UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE ELECTRIC POWER INDUSTRY

Master's Thesis

Cost-Benefit Analysis Of Solar Energy Models For Large Consumers In Mexico: 1) Power Purchase Agreements, 2) Leasing, 3) Engineering, Procurement, And Construction Contracts under Net Metering and Net Billing

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1. Introduction

1.1 Context of the Mexican Energy Sector

Mexico's energy sector is at a crucial juncture, shaped by significant shifts in policy, market dynamics, and the growing imperative for sustainable energy solutions. Historically, the country has relied heavily on fossil fuels, particularly oil and natural gas, to meet its energy needs. However, the global shift towards renewable energy, coupled with Mexico's rich solar and wind resources, has opened up new avenues for the country's energy future. In recent years, the Mexican government has made substantial efforts to reform the energy sector, aiming to increase the share of renewables in the energy mix and reduce greenhouse gas emissions. The Energy Reform of 2013 was a pivotal moment, introducing measures to promote competition in the electricity market and encouraging private investment in renewable energy projects (Gobierno de México, 2013). Despite these reforms, the sector has faced challenges, including regulatory uncertainty and fluctuating policy directions under different administrations.

The current administration has adopted a more closed approach to energy policy, focusing on strengthening the role of the state-owned CFE and limiting private sector involvement in new energy projects. This shift has significantly impacted the pace of renewable energy development in Mexico, particularly in the solar sector. The suspension of long-term energy auctions, which were instrumental in securing competitive prices for renewable energy, has further added to the uncertainty in the market. These auctions, managed by the Centro Nacional de Control de Energía (CENACE), played a critical role in setting benchmark prices for renewable energy projects, with the last auction in 2017 establishing a price of 389.5 MXN/MWh for solar energy. The cancellation of the subsequent auction in 2018 has left a gap in the market, with no new long-term contracts being awarded since then.

In this context, adopting solar energy in Mexico, particularly in the industrial sector, presents both opportunities and challenges. The country’s high solar irradiance makes it one of the most promising regions for solar energy development globally. However, the lack of regulatory stability and the recent policy shifts have created an environment of uncertainty for investors and consumers alike. This research aims to explore these dynamics by examining the financial viability of different solar energy procurement models, including self-financed installations, Power Purchase Agreements (PPAs), and leasing options. By providing a detailed analysis of these models, this study seeks to offer valuable insights for stakeholders looking to navigate the complexities of the Mexican energy market and make informed decisions in the evolving landscape.

1.2 Motivation and Research Objectives

The motivation for this research stems from the observed gap in knowledge and understanding of solar energy procurement models among industrial consumers in Mexico. Despite the country's significant potential for solar energy generation, there is a noticeable lack of awareness and expertise within the industrial sector regarding the financial and operational benefits of different solar energy schemes. This gap is particularly evident in the context of Power Purchase Agreements (PPAs), which offer a compelling solution for companies looking to reduce electricity costs without significant upfront investment. However, the complexity of these agreements, coupled with the uncertainties in the regulatory environment, has limited their adoption in Mexico.

This thesis aims to bridge this knowledge gap by providing a comprehensive analysis of various solar energy procurement models from the perspective of large industrial consumers in Mexico. The primary objective is to identify the most beneficial model regarding cost-effectiveness, sustainability, and practicality. This involves not only a detailed examination of the financial outcomes associated with each model but also an assessment of the risks and challenges inherent in the Mexican energy market. Specific objectives of this research include:

- Analyze Different Solar Energy Schemes in Mexico: Conduct a thorough analysis of different solar energy schemes, including PPAs, Engineering, Procurement, and Construction (EPC) contracts with net-metering and net-billing options, and leasing models.
- Determine the Most Beneficial Scheme: Identify the solar energy scheme that offers the greatest benefits to large industrial consumers in Mexico, considering factors such as cost savings, long-term financial viability, and ease of implementation.
- Develop Financial Models: Create detailed Excel models to quantitatively compare the financial performance of each scheme, accounting for variables such as inflation, maintenance costs, and energy price fluctuations.
- Assess Investor and Client Risks: Evaluate the risks associated with each procurement model, particularly those related to electricity pricing, energy consumption patterns, and potential regulatory changes.
- Review Regulatory Framework: Analyze the current regulatory landscape in Mexico, including the procedures for installing solar panels on industrial properties and the implications of different compensation models.

By achieving these objectives, this research provides valuable insights for both industrial consumers and investors, helping them make informed decisions in an increasingly complex and competitive energy market.

1.2. Presentation of the Problem

Mexico has significant potential for solar energy development due to its geographical location, which provides high solar irradiation levels. Despite this potential, the adoption of solar energy in the industrial sector has been slow. This is primarily due to a lack of understanding of the different solar energy procurement models and their financial implications. This thesis addresses this issue by examining three primary models for solar energy procurement and usage: Power Purchase Agreements (PPAs), Engineering, Procurement and Construction Contracts (EPC) with Net-metering and Net-billing options, and solar panel leasing.

The core problem this research aims to solve is identifying which of these models offers the most benefits to large industrial consumers in Mexico. Benefits are assessed in terms of cost-effectiveness, sustainability, and practicality, considering the specific regulatory and market conditions in Mexico. The problem is further compounded by the fluctuating nature of electricity prices, varying energy volumes, and evolving energy policies, making it challenging for industrial companies to make informed decisions.

1.3 Importance of Addressing the Problem

The adoption of solar energy in Mexico's industrial sector presents a significant challenge, especially considering the country's commitments to reduce carbon emissions under international agreements. Addressing this issue is essential for both the nation's economic sustainability and environmental responsibilities.

For large industrial consumers in Mexico, electricity costs represent a significant portion of operating expenses. Identifying the most cost-effective solar energy procurement model—whether through Power Purchase Agreements (PPA), Engineering, Procurement, and Construction (EPC) contracts with Net-metering and Net-billing options, or solar panel leasing—can lead to substantial savings. Given the volatility of energy prices in Mexico, choosing an appropriate solar energy model could provide price stability and predictability, which are crucial for long-term financial planning. Moreover, reducing energy costs through solar adoption allows companies to reinvest savings into other areas, potentially leading to increased innovation and competitiveness in both local and international markets.

Promoting solar energy aligns with Mexico’s broader sustainability goals, particularly its commitment to reduce greenhouse gas emissions as part of the Paris Agreement. Mexico has pledged to cut its emissions by 35% from business-as-usual levels by 2030 and to achieve net zero emissions by 2050. However, the country has faced significant challenges in meeting these targets, partly due to recent policy shifts favoring fossil fuel use over renewable energy development (Reuter, 2022). For industrial consumers, transitioning to solar energy not only supports these national objectives but also helps mitigate the environmental impact of their operations, thereby enhancing their corporate social responsibility (CSR) profiles. This transition is critical in an era where consumers and investors are increasingly prioritizing sustainability.

Increased use of solar energy can significantly reduce Mexico's dependence on imported fossil fuels, thereby enhancing national energy security. This is particularly important for industrial consumers, who rely heavily on a stable and affordable energy supply for their operations. By investing in solar energy, companies can protect themselves from the risks associated with energy supply disruptions and price fluctuations in the global fossil fuel markets. This contributes to the stability of the business environment and aligns with the national goals of achieving greater energy independence (Baker Institute, 2013).

