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Prices versus Quantities: Re-thinking Electricity Subsidies in the context of Nearshoring in Mexico

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Abstract

This paper proposes a paradigm shift from price-based to quantity-based electricity subsidies, inspired by the characteristics of distributed generation technologies such as photovoltaics (PV solar). This approach, aimed at addressing the significant challenges in Mexico's electricity sector exacerbated by nearshoring, entails reallocating government budgets towards the procurement of solar panels for individuals or households. The paper examines the potential of this strategy to alleviate the current electricity sector's constraints, expand fiscal capabilities, and support Mexico's transition to a greener economy amid the realignments in the global supply chain. We argue that subsidizing quantities, rather than prices, could reduce market distortions and potentially solve long-standing investment issues in the country's transmission, distribution, and generation infrastructure. This approach would not only mitigate the immediate demand-supply imbalance but also lay the groundwork for a sustainable and resilient energy infrastructure, offering a pragmatic solution to the intertwined challenges of energy policy, fiscal responsibility, and industrial development in the context of nearshoring.

1. Introduction

Electricity subsidies present a significant challenge for energy, fiscal, and social policies. In some countries, electricity subsidies are already regarded as the costliest social program in terms of resource allocation, surpassing, for example, budgets allocated to education. Traditionally, these subsidies have been administered through pricing, where consumers pay a fraction of the production cost. However, this approach leads to distortions, including cross-subsidization among different consumer types (domestic, industrial, agriculture), across regions with varying weather conditions, and between consumption levels, resulting in a complex network of distortions. Some authors advocate for energy tax reforms and the gradual reduction of electricity subsidies as subsidies often delay the adoption of cost-effective, energy-efficient technologies (Joskow & Marron, 1993). However, in many countries, the political terrain makes eliminating these subsidies a daunting, if not impossible, task (Fattouh & El-Katiri, 2015; Shah, Giordano & Mukherji, 2012).

This paper explores an alternative approach to restructuring subsidies, allowing them to simultaneously fulfill, within these constraints, other desirable policy objectives as well. This approach requires a nuanced grasp of the interaction between economic efficiency and political viability. Taking inspiration from Weitzman (1974), widely applied in environmental economics to regulate emissions via taxes or permits, we explore the alternative approach of subsidizing quantities of electricity instead of prices. This option is now viable due to innovations in the electricity sector, particularly distributed generation technologies like photovoltaics, PV solar henceforth. Such advancements enable governments to potentially allocate a designated solar capacity to individuals or households, to produce a quantity of subsidized electricity.

The proposed strategy involves a complete reallocation of the government's budget from price subsidies to the procurement of solar panels. While the allocated quantity may not cover an entire household's demand, it could assist in meeting basic needs, with the remaining demand being purchased from the market, and supplied from the most efficient sources. This approach would aid in reducing some market distortions, as the market would only witness lower demand, as part of that consumption would be occurring behind the meter. This policy could also yield additional benefits, such as addressing long-standing infrastructure investment issues in transmission, distribution, and generation.

To illustrate this proposal, we analyze the case of Mexico. The Mexican electricity system faces a challenging scenario characterized by a surge in demand against a constrained supply due to years of underinvestment. Even if decisions were made today to rectify this situation, the lasting impact of delayed investments may persist. Compounding this issue is the external pressure from a remarkable surge in demand attributed to the shifting dynamics of global supply chains. Production previously located offshore is now being relocated to countries closer to consumption centers, a trend referred to as “nearshoring” (Duran-Fernandez, 2023). This shift, ignited by the US-China trade tensions that began in 2018 and further intensified by the COVID-19 pandemic and various environmental crises, has prompted multinational corporations to seek alternative locations for their operations. Mexico has emerged as one of the countries that have significantly benefited from these changes, surpassing China as the primary exporter to the USA (Alfaro & Chor, 2023).

This phenomenon underscores the urgent need for Mexico to address its electricity sector’s vulnerabilities, not only to meet current demands but also to capitalize on the opportunities presented by nearshoring. There is an urgent need to address infrastructure deficiencies through unconventional methods, as the conventional approach would simply take too long to materialize. Our proposal would aim to reduce the domestic sector's demand behind the meter, freeing up additional energy for industrial use, which in turn would enable the absorption of additional investments seeking to relocate to Mexico promptly. In the meantime, this approach would buy time to develop utility-scale capacity. This approach is particularly appealing as it circumvents the complexities associated with large-scale infrastructure projects, instead framing the challenge as a modular one (Flyvbjerg & Gardner, 2023), which focuses on the manufacturing and mass production of solar panels. By shifting subsidies from expenditures into capital investments, this strategy has the potential to reorient fiscal, energy, and social policy considerations toward the realm of industrial policy. An additional benefit is that this policy could assist firms in achieving environmental, social, and governance (ESG) objectives that necessitate greening their supply chains.

This proposal is not aimed at enhancing the overall efficiency of the electricity system. It's plausible, for instance, that expanding capacity through domestic rooftop solar could be more expensive than other options, such as community solar or utility-scale solar capacity. Rather, our proposal seeks to assist an emerging country in capitalizing on the nearshoring trend by enabling the swift deployment of electricity capacity through the reassignment of current subsidy resources. Importantly, this reallocation is designed to ensure that both households and the government remain indifferent to the change. In essence, our focus lies more on the reallocation of subsidies rather than on how to best allocate the capacity expansion budget. However, this policy overlooks a fundamental distortion; the lack of incentive for energy savings due to electricity pricing not reflecting its full cost. Consequently, this oversight exacerbates the demand for additional capacity, which could otherwise be minimized.

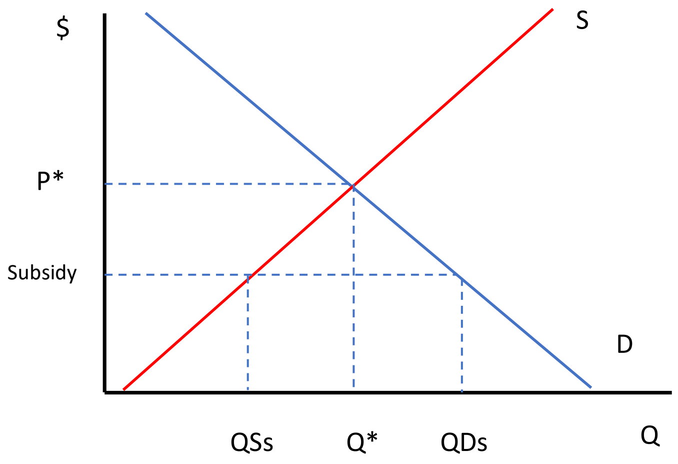
The paper is structured as follows. Section 2 sets the theoretical background of the debate between pricing and quantity-based approaches concerning welfare considerations. Section 3 examines the case of Mexico's electricity sector and how nearshoring exacerbates longstanding issues in the electricity sector. In section 4 we analyze the economic and financial aspects of this proposal. Section 5 discusses the political economy aspects of this proposition and in section 6 we discuss its limitations. The paper concludes in section 7.

