléndez and López-Vallejo 2018), as this state is planning to obtain 100% of its electricity from decarbonized sources by 2045 (GNEB 2019). Policies in California allow for renewable resources located in Mexico to satisfy this goal (GNEB 2019).

This asymmetric relationship is trying to find a balance with two strategies. Despite the Baja California economy being mostly fueled by natural gas, wind and solar local electricity projects are growing. According to the 2019 Annual Report of CFE (2019:99), in 2017, there were 1,427 applications for interconnection to the grid of distributed generation, and in 2019, there were 2,425. The second strategy is negotiation with the California government and its companies to provide a percentage of renewable electricity locally. Meanwhile, Baja California considers gas a transition fuel and intends to participate in the gas exports market via Energía Costa Azul (El Financiero 2021).

In sum, this electricity hub represents one model of how renewables can be integrated into cross-border energy trade. Despite that California is using most of the green electricity produced in Baja, the Mexican state is trying to diversify its energy mix and include more renewables for local consumption. The only limitation today is the insufficient cross-border infrastructure to operate new renewable deployment. However, the constant increase of climate ambitions in California may account for future investment.

CONCLUSIONS AND FINDINGS

This paper argued that policies on both sides of the border determine how markets and infrastructure work under the three electricity hubs.

It presented three policy factors crossing all cases: policy differences regarding centralization and decentralization of energy, the lock-in of cross-border trade into fossil fuels due to Mexico's dependency on U.S. oil and gas and Texas historical fuels production, and the small size of the cross-border electricity market. Central policies in Mexico affect decision making regarding energy trade. The 2013 energy reform opened the door for renewable deployment in the country; border states benefited from renewable foreign investment. Recently, national policies changed and went back to a pro-fossil approach, limiting the decarbonization path of Mexican states. The main finding of this paper is that, due to national and state policies, all three hubs run in different directions regarding renewables. Given the success of the gas-and-oil market, the CFE-ERCOT has no incentives to include renewables in cross-border trade, despite Texas being one of the states with more renewable deployment for domestic use in the U.S. The CFE-ERCOT has little electricity trade (emergency only), also based on fossil fuels. Nonetheless, it has the potential to enlarge the market by including wind and solar in trade. This case could follow CFE-CAISO's path, where Mexican states import renewable electricity deployed in Texas to comply with their decarbonization goals. The CFE-CAISO case seems to be a model to transform the region into a green electricity hub. Ironically, what at one point in history was a curse for Baja California (being too far away from the Mexican power grid), today gives it certain independence from national policies and leaves room to design energy policies with a cross-border approach. The only limitation that other hubs might want to overcome is the asymmetric use of renewable energy generated in the region.

As established earlier, even with renewable deployment on both sides of the border and the political will to integrate them into cross-border trade, the limited and ill-maintained infrastructure is an obstacle to overcome in the three hubs. Investment is needed to update the grid and increase its power capacity. In this context, institutions such as NADBANK can contribute to renewable integration. But once again, the uncertainty of Mexican energy policy might prevent this type of project from developing.

In the case of Mexico, border states that were starting to deploy renewables have found obstacles to continue with projects or to attract new ones as the current administration's goal is to focus on gas and oil to fuel the Mexican economy. This policy strategy has deepened the dependency on Texas gas as the main source for providing electricity. Investment in gas-and-oil pipelines and facilities is clearly a priority for the current administration over modernization and construction of transmission infrastructure.

A subsequent finding of this paper is that the straightforward strategy followed by California to comply with decarbonization goals through a cleaner energy mix aided by electricity trade has not been followed by other hubs. Neither Texas nor New Mexico is aligning its energy deployment with decarbonization goals. On the Mexican side, states are tied to national policies privileging fossil fuels as sources for electricity generation. However, there is potential for the California experience to diffuse to the CFE-EPE region through inter-hub agreements leading to interconnections.

The last finding is that, even though the CFE-CAISO hub is the only case where renewables integrate trade, this hub can only be conceived as a partial green electricity. It is necessary to acknowledge the disparity of energy sources between both partners, where California's companies generate renewable electricity in Mexico and export it for domestic consumption (López-Vallejo 2017). Nonetheless, the Baja California government is negotiating with California to balance this trade. Ironically, what at some point in history was a curse for Baja California (being too far away from the Mexican power grid), today gives it certain independence from national policies and leaves room to design energy policies with a cross-border approach.

This paper concludes that electricity hubs in the U.S.-Mexico cross-border region are yet to be consolidated. If climate and decarbonization policies and instruments are already being developed in states on both sides of the border, their inclusion might be a natural step toward diversification of cross-border trade.

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