From the perspective of industrial consumers, the regulatory landscape in Mexico presents both challenges and opportunities. While the current administration has made policy shifts that have slowed the momentum of renewable energy projects, the legal framework still offers pathways for compliance and potential benefits. Companies must navigate the complexities of obtaining the necessary permits and adhering to environmental regulations, which can be time-consuming and costly. However, those that successfully implement solar energy solutions can gain a competitive edge by reducing operational costs and ensuring compliance with both national and international regulations.

1.4 Scope of the Research

This research focuses on large industrial consumers in Mexico, analyzing the financial and operational implications of adopting solar energy through different procurement models. The study is limited to three primary models: PPAs, EPC (with Net-metering and Net-billing), and leasing. The analysis spans a defined time horizon, typically the expected lifespan of solar energy systems, which is around 25 years.

2. State of the Art

This chapter provides an overview of the existing knowledge and research relevant to the different aspects of solar energy procurement and deployment in Mexico. This chapter is designed to give a comprehensive understanding of the current landscape, highlighting key regulatory and financial aspects that shape the adoption of solar energy in the industrial sector.

This chapter begins by exploring the three primary financing schemes considered in this study: self-financing (EPC), Power Purchase Agreements (PPA), and leasing.

Following this, the chapter examines the regulatory framework governing solar energy installations in Mexico. This section details the administrative processes, legal requirements, and technical specifications necessary for the installation and interconnection of solar panels in industrial enterprises. The complexities of the Mexican energy regulatory landscape are discussed, with a focus on the processes mandated by government entities such as the Secretaría de Energía and the Comisión Reguladora de Energía (CRE).

The compensation models for solar energy, specifically net metering and net billing, are also explained in detail. This segment explains the mechanics of these models, how they impact the financial returns of solar energy projects, and the specific regulations that guide their application in Mexico.

Additionally, the chapter breaks down the components of electricity bills under the GDMTH tariff, which is applicable to high-demand consumers. Understanding these components—energy charges, capacity charges, distribution charges, and transmission charges—is essential for evaluating the savings structure of PV systems.

Finally, the chapter discusses the risks associated with solar self-consumption installations. This includes an exploration of volumetric risk, price fluctuation risk, political risk, consumption risk, and financial risks. The discussion highlights how these risks can impact the financial performance and viability of solar energy projects in Mexico, and the strategies used to mitigate them.

2.1 Engineering, Procurement, And Construction Contract

Under the EPC model, the client directly invests in the PV system. This scheme involves the client financing the entire project upfront, including the design, procurement of materials, and construction of the solar installation. The EPC contractor is responsible for delivering a fully operational solar power system that meets the client's specifications. This model provides the client with complete ownership of the PV system, allowing them to benefit fully from any energy savings or revenues generated from excess energy production. However, the client also bears all risks associated with the investment, including operational and maintenance costs over the system's lifetime. The contracting schemes will be evaluated under two compensation models for solar self-consumption available in Mexico: net-metering and net-billing. These schemes are explained in the following section.

2.2 Power Purchase Agreements (PPA)

Power Purchase Agreements (PPAs) are critical instruments in the financing of renewable energy projects, providing a mechanism for consumers to secure long-term energy supply at a predetermined rate. These agreements typically span 10 to 25 years, during which the energy producer—often a third-party developer or an independent power producer (IPP)—sells electricity to the consumer at a lower price (Energía Real, 2024).

One of the key advantages of PPAs is the reduction in upfront capital expenditure for consumers. Instead of investing heavily in the PV system, the consumer can simply purchase the energy produced by the project. Furthermore, the PV system is operated and maintained by the investment fund while the contract is valid. Once the contract expires, ownership of the PV system is transferred to the client (Energía Real, 2024). This model is particularly appealing for industrial consumers who may lack the capital to invest in large-scale energy projects but still wish to benefit from the cost savings and environmental benefits of renewable energy.

However, despite the widespread adoption of PPAs globally, there is limited research specifically focused on their application in the Mexican industrial sector. The evolution of Mexico's energy market, including potential shifts in policy under different administrations, could significantly influence the attractiveness of PPAs for industrial consumers.

Further research is needed to assess how these factors might affect the performance of PPAs in Mexico. This includes evaluating the potential risks associated with regulatory changes, understanding the role of LMPs in PPA pricing models, and exploring how these contracts can be structured to maximize benefits for both producers and consumers in the Mexican market.

2.3. Solar Panel Leasing

Solar panel leasing has emerged as a viable alternative to traditional solar energy procurement methods, particularly for consumers who are hesitant to commit large sums of capital to purchase solar equipment outright. In a typical solar leasing arrangement, the leasing company owns the solar panels and installs them on the consumer's property, while the consumer pays a fixed monthly fee for the use of the system. This model not only lowers the barrier to entry by eliminating upfront costs but also shifts the responsibility for maintenance and repairs to the leasing company, reducing the operational burden on the consumer. Once the contract expires, ownership of the PV system is transferred to the client (Leasing Solar, 2024).

Research on solar panel leasing in Mexico is sparse. There is a need for detailed analyses of leasing agreements and their long-term financial implications for industrial consumers in Mexico.

2.4. Regulatory framework in Mexico

2.4.1. Installation Process of Solar Panels in Industrial Enterprises

According to (Secretaría de Energía, 2016), to interconnect a power plant with a capacity below 0,5 MW, the process begins with submitting an interconnection request to the distributor via the Supplier. The necessary documents include the interconnection request form, a geographic location sketch of the power plant, a single-line diagram of the power plant and any load centers sharing the interconnection point, technical specifications of the generation technology, and details on the current inverter or adjustment system if applicable. Additionally, a copy of the latest electricity bill is required for any load center sharing the interconnection point. The applicant must present this documentation using the formats issued by the CRE.

Once submitted, the distributor evaluates the request to ensure compliance with interconnection schemes and checks the distribution circuit's available capacity. If no further study is required, the Distributor provides the Supplier with a Resolution Letter indicating its validity. However, if a study is necessary, the applicant bears the study cost, and the Distributor conducts it, providing the results through the Supplier. The study may outline required infrastructure and specific works, detailed in a budget letter with a validity period.

If the applicant agrees with the resolution letter or study results, they notify CENACE via the Supplier to proceed with the interconnection. The next step involves signing an Interconnection Contract between the Distributor and the applicant. If a more cost-effective technical solution is found, the applicant can propose it to the Supplier, who may consult the Distributor to reevaluate the request. Once agreed upon, either the applicant or Distributor performs the necessary works for interconnection, including system adjustments. An Inspection Unit may be hired to certify compliance with requirements, and the Distributor then integrates the generation into the General Distribution Networks.

Before formalizing the Interconnection Contract, verification of several steps are necessary. These include completing the Interconnection Study (or a statement from the Distributor or CENACE indicating it is unnecessary), obtaining the applicant's agreement with the Resolution Letter or study results, and addressing any required infrastructure or specific works. The respective contract is then formalized using the model provided by the CRE for power plants with capacities below 0,5 MW. Figure 1 summarizes the whole process in a flow chart.