2. Theoretical background

A Pigouvian tax is a type of tax levied on any market activity that generates negative externalities. They intend to rectify market inefficiencies by encouraging individuals or businesses to reduce socially harmful behaviors, such as pollution (Pigou, 1932; Baumol, 1972; Galinato & Yoder, 2010). We reinterpret subsidies as a type of negative Pigouvian tax, as they could help achieve goals that can't be achieved through market mechanisms alone. Subsidies supporting renewable energy exemplify how they help propel deployment toward an ideal, optimal level. Subsidies on the consumer side, such as those for electricity, reduce the price consumers pay at the point of purchase. Reduced prices stimulate higher consumer demand for the subsidized product, moving consumption toward an ideal, optimal level.

There are two potential problems with this. The first is that redirecting resources to the consumption of goods that are seen as improving social welfare may come with an opportunity cost, possibly overlooking other alternatives. The second is that altering relative prices can result in shortages, as demand outpaces supply, necessitating additional government spending to meet this excess. Figure 1 shows graphically these two shortcomings. Setting subsidies (S) lower than the equilibrium price (P*), with this subsidy producers are willing to offer a quantity denoted by QSs while consumers are willing to buy a quantity denoted by QDs. Producers incur losses if they produce beyond Q*. Therefore, governments need to divert resources to cover the amount of the triangle BCD.

Figure 1: Shortages and diverted public resources



Source: Authors

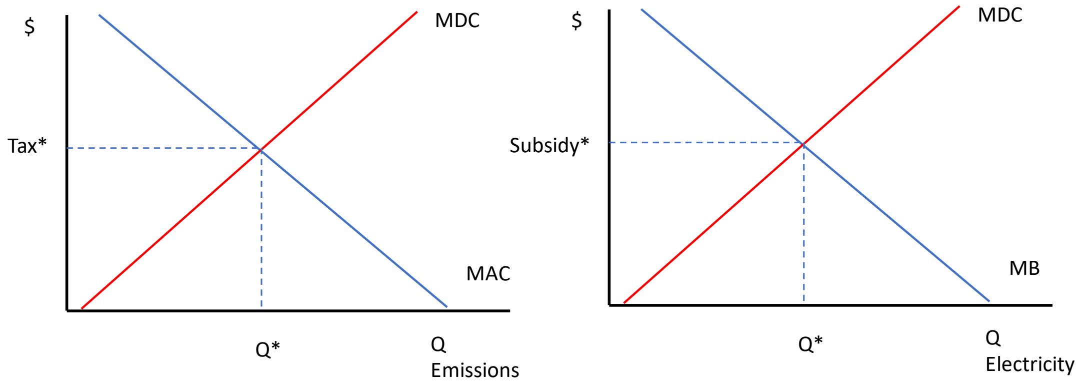
The approach we are proposing can address these two concerns at the same time. This approach mitigates potential opportunity costs associated with subsidizing consumption, by directing support towards durable goods that enable self-consumption. Also subsidizing quantities rather than prices offers a more manageable approach to subsidize just the right amount of electricity that maximizes welfare.

The theoretical basis of this proposal draws from Weitzman's (1974) application in environmental economics, which posits that controlling emissions can be efficiently managed through taxes (a price instrument) or permits (a quantity instrument). Since the marginal cost of producing electricity with PV solar is zero - which means that production can be added without increasing total production costs, which is the upfront cost — subsidizing quantities would yield a similar outcome, in terms of welfare, as subsidizing prices in the relevant segment.

The mechanics of each route, however, offer different advantages and disadvantages. Using the example of environmental economics to illustrate this point, price-based systems entail taxing pollution emissions, which ensures a known cost for each unit of pollution abatement. Firms select their emission levels by weighing their internal abatement costs (MAC) against the external fixed tax. A pigouvian tax would be equal to the marginal damage cost (MDC). Quantity-based systems, on the other hand, fix quantities, namely the maximum allowable emissions. While quantity instruments secure specific emission levels, they lack the cost-effectiveness of price-based mechanisms.

Applying a symmetrical argument in the opposite direction, we consider a subsidy as a negative tax. While pollution is a 'bad', electricity is a 'good'. Therefore, rather than reducing the quantity of pollution, governments seek to increase the quantity of electricity up to an optimal level. In theoretical terms, governments should subsidize the amount of electricity up to the point where the social marginal benefit of subsidization (MB) equals the marginal cost of the subsidy itself (MC). The social marginal benefit of subsidies is a conceptual construct. We can think of this quantity as the amount of electricity that guarantees access to some basic services (refrigeration, lighting, for instance) but perhaps not air-conditioning. The marginal cost of subsidization can be for instance the total of costs of distorted prices, the additional public funding needed to meet over-demand, and the opportunity cost of subsidizing one sector over another. Figure 2 illustrates this point. While conceptually clear, determining the efficient subsidy value proves challenging. To maintain the notion that both instruments—prices versus quantities—are equivalent and interchangeable for achieving the desired level of efficiency, we ensure that the government spends the same amount on either.

Figure 2: Optimal Pigouvian tax vis-à-vis optimal subsidy in electricity

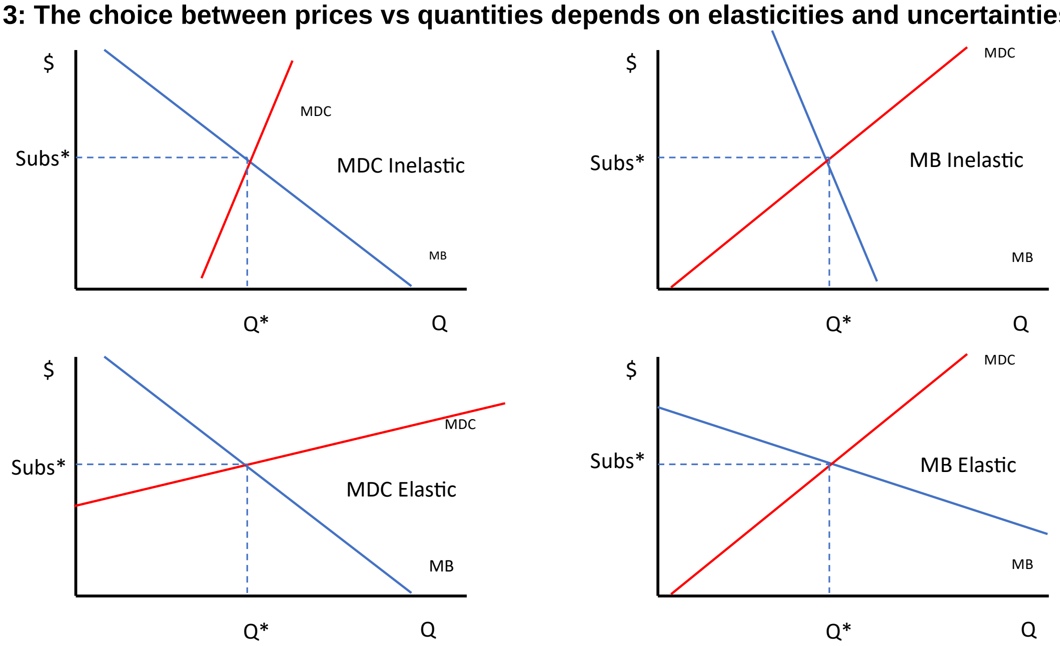


Source: Authors

Without subsidies, consumers might not be consuming this optimal amount due having lower incomes, or because the production costs could be excessively high. Governments can help realize the efficient provision of electricity by charging customers less than the cost of production (price subsidies) or by directly providing the quantities themselves (quantity subsidies). Price-based electricity subsidies ensure certainty regarding the cost per unit of electricity consumption but may lead to consumption surpassing the socially optimal level due to reduced prices, which would lead to distortions and shortages. A quantity-based approach to electricity subsidies establishes the ideal consumption level at prices below the market rate but does not ascertain the actual cost.