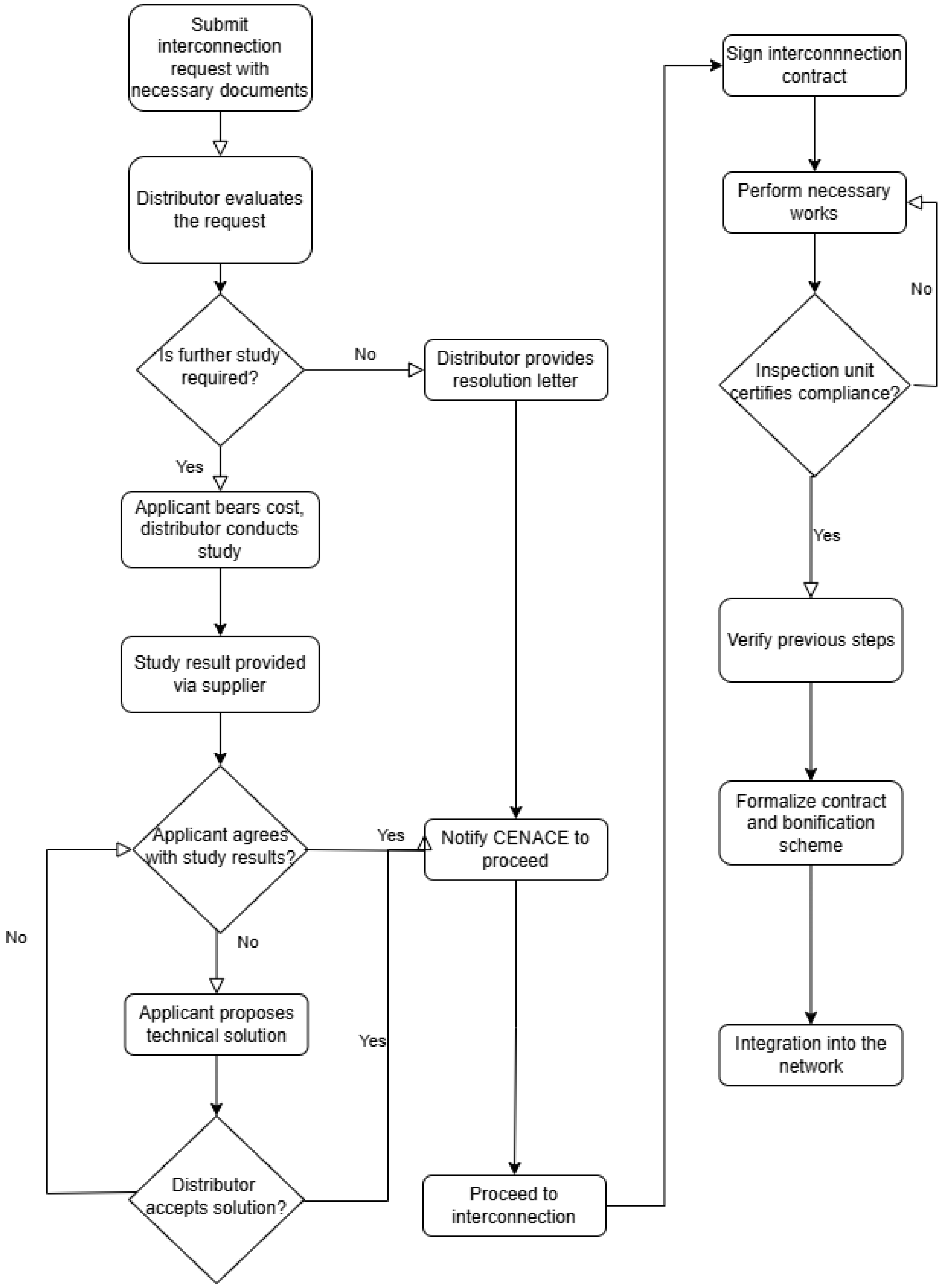

Figure 1. Interconnection process flow chart

2.4.2. Compensation Models

2.4.2.1. Net Metering

Net metering is a compensation model associated with the interconnection that considers the exchange of energy flows between the power plant and one or more load centers with the distribution networks. This system compensates for the energy delivered by the distributed generation power plant to the distribution networks with the energy received by one or more end users from the General Distribution Networks during the corresponding period. Consequently, the compensation contract must be associated with one or more electricity supply contracts at the applicable final supply tariff.

In this compensation model, the exempted generator – which according to (Comisión Reguladora de Energía (CRE), 2017) is the PV plant owner – can deliver electrical energy to one or more load centers and supply any excess energy to the distribution networks for later use during periods when it is not generating electricity. This compensation model applies to both a power plant and a load center sharing the same interconnection point.

According to (Comisión Reguladora de Energía (CRE), 2017), for installations with medium voltage interconnection and hourly tariff supplies, the net metering compensation is determined as follows:

$$EFnp = \max(0, EESn - ERGn)\, p$$

Definitions:

- EFn: Normal electrical energy consumption of the supply during the billing month 'n'.
- EESn: Electrical energy delivered by the supplier during the billing month 'n'.
- ERGn: Electrical energy received by the supplier during the billing month 'n'.
- p: Applicable hourly period (peak, intermediate, and base, or corresponding periods in a decreasing manner according to the final supply tariff).

When the difference (EESn - ERGn) is negative, it is considered a credit in favor of the exempt generator, which is accumulated as energy from previous months. This credit is classified according to the hourly period and month in which it was generated and automatically compensated at retail price in subsequent billing periods as long as there is a credit available for the exempt generator.

When the difference (EESn - ERGn) is positive and there is accumulated energy from previous months in favor of the Exempt Generator, the compensations are made from the oldest to the most recent month until the accumulated energy is exhausted or the normal supply billing for the month is zero kWh. If the normal supply billing for the month reaches zero kWh before the accumulated energy from previous months is exhausted, the remaining energy is conserved, classified by the hourly period and month it was delivered, for future compensations. This energy must be compensated for within a maximum period of 12 months following the month in which each part originated. If not compensated within this period, the exempt generator may request the liquidation of the expired credit at the average value of the Local Marginal Price during the time interval in which the credit was generated, calculated at the corresponding node.

Since energy charges vary depending on the hour and month of generation, to make compensations, the accumulated energy from previous months must be converted to current equivalent kWh using the following considerations:

- Ordinary: The charge for the energy from the oldest month is considered against the charge for the energy of the billable month.
- Hourly: When converting accumulated energy within the same hourly period, the charge for the energy from the oldest period is considered against the charge for the energy of the same period in the billable month.

In this case the client's tariff is GDMTH, therefore hourly classification applies. The energy charges for the user in the billing month are those resulting from applying the established rates in each hourly period to the value of EFn in kWh. After making the compensations, the resulting value of energy is considered a credit in favor of the supplier and is billed to the user at the applicable final supply tariff.

2.4.2.2. Net-billing

Net billing is a compensation regime associated with the interconnection where the energy generated by an exempt generator is delivered to the distribution networks, while independently, the energy received by the load center from these networks is considered. This scheme ensures that any surplus energy produced by the photovoltaic system is fed back into the grid and compensated at the Local Marginal Price (LMP).

In the net billing scheme, the interconnection contract is linked to an electricity supply contract. This means there will be simultaneous delivery and reception of electricity to and from the distribution networks at the same interconnection point. The energy delivered by the exempt generator is recorded separately from the energy received by the load center from the supplier.

The compensation for the energy delivered to the distribution networks is calculated using the LMP at the corresponding node. This is determined based on the hourly energy profile. The generator must have a meter capable of recording and storing the data of the energy delivered, or a communication system that transmits the hourly energy values to the electricity supplier for compensation calculation.

The compensation is paid at the real-time value when the energy is delivered to the General Distribution Networks. It is calculated as the sum of the energy delivered multiplied by the LMP at the time of delivery. The compensation for net billing and total energy sale is determined as follows:

$$CFn = \sum_{h=0}^{n} (EEGh * PMLh)$$

- CFn: Compensation for the energy delivered to the General Distribution Networks in the billing period n.
- EEGh: Energy delivered in hour h to the General Distribution Networks in the billing period n.