The optimal choice between price-based and quantity-based subsidies hinges on the elasticity of both marginal benefits and the costs of subsidization, often influenced by factors like electricity demand elasticity and weather conditions. Weitzman's (1974) perspective underscores the importance of uncertainty: in situations where uncertainty clouds the marginal benefits of subsidies, he leans towards favoring quantity-based subsidies (see Figure 3). However, when uncertainty surrounds the variability in marginal costs, a price-based subsidy is deemed more advisable than a quantity-based permit. Weitzman's guidance suggests that when the marginal benefit of subsidization remains relatively unchanged with incremental subsidy increases, and the marginal costs are highly responsive to these changes, opting for a price-based mechanism becomes more favorable. This aligns with the notion that a price-based approach would be beneficial if the marginal benefits of subsidization are less affected by subsidy levels, while the marginal costs are highly sensitive to these adjustments. Furthermore, the elasticity of demand for quantity-based subsidies plays a pivotal role; if demand is inelastic, Weitzman leans towards quantity-based subsidies, whereas if demand is elastic, his recommendation veers towards a price-based mechanism.

Figure 3: The choice between prices vs quantities depends on elasticities and uncertainties



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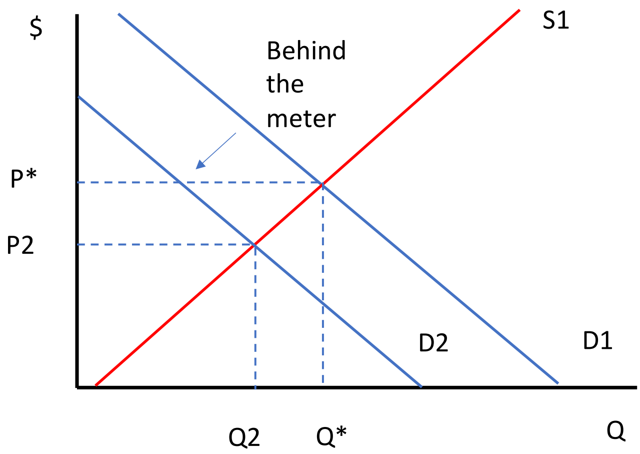
In practical terms, it would also be impossible for governments to cover all consumption, only a fraction of it. Our proposal is that after this fraction is covered, the residual demand is met by the market. This has two benefits: one is that it eliminates further distortions in the market; the second is that this proposal would make the market price lower as well. We can think of PV solar as both a demand and a supply technology, a 'prosumer' technology. By adding zero marginal costs capacity behind the meter, the utility or the system operator would just observe a shift of demand to the left, leading to overall lower prices as well as shown in Figure 4.

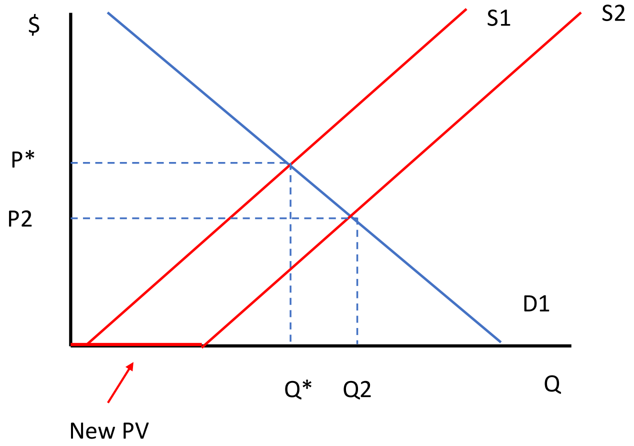
Figure 4: Self-generation and consumption would be observed by the system operator as a decrease in demand behind the meter



Source: Authors

From the total electricity sector perspective, the supply curve S1 will change to S2 as shown in Figure 5. The first units of the supply side will offer electricity at zero marginal cost, and therefore will push the supply curve to the right (S2 in figure 5). Therefore, what we would expect with this policy change is a more focused subsidy, that eliminates further distortions, and that reduces the overall market price.

Figure 5: Subsidies for PV panels are added to the total installed capacity in the electricity sector



Source: Authors

In summary, our approach tackles market inefficiencies by subsidizing specific quantities of electricity, aligning the social benefit with the subsidy cost. This focuses on essential services while letting the market handle the rest, reducing distortions and possibly lowering overall prices. Shifting from expenditure-based subsidies to investment in durable goods could enhance installed capacity, further impacting market dynamics positively.

3. Case study: Mexico in the context of nearshoring

Mexico's electricity sector has struggled to construct new capacity for generation and transmission over the last few years, creating a deficit that has been exacerbated by the recent phenomenon of nearshoring. Insufficient electrical infrastructure might hinder the realization of investments. Moreover, should these investments be realized, they could amplify preexisting issues within the electricity sector. The reason is that while nearshoring could rapidly accelerate short-term economic growth, the electricity sector might take several more years to recover from the backlog due to the extensive timelines associated with long infrastructure projects (Fuentes, 2023).

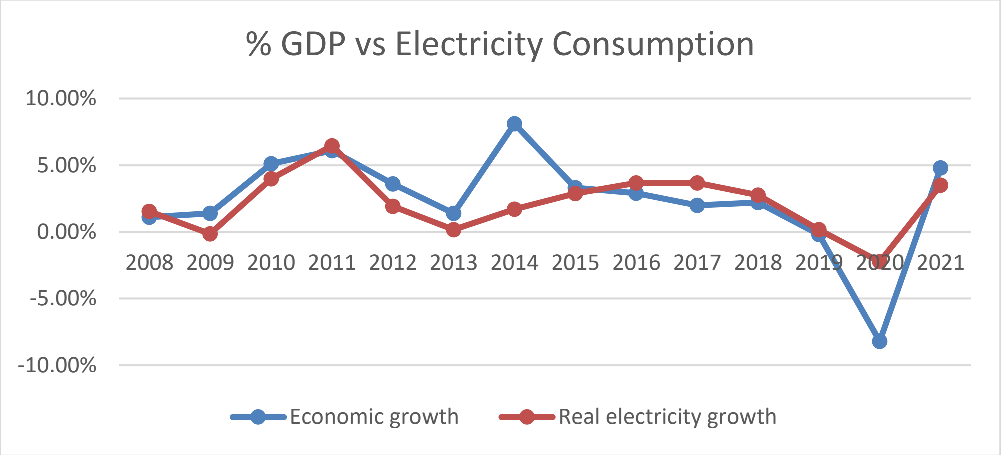
The electricity market is a complex system requiring a constant balance between supply and demand. Sustaining this equilibrium requires electricity generators to be consistently prepared to meet varying demands, not to mention the time needed to develop transmission lines. Conversely, electricity demand is characterized by its high volatility, fluctuating sharply by the hour, day, and season. Excessive demand fluctuations can lead to network failures and compromise the quality of electricity supply. As electricity storage remains expensive, meticulous long-term planning becomes indispensable. Therefore, given the extensive lead times associated with electricity investments, we presume that the current supply status of the electricity sector in Mexico reflects decisions made four or five years ago.

The planning of Mexico's electricity sector falls under the jurisdiction of the Ministry of Energy (SENER). SENER releases an annual report named *Prospectiva del Sector Eléctrica*, providing a 10-year outlook. This report encompasses various topics, including demand forecasts, the required investments to maintain a robust reserve margin, and historical data. The 2018 *prospectiva* is an important benchmark because after that there was a change in electricity policy.

One of the most important instruments that were given by the Electricity Reform bill in 2013 was the set up of Long-Term Auctions that were implemented by the system operator, CENACE. These were competitive auctions where private companies would develop projects following SENER and CENACE guidelines. Most of these projects were for renewable sources like wind, solar, hydroelectric, and geothermal energy. In May 2020, SENER cancelled a mechanism intended to bolster the role of Mexico's utility company, the Comisión Federal de Electricidad (CFE), in the market. This decision sparked controversy as it raised concerns about potential breaches of Mexico's trade agreements, such as the USMCA, and international commitments related to climate change and renewable energy.

The cancellation of these rounds has not yielded the anticipated negative impact on the electricity sector, though. During the acute phase of the Covid-19 pandemic, Mexico experienced a sharp contraction in its GDP of -8 per cent, followed by a recovery of 4.7 per cent in 2021 and 3.1 per cent in 2022. Electricity consumption mirrored this trend, closely aligning with the patterns observed in GDP growth, including an economic rebound in 2021 (see Figure 6).

Figure 6: GDP growth vs electricity consumption growth



Source: Authors with data from INEGI and SENER

However, economic growth — and therefore electricity demand — can quickly recover, driven further by post-pandemic rebounds and augmented by nearshoring investments.

Based on results from Fuentes (2023) which analyzes the variance between the projected target outline in the *Prospectiva del Sector Eléctrico 2018* and actual capacity, is a capacity gap of 21,607 MW. Reasons for this gap could be attributed to legal and regulatory changes in the sector.

The interplay of lower-than-expected demand and capacity additions falling short of initial projections has nonetheless raised concerns about the reserve margin. The reserve margin indicates surplus generation capacity in the energy system, ensuring adequate electricity availability in unforeseen scenarios like equipment failures, extreme weather, or sudden demand fluctuations. The optimal reserve margin varies based on system traits, demand trends, and risk tolerance. Typically, a 15 to 20 per cent reserve margin is considered essential for system reliability and blackout prevention. However, during the severe heatwave in Mexico in June 2023, CENACE issued a critical alert as the reserve margin dipped to 5 per cent at times. While this was a temporary call of urgency, it is an indication of the resiliency of the electricity sector to external shocks.

Assessing the state of transmission, which is also overseen by the CFE, is more complex. Unlike generation analysis, appraising transmission capacity involves interconnections, expansions (e.g., kilometers), and modernizing networks for the efficient utilization of capacity. Summarizing transmission's status with a single metric proves challenging due to its multifaceted nature. Instead, we focused on tracking the progress of major projects outlined in the last available outlook.

The Reynosa-Monterrey Transmission Project, a 600 km high-voltage line linking Tamaulipas and Nuevo León, commenced bidding in October 2018 and was awarded to IEnova and TC Energy in April 2019, valued at around $300 million. However, President Andrés Manuel López Obrador halted the project in October 2020 due to cost concerns, leaving its future uncertain. Similarly, the Baja-SIN Interconnection, aiming to connect Baja California and Sinaloa across 1,400 km, faced opposition over environmental and land use issues, stalling its progress. The Smart Grid initiative (REI), designed for real-time electricity management across Mexico, lacked public progress updates by 2021, hindered by technological and regulatory obstacles. Lastly, the Yautepec-Ixtepec Transmission Line, meant to bolster electrical transmission between Morelos and Oaxaca, experienced delays in land acquisition and construction, leading to its cancellation without subsequent revival efforts under the new administration.

The scenario we portray here illustrates market forces — such as delays in infrastructure investment, prolonged lead times, heightened post-pandemic demand, increased electricity needs from nearshoring, and additional demands due to heatwaves — converging to strain the electricity system. A prudent consideration merits a note of caution though. According to the *Programa de Desarrollo del Sistema Eléctrico Nacional* (PRODESEN), there is a total of 8,282 MW of additional electricity production capacity under construction and scheduled to come online before 2025. We don't include that in the analysis until it does, because as we showed, capacity builders have been consistently missing targets. Also, this analysis doesn't differentiate between technology types, impacting not just the demand segment served (like baseload, mid-merit, or peak) but also potentially affecting new investments that prioritize clean energy to fulfill ESG commitments from their corporate headquarters. We also recognize that circumstances since 2018 have radically changed, and this altered landscape would have naturally changed forecasts anyway. However, given the slow pace of investments, decisions made afterward are more likely to affect upcoming years rather than the immediate short term. Significant discrepancies between these forecasts could still indicate potential short to medium-term structural issues.

In sum, the Mexican electricity system is currently navigating a challenging scenario with a significant surge in demand paired with a constrained supply, a consequence of years of underinvestment. Even if energy auctions were to be reinstated or alternative mechanisms introduced, the impact of these delayed investments could continue to affect the sector's reserve margins. Recognizing the prolonged timelines inherent in constructing new infrastructure, our study proposes an alternative approach.

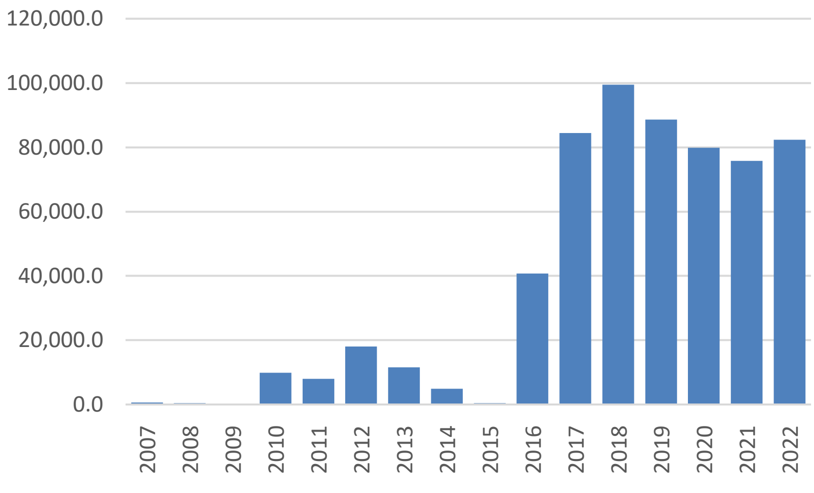
4. Results

We explore reducing residential electricity demand by shifting from traditional price subsidies to a model where the government subsidizes quantities through the distribution of solar panels. The premise is to eventually reallocate the budget entirely from price subsidies to solar panel procurement. Mexico's current social policy provides unconditional cash transfers to large segments of its population. Aligning this subsidy with in-kind benefits for electricity subsidies is logical. A precedent exists where in lieu of electricity subsidy payments, funds could go towards substantial appliance efficiency incentive programs (Leventis et al., 2013; Friedman and Sheinbaum, 1998).