- PMLh: Local Marginal Price in hour h at the node corresponding to the interconnection point of the PV system during the billing period n.

It is important to note that the Local Marginal Price (LMP) is always lower than the price the company would be paying if they were consuming the energy directly from the grid. As a result, the return in the net billing scheme tends to be lower compared to the net metering scheme, where excess energy is credited at the retail rate.

2.5. Electricity Bill in Mexico

Electricity billing for high-demand medium voltage consumers encompasses several key components that contribute to the total cost. Each component is calculated based on specific criteria and applicable tariffs. In this section, we will discuss the various billed components under the GDMTH tariff, which include energy charges, capacity charges, distribution charges, and transmission charges.

2.5.1. Energy charge

The GDMTH tariff is specifically designed for consumers with a demand exceeding 100 kW. This tariff is applicable across 16 different tariff zones in Mexico, with the relevant zone for this analysis being the Bajío region. The pricing structure under this tariff is segmented into three distinct periods: Base, Intermediate, and Peak. These periods have varying energy prices, which increase from Base to Peak (Comisión Federal de Electricidad (CFE), 2024). The following tables detail the operational schedule for each period and the corresponding charges. The tariff periods are determined by the time of day and vary seasonally, as can be seen in Figures 2 and 3:

Del primer domingo de abril al sábado anterior al último domingo de octubre

Día de la semana	**Base**	**Intermedio**	**Punta**
lunes a viernes	0:00 - 6:00	6:00 - 20:00 22:00 - 24:00	20:00 - 22:00
sábado	0:00 - 7:00	7:00 - 24:00	
domingo y festivo	0:00 - 19:00	19:00 - 24:00	

Figure 2. Summer Tariff Periods

Del último domingo de octubre al sábado anterior al primer domingo de abril

Día de la semana	Base	Intermedio	Punta
lunes a viernes	0:00 - 6:00	6:00 - 18:00 22:00 - 24:00	18:00 - 22:00
sábado	0:00 - 8:00	8:00 - 19:00 21:00 - 24:00	19:00 - 21:00
domingo y festivo	0:00 - 18:00	18:00 - 24:00	

Figure 3. Winter Tariff Periods

The specific pricing for each period is established in (Comisión Federal de Electricidad (CFE), 2024). The prices are adjusted monthly and are available on the CFE's official website. The accurate application of these tariffs is critical for calculating the electricity costs under the GDMTH scheme.

$$\begin{aligned} Energy\ Charge \\ &= (Base\ Consumption * Base\ Tariff\ Price) \\ &+ (Intermediate\ consumtpion * Intermediate\ Tariff\ Price) \\ &+ (Peak\ Consumption * Peak\ Tariff\ Price) \end{aligned}$$

The division of the day into these tariff periods ensures that consumers are charged based on their actual demand during different times of the day, promoting efficient energy use and providing opportunities for cost savings by shifting consumption to lower-priced periods.

2.5.2 Capacity Charge

The maximum demand to which capacity charges, expressed in $/kW-month, will apply, shall be the lesser of the values defined below (Comisión Federal de Electricidad (CFE), 2024):

$$\min\left\{Dmax_{punta}, \left[\frac{Q_{mensual}}{24 * d * F.C.}\right]\right\}$$

Where Dmaxpunta is the maximum demand coinciding with the peak period measured in kilowatts, Qmensual is the monthly consumption recorded in the billing month in kWh, d is the number of days in the billing period, and F.C. is the load factor (0,57) (Comisión Reguladora de Energía (CRE), 2018).

In cases where there is no peak period and/or for users supplied at low and medium voltage without demand measurement systems, the following formula will be used (Comisión Federal de Electricidad (CFE), 2024):

$$Demanda = \left[\frac{Q_{mensual}}{24 * d * F.C.}\right]$$

For load centers receiving energy as part of a self-supply electricity generation permit, Dmaxpunta and Qmensual will be the maximum demand coinciding with the peak period measured and the monthly consumption supplied during the billing month by CFE SSB.

The result of this equation will be multiplied by the applicable tariff to obtain the monthly capacity charge.

$$Capacity\ Charge = Demand * Capacity\ Tariff\ Price$$

2.5.3. Distribution Charge

The maximum demand to which distribution charges, expressed in \$/kW-month, will apply, shall be the lesser of the values defined below (Comisión Federal de Electricidad (CFE), 2024):

$$\min\left\{Dmax_{mensual}; \left[\frac{Q_{mensual}}{24 * d * F.C.}\right]\right\}$$

Where Dmaxmensual is the maximum demand recorded in the month corresponding to the billing, Qmensual is the monthly consumption recorded in the billing month in kWh, d is the number of days in the billing period, and F.C. is the load factor (0,57) as per section 3.1.2 of the Single Annex of Agreement A/053/2022.

In cases where there is no peak period and/or for users supplied at low and medium voltage without demand measurement systems, the following formula will be used:

$$Demanda = \left[\frac{Q_{mensual}}{24 * d * F.C.}\right]$$

For load centers receiving energy as part of a self-supply electricity generation permit, Dmaxpunta and Qmensual will be the maximum demand recorded and the monthly consumption supplied during the billing month by CFE SSB.

The result of this equation will be multiplied by the applicable tariff to obtain the monthly distribution charge.

$$Distribution\ Charge = Demand * Distribution\ Tariff\ Price$$

2.5.4. Transmission charges

Transmission charges are a crucial component of the electricity billing for high-demand medium voltage consumers. These charges are calculated based on the monthly energy consumption and the applicable transmission tariff (Secretaría de Gobernación, 2023). Figure 4 shows the table where transmission tariffs are set

Nivel de tensión	Generadores Generadores interconectados	Consumidores Servicio de suministro
Tensión $\geq$ 220 kV	0.0595	0.0772
Tensión < 220 kV	0.1077	0.1758

Figure 4. Transmission Tariffs

The applicable transmission tariff for consumers operating at a voltage level below 220 kV is 0,1758 MXN per kWh. This rate is used to calculate the total transmission charges for the client by multiplying the monthly energy consumption by this tariff. To determine the monthly transmission charges, the following formula is applied:

$$Transmission\ Charge\ (MXN) = Monthly\ Consumption\ (kWh)\ x\ Applicable\ Tariff\ (MXN/kWh)$$

2.6. Risks related to solar self-consumption installations

This section focuses on the critical role of risk assessment in evaluating these solar energy procurement models. Specifically, it addresses four key types of risk: counterparty credit risk, volumetric risk, price fluctuations, and regulatory/political risk. Each of these risks can significantly impact the financial outcomes of solar energy projects, influencing the decision-making process for industrial consumers.

Counterparty credit risk is the possibility that a contracting party in a long-term agreement, such as a PPA, may default on its obligations, leading to financial losses (Bank for International Settlements, 2019). This risk is especially relevant in the context of PPAs, which often lack collateral and rely heavily on the creditworthiness of the parties involved.

Volumetric risk arises from the variability in solar energy production, which is influenced by environmental factors such as weather conditions (Tranberg, Thrane Hansen, & Catania, 2018) This risk is crucial to consider, particularly in compensation models like net metering and net billing, where the timing and quantity of energy generation relative to consumption play a critical role in determining financial returns.

Price fluctuations over time introduce another layer of uncertainty, as changes in electricity market prices can affect the long-term viability of solar energy contracts. Understanding how these fluctuations impact each procurement model is essential for accurate financial forecasting.