Our analysis centers on three areas. First, we analyze the extent to which current constraints in the electricity sector could be ameliorated by redirecting electricity subsidies towards distributing solar panels. Also, how this change could remove fiscal limitations to address other social needs. Secondly, we analyze the scenario where the procurement of solar panels is financed with bonds rather than actual fiscal resources. Lastly, we examine how these strategies would impact the electricity expenses and consumption patterns of average households.

Annual subsidies for electricity consumption averaged MXN 81.6 billion (4.79 billion USD) in real terms over the last five years, using 2022 as the base year (SHCP, 2023). This amount represents approximately 0.34 per cent of Mexico's 2022 GDP (see Figure 7). These subsidies have been in place since 2010, notably surging in 2017 to reach their current levels. Based on market prices (including installation costs) from December 2023, our estimates suggest that reallocating these funds could enable the acquisition of approximately 4.4 to 6.8 million solar panels. Such an investment could significantly bolster Mexico's overall power capacity, contributing an annual addition of between 2,207 MW and 3,403 MW, as outlined in Table 1.

Figure 7: CFE Subsidies – MXN Million (2022=100)



Source: SHCP (,2023)

Table 1: Parameters

	Value
Solar Panel Price (MXN)	12,000-18,500
Solar Panel Capacity per unit	500 W
Current subsidy (MXN Million)	81,672
Panels that can be purchased with subsidy (Million)	4.4-6.8
Additional Capacity (MW)	2,207-3,403

Sources: [1] Solar Panel Cost and Capacity: Market Research Carried Out with Retail Providers in Mexico During Q1 2023. Retrieved from https://www.enersing.com/precio-de-paneles-solares-para-casa on December 7, 2023. This source provides detailed information on the average price per solar panel, considering various factors such as brand and power capacity. [2] Current Subsidy: Average Subsidy between 2019 and 2022 in Real Terms (Base 2022=100). SHCP (2023). This information offers insights into the average level of subsidy provided over the specified period, adjusted for real terms based on the year 2022. [3] Panels that Can Be Purchased with Subsidy and Additional Capacity: Authors' Estimations. These estimations are based on the parameters, giving a calculated perspective on the number of panels that can be acquired under the current subsidy and the additional capacity that could be generated.

As previously discussed, we calculate a current capacity shortfall of 21,607 MW in electricity generation. Additionally, SENER anticipates a need for a 40,135 MW capacity surge from 2023 to 2033, totaling an investment requirement of approximately 61,742 MW over the coming decade to meet demand. Redirecting current electricity subsidies toward procuring solar panels could potentially close the existing capacity gap within a timeframe ranging from 6.3 to 9.7 years. Over a decade, this subsidy reallocation could satisfy 36 to 55 per cent of the overall capacity needs, addressing both the current gap and future demands. This estimate does not account for potential additional demand resulting from nearshoring, as this phenomenon had not commenced in 2018.

Now, we assess the potential of utilizing financial markets to enhance the procurement of solar panels through the allocation of existing fiscal resources for subsidies. In this scenario, we propose that the Mexican Government would issue bonds, with the current subsidy allocation serving as the payment source. Using current market interest rates for 10- and 20-year inflation-indexed bonds (UDIBONOs), our calculations indicate that a 10-year UDIBONO could generate approximately MXN 640.2 billion, while a 20-year instrument could raise MXN 1,058.7 billion. These amounts represent 7.8 and 12.9 times the annual subsidies currently allocated to the Mexican utility, CFE (see Table 2).

Table 2: Credit facility parameters

	10 years	20 years
Loan		
UDI Million	82,136	135,820
MXN Million	640,255	1,058,717
Maturity	10 years	20 years
Interest Rate (UDIBONO)	4.69%	4.54%
Annual constant payment		
UDI	10,477	10,477
MXN	81,676	81,676

Source: The authors´ estimates are based on UDI and UDIBONO interest rates as quoted by Banxico on December 7, 2023.

The proceeds from these bonds could significantly enhance the acquisition of solar panels. We estimate that it would be feasible to procure between 53 and 88 million solar panels, thereby increasing total capacity by 26,677 to 44,133 MW. Such an increase would be adequate to close the existing capacity gap within the first year of the program for both the 10- and 20-year bond scenarios. Moreover, in a favorable scenario where solar panel prices continue to decline, the 20-year bond could potentially raise sufficient funds to meet future capacity demands up to 2027 (see Table 3).

This analysis indicates the feasibility of employing a financial strategy to tackle the current capacity shortfall and fulfill impending demands. Consequently, this proposition could alleviate immediate bottlenecks, allowing larger-scale generation projects the necessary time to develop.

Table 3: Credit facility results

Description	UDIBONO 10 years	UDIBONO 20 years
Unit PV solar panel price (MXN)		
High	12,000	12,000
Low	18,500	18,500
PV solar panel capacity per unit (Watts)	500	500
Peak sun hours	5.5	5.5
Resources raised by the UDIBONO (MXN)	640,256	1,058,717
PV solar panel procurement		
Cost (MXN)		
High	53,354,661	88,226,426
Low	34,608,429	57,227,952
Capacity (MW)		
High	26,677	44,113
Low	17,304	28,614

Sources: [1] Solar Panel Cost and Capacity: Market Research Conducted with Retail Providers in Mexico, Q1 2023. Accessed from: https://www.enersing.com/precio-de-paneles-solares-para-casa on December 7, 2023. This source provides an average price per solar panel, taking into account both the brand and the power capacity. [2] Peak Sun Hours for 1-Axis Tilt Sunlight Hours in Mexico. Accessed from: https://www.turbinegenerator.org/solar/maine/mexico/ on December 7, 2023. This resource offers information on the expected peak sun hours in Mexico, averaging 4.4 hours per day. [3] Funding: The funds raised through UDIBONO are estimated for a credit facility with a constant amortization over a repayment period of 10 and 20 years, offering a fixed rate in UDIs. The constant amortization represents the average CFE subsidy for 2019-2022 in real terms, quantified at MXN 81,672, expressed in UDIs. [4] Capacity Estimation: The capacity is calculated based on the capacity of individual PV solar panels (500 MW), the average peak sunlight hours (5.5 hours), and the total number of individual PV solar panels. This method provides a comprehensive and detailed estimate of the potential solar energy capacity.

4.1 Distributional aspects

From our initial findings, the policy appears broadly neutral. However, from the consumer's perspective, the outcomes of our proposed strategies are less straightforward. We analyze the case of an average four-person household with an annual energy consumption of 9,316 MWh (the national average). By comparison with current CFE prices, we estimate that this household would receive a subsidy of MXN 35,780.45 per year relative to what they would pay under the highest tariff (Domestic High Consumption Tariff, DAC).