Finally, political risk reflects the potential for regulatory changes, such as the possible transition from net metering to net billing in Mexico (Mexico Business News, 2022), which could alter the financial dynamics of solar energy projects. The possibility of such shifts necessitates a proactive approach to risk management, ensuring that industrial consumers are prepared for potential changes in the regulatory landscape.

2.6.1. Volumetric Risk in Renewable Energy PPAs

Volumetric risk is a significant factor affecting the financial performance of renewable energy PPAs, especially in solar energy projects. This risk emerges from the inherent variability in solar energy production due to fluctuating environmental conditions such as cloud cover, seasonal changes, and overall solar irradiation levels. Since solar power generation is not constant, it introduces a level of uncertainty in energy output predictions, which can impact the expected financial returns of PPAs.

In this thesis, we utilize data from Meteonorm, a comprehensive weather database, to model solar irradiation and assess volumetric risk. Meteonorm combines surface measurements from over 1.300 global weather stations with satellite data, creating detailed solar irradiation forecasts. These forecasts are crucial for simulating long-term solar energy production and understanding how variability in solar irradiance can affect energy output over time. The data provided by Meteonorm includes Typical Meteorological Year (TMY) datasets, which offer a standardized view of expected weather conditions based on historical data. This data is particularly useful for estimating potential solar energy production and, by extension, the volumetric risk associated with it (Meteonorm, 2024).

However, it's important to note that while Meteonorm is widely used, it does have some limitations. For instance, the method of generating TMY datasets involves some degree of uncertainty, particularly in regions where ground-based measurements are less frequent or of lower quality (Solcast, 2024). Despite these limitations, Meteonorm's conservative approach to data projection makes it a valuable tool for creating prudent and reliable simulations. This conservatism can be beneficial in avoiding the overestimation of solar energy production, thereby providing a more secure basis for financial planning in solar energy PPAs(Solcast, 2024).

Accurate solar irradiation forecasts are critical because any discrepancy between expected and actual solar energy production can have significant financial implications. Underestimating solar variability could lead to financial shortfalls if the energy produced falls below expectations, impacting the cost-effectiveness of PPAs. On the other hand, overestimating production might result in less favorable outcomes under schemes like net metering or net billing, where the timing and quantity of energy generation relative to consumption are vital.

By integrating Meteonorm data into our analysis, we aim to provide a robust framework for estimating and managing the risks associated with solar energy production variability. This approach aligns with methodologies discussed in existing literature, which emphasizes the importance of accurate modeling in managing volumetric risk in renewable energy contracts.

2.6.2. Price Fluctuations and Long-Term Viability

The financial viability of solar energy procurement models is heavily influenced by fluctuations in electricity prices over time. Understanding how these price changes impact the expected savings and overall cost-effectiveness of these models is crucial for large industrial consumers considering solar energy in Mexico.

Over the past 20 years, electricity tariff prices in Mexico have increased by an average of 6,9% annually. This historical trend can be used alongside inflation to project future electricity tariff prices, providing a reasonable estimate for how costs might evolve in the coming years. However, this approach does not apply to Local Marginal Prices (LMPs), which have shown significant volatility without a clear long-term trend.

LMPs in Mexico, recorded hourly since January 2017 (Centro Nacional de Control de Energía (CENACE), 2024), have fluctuated widely. Notably, prices hit a low in 2020 during the Covid-19 pandemic due to reduced demand and other economic factors, while 2018 saw record highs. Given this volatility and the lack of a clear trend, predicting future LMPs is challenging. Therefore, we will consider different scenarios with varying trends—increasing, stable, and decreasing LMPs—to evaluate their potential impact on the financial outcomes of solar energy models.

2.6.2.1. Price Increase Scenario

One of the critical factors driving the potential increase in electricity prices is the slow growth of renewable energy installations. The current Mexican government has implemented policies that restrict private sector investment in new electricity generation projects until the state-owned CFE controls at least 56% of the national generation portfolio. This approach has effectively slowed the expansion of renewable energy projects, particularly those driven by private investment, leading to a situation where energy supply may not keep pace with growing demand (Baker Institute, 2023).

Moreover, rising electricity consumption further exacerbates this situation. According to (Secretaría de Energía, 2024), the final electricity consumption in the Sistema Interconectado Nacional (SIN), which is relevant to our simulation, grew by 4,1% in 2023. Additionally, the maximum demand within the SIN increased by a substantial 10,2% during the same year. These growth rates highlight the increasing pressure on the national grid to meet rising energy needs.

Compounding these challenges is the aging electricity infrastructure in Mexico. PRODESEN 2024-2038 outlines a planned public investment of only 567,4 million USD in transmission and distribution networks for 2024 (Secretaría de Energía, 2024). However, the (Confederación Patronal de la República Mexicana (COPARMEX), 2024) estimates that an annual investment of 9 billion USD is necessary to adequately maintain and improve the national electricity infrastructure. This significant gap between planned and required investments emphasizes the inadequacy of current infrastructure spending. As a result, the underinvestment is likely to lead to more frequent power outages and increased energy and congestion charges within LMPs, further driving up electricity prices.

Adding to these pressures, there is a notable inflationary trend in tariff prices, particularly in the Bajío region, which includes Querétaro. According to (Comisión Federal de Electricidad (CFE), 2024) the energy price in the intermediate time frame (mostly corresponding to sunlight hours) in Querétaro has increased by 67% from 1,2 MXN/kWh in 2017 to 2,005 MXN/kWh in 2024. This reflects an average annual inflation of 10,31%.

These factors collectively support the hypothesis that electricity prices, particularly LMPs, are likely to rise in the short to medium term. This anticipated increase will have different impacts on net-billing and net-metering schemes. Net-metering is more likely to benefit directly from rising electricity prices, as consumers receive credits based on retail rates, which would increase with the constant rising electricity tariffs. On the other hand, net-billing is more sensitive to the volatility of LMPs, leading to slight increase in return if the LMPs were to progressively increase.

2.6.2.2. Constant Price Scenario

In this scenario, we assume that Local Marginal Prices (LMPs) remain constant throughout the entire operational lifetime of the photovoltaic plant. This assumption is based on the most recent long-term solar auction managed by the Centro Nacional de Control de Energía (CENACE), which took place in 2017. This was CENACE's third ever auction, where a price of 20,5 USD/MWh was secured for a 20-year period (Proyectos México, 2017). With the exchange rate at that time being 19 MXN/USD, this translates to a price of 389,5 MXN/MWh.

This fixed price provides a stable and predictable revenue stream for energy generated by the PV plant under net-billing schemes. The stability of this scenario offers a conservative financial outlook, reducing the risks associated with market volatility.

It's important to note that although the third auction in 2017 successfully established long-term prices, the planned fourth auction in 2018 was later canceled, and no additional auctions have been held since then. This absence of further auctions has left the 2017 price as a key reference point for long-term energy pricing in Mexico, reinforcing the significance of the fixed LMP in this scenario.

2.6.2.3. Price Decrease Scenario

In scenarios where cheaper energy sources like solar power are increasingly integrated into the energy mix, Local Marginal Prices (LMPs) can experience a significant decrease over time. This trend is particularly evident in the Node Querétaro Industrial (03QRI-115), where LMPs have steadily declined from an average of 1537 MXN/MWh in 2017 to 893 MXN/MWh in 2024 (Centro Nacional de Control de Energía (CENACE), 2024), representing an average annual deflation rate of 5,98%.

This deflation rate was derived by analyzing hourly price data from CENACE, focusing on yearly weighted averages during sunlight hours.