In our initial scenario, where the government reallocates one year's subsidy to purchase solar panels without any credit enhancement, a household would receive two to three solar panels, providing approximately 1-1.5 KW of capacity. Factoring in their capacity and the non-subsidized electricity price, we estimate the economic value of these panels to range between MXN 13,086.51 and MXN 20,175.04 annually. Considering that the cost of these panels equals the original subsidy (MXN 35,780.45), the investment would be recouped within two to three years.

Once the government provides a solar panel to a specific household, it must redirect subsequent years' subsidies to equip other households. Our assessment shows that the present value of the electricity produced by the panel far exceeds its cost[1]. Nonetheless, comparing the household's cash flow with the subsidized tariff to the scenario where it generates electricity using the panel may result in an increase in annual electricity expenditure. This is because the annual value of electricity produced by solar panels is lower than the current annual subsidy. This has political implications, as it could lead to a short-term increase in a household's net electricity expenses, despite the long-term benefits of installing solar panels.

Now, let's consider an alternative scenario where the average household faces a non-subsidized electricity tariff. In this case, the current household's expenditure would only cover about 43 per cent of its current electricity consumption measured in kWh. To maintain its current level of consumption without increasing expenditure, the household would need five solar panels. The cost of these five panels would range between MXN 63,456 and MXN 97,829. This investment is roughly equivalent to 1.7 to 2.7 years of the subsidy they currently receive. However, the UDIBONO bond issuance could raise funds equivalent to 7.8 and 12.9 times the current annual subsidy for the 15- and 20-year periods, respectively. As a result, the funds generated through the UDIBONO could not only cover the cost of the five panels required by this household to maintain its consumption levels in the absence of subsidies, but also provide sufficient capacity to address future energy needs through similar solar panel investments for other households.

In sum, our parametric analysis suggests that redirecting subsidies towards the purchase of solar panels could substantially alleviate strategic capacity bottlenecks. The two proposed financing strategies — reallocating current subsidies to solar panel purchases and leveraging bond issuance — demonstrate comparable impacts in the medium term. Both approaches aim to address the current electricity capacity gap within approximately a 10-year timeframe. Upon successfully closing this gap, whether through a pay-as-you-go scheme or bond issuance, these strategies would effectively serve the intended policy purpose. The installed solar panels will continue to generate electricity throughout their lifespan at no extra cost to the government. This would free up significant fiscal resources that were previously allocated to pay for price subsidies, thereby enhancing the government's fiscal capacity.

5. Political economy and implementation

Transitioning from price-based to quantity-based subsidies demands careful evaluation of market dynamics, cost implications, environmental objectives, and the balancing of incentives for both producers and consumers. Moreover, the success of this policy relies on several factors such as political willingness, public perception, and the influence of established stakeholders in the energy sector. It's crucial not to underestimate potential resistance, especially in heavily monopolized or politically influenced energy sectors. This decision likely involves a nuanced combination of policies and incentives rather than a straightforward switch from one subsidy form to another.

One significant hurdle for implementing this policy lies in Mexico's broader approach to subsidies. The country extends subsidies across various demographics without targeting those truly in need. For instance, all individuals aged 65 and above receive government subsidies, irrespective of their income levels. This strategy often carries political and electoral advantages by fostering a sense of government support, evident each time recipients receive their cash transfers every other month. However, distributing solar panels is a one-time action, given their limited lifespan of 10 to 12 years. Over time, the lasting connection between the provider and the recipient might diminish, potentially impacting the political and electoral gains originally sought. We also assume that these solar panels would be permanently installed on households' rooftops,

[1] We consider discount rate of 10 per cent, net present value is positive even if interest rates double, reaching historical maximums.

but there is always the risk that they could be uninstalled to create an alternative market for solar panels. This would necessitate monitoring, thereby increasing the cost of this policy change.

An extensive solar panel program presents an overlooked advantage worth considering. The substantial scale of such an initiative necessitates a significant purchase of solar panels, effectively kickstarting the development of this emerging industry within Mexico. For instance, in the scenario where current funds are enhanced with financial instruments, the procurement of PV solar panels could be as large as 88 million 500 W units, equivalent to a capacity of 44.1 MW. The global manufacturing capacity of PV solar panels in 2023 was 640 GW, and it is estimated that it can reach 1 TW by 2023 (IEEFA, 2023; IEA, 2023). This implies that Mexico's total demand for PV solar panels would be as much as 4.4 per cent of the annual global production. In practice, the annual demand would not be as high as deployment would span more than one year; however, these figures illustrate the magnitude of the proposal. Moreover, the proposal implies that Mexico will expand its current PV solar panel installed capacity by five-fold (Statista, 2023).

Past experiences in other countries demonstrate positive outcomes. For instance, China's solar PV subsidies have shifted focus from production to domestic demand, aiming to absorb excess manufacturing capacity and bolster the local market. Similarly, Canada's government support for large-scale solar PV manufacturing yields a financial return of over 8 per cent, benefiting both provincial and federal governments. This initiative would drive domestic manufacturing and installation of solar panels, evolving from a fiscal, energy, and social policy venture into a comprehensive industrial policy initiative. Beyond its initial objectives, this program could exert profound effects on employment and industrial growth, fundamentally reshaping the landscape of the country's industrial development. In the current context, solar panel delivery is largely dependent on Chinese supply. Despite the emergence of new producers, the argument regarding infrastructure delays must be weighed against the current challenges in solar panel production and delivery, including shortages of raw materials.

There is an additional consideration regarding geographical distribution. The proposal aims to implement this policy nationwide, yet doing so uniformly may pose equity challenges. Certain areas may have greater needs due to factors like hotter climates or higher solar potential, while others, particularly densely populated urban areas, may face limitations due to limited rooftop space for subsidized panels. Addressing these geographical disparities in implementation is crucial. One approach could involve initiating pilot projects strategically selected based on criteria such as susceptibility to nearshoring investment, the need to bolster local reserve margins, the potential for significant reductions in behind-the-meter domestic demand due to favorable weather conditions, and the potential for transmission and distribution networks to benefit from reduced loads. A targeted approach would involve mapping radiation, generation constraints, network status, and the potential for nearshoring investments to ensure a more effective and equitable rollout of the policy.

The successful implementation of this solar panel initiative cannot be viewed solely as a public sector endeavor. It necessitates a collaborative, symbiotic alliance between the public and private sectors, extending its reach beyond just the electricity sector. This collaboration would likely begin by providing education to address technical and logistical capability constraints that could otherwise hinder the large-scale deployment of solar panels. Also, the scale of the solar panel purchase program outlined in this paper opens the possibility of relocating solar panel manufacturing facilities to Mexico. This move could not only reduce logistical and environmental costs but also spur regional economic development. This initiative presents a significant opportunity for innovation and the development of a coordinated industrial policy, as discussed by Mazzucato and Semieniuk (2018)

6. Limitations

There are potential unintended consequences of this policy stemming from system-wide challenges posed by a significant increase in solar power generation. A substantial rise in solar capacity can impact wholesale markets, potentially causing strains such as the emergence of a California-type duck curve, where behind-the-meter production alters the demand curve observed by utilities and the market. California's experience indicates diminishing marginal benefits from solar, and the form of subsidy could introduce inefficiencies. However, the validity of these concerns depends on the starting point. The underlying assumption of this policy is that Mexico is distant from experiencing diminishing benefits, particularly when compared with states or countries like California, the UK, or Germany, where a duck curve is observed. Also, some parameters from our calculations may change once the actual proposal is implemented. For instance, in section 2, we anticipated a decrease in overall electricity prices. Treating new capacity as additional would shift the supply curve to the right, resulting in this outcome. However, there may not necessarily be a corresponding reduction in the need for 'equivalent firm power' as defined by Helm. Under certain conditions, the overall system's cost may increase, as solar panels would displace certain technologies depending on the demand curve occurring at specific times. Therefore, further exploration is warranted to identify the technologies that would be displaced.

Another limitation of the proposal is that the impact on the network would not be uniform. While in some specific locations, this policy would alleviate congestion in the network, extending the need for upgrades or expansion, in others it would be redundant or unnecessary. The implementation of the policy could strategically commence in strategical locations within the state of Nuevo Leon, where the electricity system is notably stressed. These areas, already attracting nearshoring investments and possessing favorable solar conditions, serve as ideal starting points. By targeting such locations, where demand is high and infrastructure is strained, the policy can immediately alleviate pressure on the system while maximizing the benefits of solar energy integration. Moreover, the presence of nearshoring investments underscores the importance of ensuring a reliable and sustainable energy supply, further emphasizing the necessity of this targeted approach. As a result, beginning the implementation in these key areas not only addresses immediate challenges but also sets a precedent for broader adoption across regions facing similar energy constraints.

Finally, a crucial aspect involves determining the optimal subsidy level. Empirical evidence not only from Mexico (Labeaga et al., 2020) but also from other countries underscores the benefits of gradually phasing out subsidies. For instance, Gasim et al. (2023b) demonstrate that Saudi Arabia's 2016 price reform led to a collective yearly welfare increase of USD $11.6 billion (2010 value) by 2016, along with avoiding a total of 164 million tonnes of cumulative carbon dioxide emissions between 2016 and 2018, attributable to the energy price reform. This suggests that current subsidized consumption, in general, might be beyond the optimal level. This policy therefore fails to address a fundamental distortion, namely the absence of incentives for energy conservation, because electricity pricing does not reflect its full cost. As a result, this oversight worsens the demand for additional capacity, which could otherwise be reduced. However, most existing subsidy frameworks are more politically motivated than rooted in efficiency rationale (Carreón-Rodriguez, Jiménez, and Rosellón, 2005). Conducting a comprehensive evaluation of the most efficient electricity subsidy levels is crucial, particularly in alignment with Mexico's environmental and social goals.

7. Conclusions

We propose an innovative approach in the use of electricity subsidies by subsidizing quantities instead of prices. Leveraging advancements in the electricity sector, especially distributed generation technologies like PV solar, this approach would allow governments to allocate specific solar capacity to individuals or households. While this allocation may not cover entire household needs, it can contribute to meeting basic requirements, with additional demand fulfilled through the market. This strategy would minimize market distortions, enabling the market to observe reduced demand behind the meter, while the most cost-effective technologies cater to the remaining demand incrementally.

We analyze this proposal in the Mexican context, a crucial player in nearshoring, but with multiple market forces straining the electricity sector. Delays in infrastructure investment, amplified post-pandemic demand, and the increased electricity needs from nearshoring are converging and are likely to soon impact the sector's reserve margins. Our analysis explores redirecting subsidies towards solar panel acquisition to ease capacity bottlenecks and create fiscal space for economic growth.

Our results show that reallocating funds that now finance price subsidies could enable the acquisition of approximately 4.4 to 6.8 million solar panels, significantly boosting Mexico's power capacity by 2,207 MW to 3,403 MW annually. Over a decade, redirecting subsidies towards solar panel acquisition could fulfill 36 to 55 per cent of total capacity needs, bridging both current gaps and future demands. Issuing bonds to support this initiative could potentially secure between 53 and 88 million solar panels, amplifying total capacity by 26,677 to 44,133 MW. Such a leap would effectively close the existing capacity gap within the inaugural year of the program under both 10- and 20-year bond scenarios. This financial strategy not only ensures consumer welfare remains intact but also alleviates immediate bottlenecks, providing space for expansive generation projects to mature. Our initial findings suggest that, from a distributional and social perspective, the policy is broadly neutral. Most importantly, this policy shift towards subsidizing solar panel purchases would increase environmentally sustainable power generation. This aligns with wider sustainability goals, positioning it not only as an economically sound strategy but also as a vital step towards environmental sustainability.

This paper outlines novel avenues for further exploration beyond its initial insights. Other variants of this policy could involve subsidizing solar capacity located on household rooftops or implementing collective self-consumption initiatives. Publicly funded solar panels could be utilized, reducing the cost of generation compared with rooftop panels. This model is particularly beneficial for individuals without usable rooftops or those residing in buildings. The common objective is to invest in low-cost solar energy and incentivize consumption when the sun shines. Future research could delve into nuanced analyses across various socioeconomic cohorts and states, considering the diversity in electricity consumption patterns and tariffs. Another avenue for research could be the role of industrial policy in facilitating the widespread adoption of sustainable solar energy. Encouraging a comprehensive and multidisciplinary approach, we call for deeper investigations into the economic, political, and technological implications of these crucial topics.

This proposal, while not a cure-all for the underlying structural issues within the electricity sector, offers a pragmatic approach to navigating the prevailing economic conditions. The ideal solution for Mexico's electricity market involves a series of comprehensive reforms, including the liberalization of power generation and distribution, the elimination of electricity subsidies and other market distortions, and stringent regulation of non-competitive behaviors. However, this proposal does not claim to represent the optimal solution; instead, it aims to balance economic efficiency against existing political constraints. It offers a technically sound and politically feasible strategy that can be executed within the current capabilities of the Mexican state. By doing so, it seeks to mitigate economic costs and provide a viable path forward, acknowledging the limitations and opportunities that define Mexico's energy policy landscape.

References

Alfaro, L., & Chor, D. (2023). *Global Supply Chains: The Looming 'Great Reallocation'* (No. w31661). National Bureau of Economic Research.

Baumol, W. J. (1972). 'On taxation and the control of externalities'. *The American Economic Review*, 62(3), 307–322.

Branker, K., & Pearce, J. (2010). 'Financial Return for Government Support Financial Return for Government Support of Large-Scale Thin-Film Solar Photovoltaic Manufacturing in Canada'. EnergyRN: Photovoltaics (Topic). https://doi.org/10.2139/ssrn.2010149.

Browning, M. (1987). 'Prices vs. Quantities vs. Laissez-faire'. *The Review of Economic Studies*, 54, 691–694. https://doi.org/10.2307/2297490.

Carreón-Rodriguez, V. G., Jiménez, A., & Rosellón, J. (2005). *The Mexican Electricity Sector: economic, legal and political issues*. Cambridge University Press (online book).