Incorporating this 5,98% deflation rate into solar energy procurement models reveals mixed financial outcomes for consumers. While the decreasing LMPs could potentially offer the potential for lower costs when purchasing energy, the returns from selling excess solar energy could decrease as well, given the falling prices. Thus, while consumers might see reduced costs for grid energy, the financial benefits from solar energy sales could be somewhat diminished, depending on the timing and scale of their energy generation and consumption.

Despite the observed deflation in LMPs in Querétaro, with a 42% decrease over the past few years, tariff prices have shown a contradictory trend, increasing by 67% in the same period. This disconnect suggests that while the cost of electricity procurement through LMPs has decreased, consumers are still facing higher energy costs due to the rising tariff prices. Additionally, it's important to note that tariff prices in Querétaro apply uniformly across the entire Bajío region, covering multiple nodes. However, the net billing scheme differentiates between these nodes, applying specific LMPs to each one. This discrepancy implies that while the region-wide tariff prices remain constant throughout the different nodes, the actual financial impact on consumers can vary significantly depending on the specific LMPs associated with their respective nodes under the net billing framework.

2.6.3. Political Risks and regulatory changes

Political risk is a key consideration in the financial viability of solar energy projects in Mexico, particularly due to the potential for regulatory shifts that could dramatically alter the landscape of compensation schemes such as net metering and net billing.

There is an ongoing risk that this favorable framework could change. The CRE has previously discussed the possibility of eliminating net metering in favor of a net-billing scheme. Under net billing, the energy consumers generate and send back to the grid would be compensated at the Local Marginal Price (LMP), which is generally a quarter of the retail rate. This shift would reduce the financial returns from solar energy projects, making them less appealing to consumers and investors alike (Mexico Business News, 2022).

Although the law mandates that existing net-metering contracts must be honored, there is a genuine concern that the CFE might take steps to transition consumers with existing PV systems to the less favorable net-billing scheme. This concern is not without precedent, as CFE has, in the past, taken actions contrary to established legal frameworks to protect its financial interests. As the pressure on CFE increases due to the rising number of consumers benefiting from net metering, the likelihood of such a transition becomes more significant.

Moreover, the CRE has already proposed draft regulations (Mexico Business News, 2022) that would eliminate net metering for medium-sized projects, intending to replace it with a self-consumption model akin to that used in Spain. This proposal, although not enacted, signals a clear direction toward reducing the benefits currently enjoyed under the net-metering scheme. The recent changes in leadership within the CRE further suggest that regulatory changes could be on the horizon, potentially forcing a shift from net metering to net billing.

Given the very real possibility of such regulatory changes, our analysis will include a scenario where net-metering contracts are converted to net billing. This scenario will help us evaluate the potential financial impacts of this regulatory shift on solar energy projects in Mexico. By simulating the effects of such a change, we can provide a more comprehensive risk assessment, giving investors and consumers a clearer picture of the potential challenges and opportunities that may arise under an altered regulatory framework. This approach ensures that our analysis remains robust and reflective of the evolving political and regulatory landscape.

2.6.4. Financial risks for investors

Investing in solar energy projects in Mexico involves several financial risks that must be carefully considered. One of the primary risks for investors is the possibility of client default, where the consumer fails to pay the agreed-upon monthly fees. Typically, the only collateral involved in these agreements is the photovoltaic installation itself. While this collateral provides some security, it is not sufficient to fully cover the investor's costs in the event of a default, especially given the depreciation of solar equipment over time.

Another significant financial risk stems from the high interest rates that are prevalent in Mexico. As of 2024, the Bank of Mexico's benchmark interest rate stands at 11.25% (Banco de México, 2024). This high interest rate environment means that financing costs for solar energy projects are substantial, putting pressure on investors to recover their investments quickly. Generally, investors aim to recover their capital within approximately five years. This relatively short recovery period helps to mitigate the risk of client default, as the financial exposure is limited to a shorter timeframe.

However, the reliance on the PV installation as the primary form of collateral means that if a client defaults after this initial recovery period, the potential losses could still be significant, especially if the equipment has depreciated or if the market conditions have shifted unfavorably. This risk is further exacerbated by the potential for regulatory changes which could reduce the financial returns from solar installations and make it more difficult for consumers to meet their payment obligations.

Given these financial risks, investors must carefully assess the creditworthiness of potential clients and consider the impact of high interest rates on the overall profitability of their investments. Additionally, contingency plans should be in place to address potential defaults, including strategies for repossessing and redeploying PV installations to minimize losses.

2.6.5. Consumption Risks

Consumption risk is a crucial factor in the financial assessment of solar energy projects, with significant implications for both investors and clients. This risk is primarily associated with the potential decline in the client's energy consumption over the project's lifespan. While an increase in energy consumption generally poses no issues (and may even enhance returns under the net billing scheme) a decrease in consumption can have adverse financial effects.

2.6.5.1. Investors' perspective

Investors rely on stable or growing energy consumption by the client to ensure a consistent revenue stream. In financing models such as PPAs and leasing agreements, revenue is generated based on the energy produced and consumed by the client. If the client's consumption decreases significantly, the amount of energy being offset or utilized by the client reduces, leading to a potential shortfall in expected revenues. This scenario directly affects the investor's return on investment (ROI), as the financial models typically do not account for significant drops in consumption. Investors, therefore, face the risk of not recouping their investments or failing to meet debt service obligations if the client's consumption declines unexpectedly.

2.6.5.2. Client's Perspective

For clients, the financial impact of reduced energy consumption is multifaceted. In net billing schemes, where the value of energy injected into the grid is typically lower than the value of energy consumed instantaneously, a reduction in consumption means that more energy might be sold back to the grid. This reduces the overall financial benefits of the solar installation. Additionally, in PPA and leasing models clients may find themselves paying for more energy than they use. Consequently, the client might experience diminished financial benefits or even losses, undermining the primary motivation for adopting such models.

3. Methodology

In this chapter, we examine the design and structure of the Excel models developed to benchmark the performance of various solar energy schemes. These models are specifically tailored to emulate the billing calculation methodology utilized by the CFE, Mexico's state-owned electric utility. By simulating monthly payments both in the current scenario (without solar panels) and after the installation of solar panels, we can provide a comprehensive analysis of cost savings and financial viability under different compensation models: net metering and net billing.