Chen, G. (2015). 'From mercantile strategy to domestic demand stimulation: changes in China's solar PV subsidies'. *Asia Pacific Business Review*, 21, 112–96. https://doi.org/10.1080/13602381.2014.939897.

Duran-Fernandez, R. (2023). 'Nearshoring y México: Pasado, presente y visión de futuro de la Globalización'. In: *Nearshoring: Retos y oportunidades para la integración y el fortalecimiento de las cadenas globales de valor en México* (pp. 15-31). Ciudad de México: Tirant lo Blanch.

Fattouh, B., & El-Katiri, L. (2015). *A brief political economy of energy subsidies in the Middle East and North Africa*. https://ora.ox.ac.uk/objects/uuid:dcbbe09e-8d29-4a11-bcef-0d809bc79d3a

Friedmann, R., & Sheinbaum, C. (1998). 'Mexican electric end-use efficiency: experiences to date'. *Annual review of energy and the environment*, 23(1), 225–252.

Flyvbjerg, B., & Gardner, D. (2023). *How Big Things Get Done: The Surprising Factors that Determine the Fate of Every Project, from Home Renovations to Space Exploration and Everything in Between*. Signal.

Fuentes R. (2023). 'Nearshoring y México: La dinámica entre Covid-19, nearshoring y el sector eléctrico'. In: *Nearshoring: Retos y oportunidades para la integración y el fortalecimiento de las cadenas globales de valor en Méxic*, 127–133. Ciudad de México: Tirant lo Blanch.

Galinato, G. I., & Yoder, J. K. (2010). 'An integrated tax-subsidy policy for carbon emission reduction'. *Resource and Energy Economics*, 32(3), 310–326.

Gasim, A. A., & Matar, W. (2023). 'Revisiting Energy Subsidy Calculations: A Focus on Saudi Arabia'. *The Energy Journal*, *44*(1), 245–276.

Gasim, A. A., Agnolucci, P., Ekins, P., & De Lipsis, V. (2023). 'Modeling final energy demand and the impacts of energy price reform in Saudi Arabia'. *Energy Economics*, 120, 106589.

Heuson, C. (2010). 'Weitzman Revisited: Emission Standards Versus Taxes with Uncertain Abatement Costs and Market Power of Polluting Firms'. *Environmental and Resource Economics*, 47, pp 349–369. https://doi.org/10.1007/S10640-010-9382-5.

IIEFA (2023). 'New Paradigms of Global Solar Supply Chain'. Institute for Energy Economics and Financial Analysis. Retrieved from: https://ieefa.org/sites/default/files/2023-10/New-paradigms%20of%20global%20solar%20supply%20chain_Oct23.pdf

IEA (2023). 'Renewable Energy Market Update Outlook for 2023 and 2024'. International Energy Agency. Retrieved from: https://iea.blob.core.windows.net/assets/67ff3040-dc78-4255-a3d4-b1e5b2be41c8/RenewableEnergyMarketUpdate_June2023.pdf

Jensen, F., & Vestergaard, N. (2003). 'Prices versus Quantities in Fisheries Models'. *Land Economics*, 79, 415–425. https://doi.org/10.2307/3147026.

Joskow, P. L., & Marron, D. B. (1993). 'What does utility-subsidized energy efficiency really cost?' *Science*, 260(5106), 281–370.

Knight, F. (2013). Risk, uncertainty and profit. *Vernon Press Titles in Economics*.

Komives, K., Johnson, T., Halpern, J., Aburto, J., & Scott, J. (2009). 'Residential Electricity Subsidies in Mexico: Exploring Options for Reform and for Enhancing the Impact on the Poor'. https://doi.org/10.1596/978-0-8213-7884-7.

Labeaga, J., Labandeira, X., & López-Otero, X. (2020). 'Energy taxation, subsidy removal and poverty in Mexico'. *Environment and Development Economics*, 26, 239–260. https://doi.org/10.1017/S1355770X20000364.

Leventis, G., Gopal, A., Can, S., & Phadke, A. (2013). 'Avoided electricity subsidy payments can finance substantial appliance efficiency incentive programs: Case study of Mexico'. Lawrence Berkeley National Laboratory https://doi.org/10.2172/1171613.

Mandell, S. (2008). 'Optimal mix of emissions taxes and cap-and-trade'. *Journal of Environmental Economics and Management*, 56, 131–140. https://doi.org/10.1016/J.JEEM.2007.12.004.

Mazzucato, M. (2018). 'Mission-oriented innovation policy: Challenges and opportunities'. *Industrial and Corporate Change*, 27(5), 803–815.

Mazzucato, M., & Semieniuk, G. (2018). 'Financing Renewable Energy: Who is financing why and why it matters'. *Technological Forecasting and Social Change*, 127, 8–22.

Morales, Y. (2022). 'Transición fiscal y financiera con nueva administración será lo más suave posible'. *El Economista*. https://www.eleconomista.com.mx/economia/Transicion-fiscal-y-financiera-con-nueva-administracion-sera-lo-mas-suave-posible-20221025-0135.html

Mundaca, G. (2017). 'Energy subsidies, public investment and endogenous growth'. *Energy Policy*, 110, 693–709.

Özdemir, Ö., Hobbs, B. F., van Hout, M., & Koutstaal, P. R. (2020). 'Capacity vs energy subsidies for promoting renewable investment: Benefits and costs for the EU power market'. *Energy Policy*, 137, pp 111166.

Paulson-Gjerde, K., & Grossman, P. (2015). 'Implications of nonlinearity in environmental instrument choice'. *Economics Bulletin*, 35, 2252-2257.

Pigou, A. (1932). 'The economics of welfare'. Routledge. doi: 10.4324/9781351304368

Scoblic, J. P. (2020). 'Strategic foresight as dynamic capability: A new lens on Knightian uncertainty'. Working Paper 96/07. Harvard Business School, Boston, MA, USA. Retrieved from https://www.hbs.edu/ris/Publication%20Files/20-093_7e70d4a3-aab8-449c-82e9-62cf143d6413.pdf

Shah, T., Giordano, M., & Mukherji, A. (2012). 'Political economy of the energy-groundwater nexus in India: exploring issues and assessing policy options'. *Hydrogeology Journal*, 20(5), 995.

SHCP (2023). Estadísticas Oportunas de Finanzas Públicas. Retreived from http://presto.hacienda.gob.mx/EstoporLayout/estadisticas.jsp retrieve March 1st, 2024

Stavins, R. N. (2019). 'Carbon taxes vs. cap and trade: Theory and practice'. Cambridge, Mass.: Harvard Project on Climate Agreements.

Statista (2023). Installed solar photovoltaic (PV) generation capacity in Mexico from 2010 to 2022. Retrieved from: https://www.statista.com/statistics/790720/installed-capacity-solar-pv-power-generation-mexico/#:~:text=Mexico's%20solar%20PV%20energy%20generation,by%20more%20than%20310%2Dfold.

Weitzman, Martin. (1974). Prices Vs. Quantities. Review of Economic Studies. 41. 477-91. 10.2307/2296698.