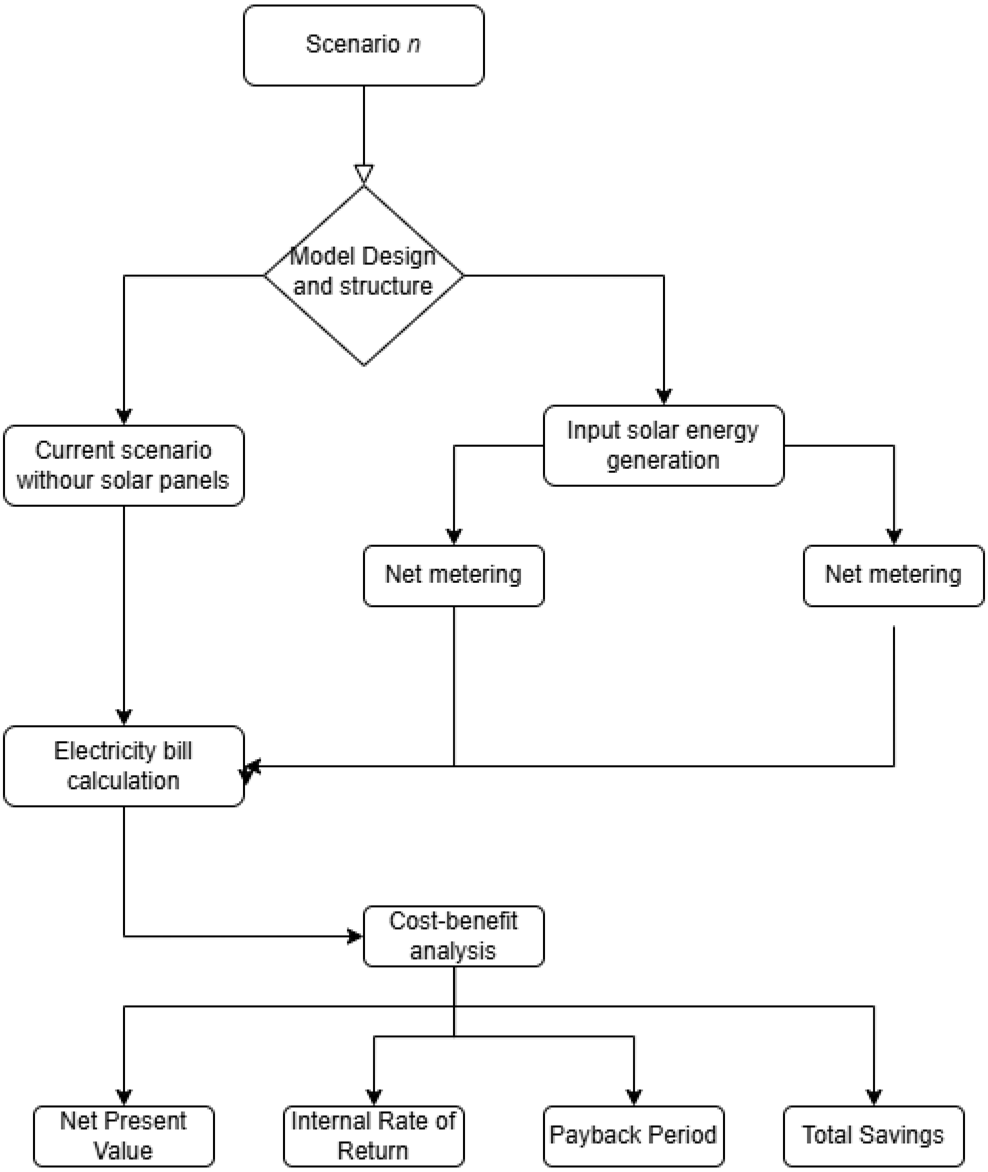

Figure 5. Methodology Flow Chart

3.1. Model Design and Structure

The Excel models are meticulously designed to replicate the CFE billing process, incorporating calculations for energy, distribution, capacity, and transmission charges. These models compute monthly payments based on the consumer's current electricity usage patterns and compare them to projected payments after the installation of solar panels.

The models provide a detailed, month-by-month analysis for 2024, focusing on several key components. First, they account for tariff prices, which include fixed charges and variable tariffs across base, intermediate, and peak periods. Distribution and capacity charges are also factored in, reflecting their monthly variations, while transmission charges are determined annually on a nationwide basis. Additionally, the models break down monthly consumption into base, intermediate, and peak periods, while also considering the maximum kW demand during each period.

For solar generation, the models project energy generation for each month and period, using historical data and system specifications. Two primary scenarios are simulated: one reflecting current payment without solar panels and the other projecting payments with solar panels installed.

In the "Without Solar Panels" scenario, the model calculates the total monthly cost based on current consumption patterns and applicable tariffs, including charges for energy consumption, distribution, and capacity charges based on maximum demand.

In contrast, the "With Solar Panels" scenario adjusts consumption figures by subtracting the generated solar energy from the total consumption for each period. This adjustment allows for the calculation of reduced energy consumption charges, adjusted distribution and capacity charges, and the potential savings achieved through solar energy generation.

The models incorporate two compensation mechanisms: net metering and net billing.

- Net Metering: Under the net metering scheme, any excess energy generated and not consumed is fed back into the grid and credited to the consumer's account as energy credits. These credits can be used to offset future energy consumption.
  The model tracks these credits and automatically applies them to reduce future bills, ensuring consumers maximize their benefits from solar energy.
- Net Billing: In the net billing scheme, excess energy is sold back to the grid at the Local Marginal Price (LMP) of the applicable node, in this case, Querétaro Industrial.

  The model calculates the difference between hourly consumption and generation to determine the excess energy for each period. This excess is then valued at the LMP and credited as monetary compensation to the consumer’s bill.

To accurately calculate the excess energy for the net billing model, we first utilize historical consumption data from a client in Querétaro. This data is analyzed over a period to provide a detailed understanding of energy usage patterns. Next, we derive an hourly consumption curve by dividing the monthly consumption for each period by the number of hours in that period. This hourly curve is crucial as it allows us to compare hourly generation and consumption, ensuring a precise calculation of excess energy.

3.2. Comparative Cost and Benefit Analysis

In this chapter, we will explain the bases for the comparative cost and benefit analysis of three different solar energy schemes: self-financed net metering, self-financed net billing, and net metering financed through a Power Purchase Agreement (PPA) or a Leasing contract. To evaluate these schemes, we will utilize three key financial metrics: Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period.

The goal of this analysis is to provide a clear understanding of the potential returns and profitability associated with each scheme, thereby aiding consumers in making informed decisions. By comparing these schemes, we aim to highlight the financial advantages and disadvantages of each approach, taking into consideration factors such as inflation, maintenance costs, and upfront investments.

3.2.1. Payback Period

The payback period measures the time required for the savings generated by the solar system to equal the initial investment cost (Investopedia, 2024). It is calculated as:

$$Payback\ Period = \frac{Net\ Solar\ System\ Cost}{Annual\ Savings}$$

Where:

- Net Solar System Cost: The total cost of the solar installation.
- Annual Utility Savings from Solar: The total money saved on electricity bills each year due to the solar system's energy production.

This metric is straightforward and commonly used to compare different quotes and understand the timeframe for recovering their investment. However, it is important to note that the simple payback period does not consider factors such as depreciation, or the project lifetime. The annual savings will be adjusted to include maintenance costs and inflation.

3.2.2. Net Present Value (NPV)

NPV represents the total value of future cash flows generated by the solar installation, discounted to their present value. It accounts for the time value of money, including factors such as inflation, opportunity cost, and risk (Investopedia, 2024). A positive NPV indicates that the project is expected to be profitable.

$$NPV = \sum \frac{Net\ Cash\ Flow}{(1 + Discount\ Rate)^{i}} - Initial\ Investment$$

Where:

- Net Cash Flow$t$: Net Cash Flow at time t. It considers the average inflation rate in the electricity bills , yearly maintenance costs, and the average regular inflation rate.
- Discount Rate The rate used to discount future cash flows to their present value.
- t: The time period. In this case, it will be 25 years.
- Initial Investment: The total upfront cost of the solar installation.

NPV helps determine the true worth of the solar system over its lifetime, providing a comprehensive view of the project's financial benefits.

3.2.3. Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) is a critical metric for assessing the annual rate of growth an investment is expected to generate. It is particularly useful for analyzing capital budgeting projects, allowing investors and companies to compare potential rates of return over time (Investopedia, 2024).

IRR is calculated using the same concept as Net Present Value (NPV), but with one key difference: it sets the NPV equal to zero. This means that IRR identifies the discount rate that makes the present value of the sum of annual nominal cash inflows equal to the initial net cash outlay for the investment. Essentially, it determines the break-even rate of return, where the investment neither loses nor gains value in present terms.

$$0 = NPV = \sum \frac{Net\ Cash\ Flow_t}{(1 + IRR)^t} - Initial\ investment$$

Where:

- NPV: Net Present Value
- Net Cash Flow$t$: Net Cash Flow at time t. It takes into consideration the average inflation rate in the electricity bills, yearly maintenance costs, and the average regular inflation rate.
- IRR: Internal Rate of Return
- Initial Investment: The total upfront cost of the solar installation.

3.2.4. Assumptions

The financial model developed for this analysis integrates several key considerations to ensure that projections are accurate and reflective of the economic conditions and operational realities of solar energy investments in Mexico. This comprehensive approach allows for a robust evaluation of the financial viability of various solar energy schemes under different scenarios, particularly considering potential regulatory changes and market trends.

The expected lifetime of the solar panels is set at 25 years, a duration based on the production warranty offered by the manufacturer. While solar panels typically continue to operate beyond this period, using the warranty period as a baseline provides a reasonable and industry-standard foundation for the financial calculations. This assumption helps align the model with standard practices and ensures that projections are grounded in realistic expectations.

Inflation rates are another critical component of the model. The general inflation rate is set at 4.98%, reflecting the average rate over the last 25 years (Banco de México, 2024),. This rate provides a stable basis for projecting future economic conditions. For electricity bill inflation, the model uses a higher rate of 6,9%, based on data from a study by Energia Real, the largest PPA investment bank in Mexico. This higher rate accounts for the faster historical increase in electricity costs compared to general inflation, which is crucial for accurately assessing the long-term savings potential of solar energy projects. LMPs' trends will be the main difference between the different scenarios portrayed

Maintenance costs are set at 27,500 MXN annually, based on a quotation from Grupo Nova, a, EPC company with over a decade of experience in Mexico. In the context of financing schemes (PPA and Leasing), these maintenance costs are covered by the investment fund for the first 10 years, as the solar PV plant remains under the fund's ownership during this period. From the 11th year onward, the responsibility for maintenance shifts to the client, accurately reflecting the typical structure of PPA agreements and ensuring that the financial model represents the real costs involved.

The net-billing scheme is evaluated under three scenarios to assess the impact of different trends in LMPs on the profitability of solar energy investments. In the first scenario, LMPs are assumed to increase annually by 10,31%, in line with the energy tariff inflation rate. This scenario reflects an upward trend in energy prices, which would enhance the profitability of solar energy projects under a net-billing scheme, as the revenue from selling excess energy would increase over time. In the second scenario, a constant LMP of 389,5 MXN/MWh is assumed throughout the project's lifetime, obtained from the most recent solar long-term auction. In the third scenario, an annual decrease of 5,98% in LMPs is used, based on trends LMPs in the Querétaro Industrial node.

3.2.5. Scenarios

This subsection provides a detailed explanation of the nine scenarios analyzed to compare the financial performance of different solar energy models for large industrial consumers in Mexico. These scenarios consider various combinations of financing methods, energy schemes (Net-Metering and Net-Billing), and LMP trends. Scenarios 1 to 7 operate under the EPC scheme, scenario 8 uses the PPA scheme, and scenario 9 applies the leasing scheme.

Scenario 1: Continuous Net-Metering for 25 Years

In this scenario, Net-Metering is applied throughout the 25-year project lifetime. The client consumes energy directly from the PV system, with any excess energy being credited at the retail electricity rate. This scenario assumes that the Net-Metering scheme remains unchanged over the entire period, offering stability and maximizing the financial benefits from self-consumption and retail rate credits.

Scenario 2: Net-Metering to Net-Billing Transition (-5.98% LMP Deflation)

Here, Net-Metering is applied for the first 6 years, after which the system transitions to Net-Billing with a -5.98% annual deflation in LMPs. This scenario reflects a situation where the income from excess energy sold back to the grid decreases over time, reducing the overall financial returns compared to continuous Net-Metering. The deflation rate was calculated using LMPs from the years 2017 to 2014 (Centro Nacional de Control de Energía (CENACE), 2024).

Scenario 3: Net-Metering to Net-Billing Transition (Constant LMPs)

Similar to Scenario 2, this scenario starts with Net-Metering for the first 6 years, transitioning to Net-Billing in year 7. However, it assumes constant LMPs throughout the project. This scenario offers a more stable income from excess energy compared to Scenario 2 but lower than continuous Net-Metering. The LMP used was extracted from CENACE's most recent long-term solar auction (Proyectos México, 2017).

Scenario 4: Net-Metering to Net-Billing Transition (+10.31% LMP Inflation)

In this scenario, Net-Metering is applied for the first 6 years, followed by a transition to Net-Billing with a +10.31% annual increase in LMPs. The rising LMPs increase the income from excess energy sold back to the grid, improving financial returns compared to other Net-Billing scenarios. LMPs' inflation was calculated using the data extracted from 2017 to 2024 in (Centro Nacional de Control de Energía (CENACE), 2024).

Scenario 5: Continuous Net-Billing (-5.98% LMP Deflation)

This scenario applies Net-Billing for the entire 25 years with a -5.98% annual deflation in LMPs. The continuous decrease in LMPs leads to progressively lower income from excess energy sales, making this one of the less financially attractive options.

Scenario 6: Continuous Net-Billing (Constant LMPs)

In this scenario, Net-Billing is applied continuously with constant LMPs. The financial performance is more stable compared to Scenario 5, but it remains less favorable than scenarios involving Net-Metering.

Scenario 7: Continuous Net-Billing (+10.31% LMP Inflation)

This scenario also uses Net-Billing for the entire project but assumes a +10.31% annual increase in LMPs. The rising LMPs enhance the financial returns, making it one of the more favorable Net-Billing options.

Scenario 8: Power Purchase Agreement (PPA)

Under the PPA model, the client does not invest any capital upfront. Instead, an investment fund finances the PV system, and the client pays for the energy produced at a discounted rate – 30% cheaper than CFE's tariffs– for the first 10 years. The PPA payments escalate with the INPC inflation rate. Net-metering applies for all 25 years. The investment fund covers maintenance costs while the contract is valid, the client will start covering the maintenance costs in year 11.

Scenario 9: Financial Leasing

This scenario involves a financial leasing model where the client also avoids upfront capital expenditure. Instead, the client pays a fixed monthly leasing fee, indexed to the INPC, for the first 10 years. The leasing model offers predictable costs with minimal initial financial burden. Net-metering applies for all 25 years. The investment fund covers maintenance costs while the contract is valid, the client will start covering the maintenance costs in year 11.

3.2.6. Risks Consideration in Financial Model Evaluation

Several risks were considered, each with the potential to significantly impact the outcomes of these investments. One of the primary risks is volumetric risk, which refers to the variability in solar energy production due to fluctuations in solar irradiance. To mitigate this risk, the analysis utilized data from Meteonorm, a reliable source for solar irradiation forecasts. By incorporating this data, the financial models are able to provide a more accurate projection of energy generation, ensuring that the financial outcomes reflect a realistic range of solar energy production.

Price fluctuation risk is another critical factor that affects the financial performance of solar energy models. Scenarios 2 through 7 specifically address this risk by considering different trends in LMPs, including scenarios where LMPs increase, decrease, or remain stable. These variations in LMPs lead to significant differences in NPV and total savings, particularly for net-billing schemes where the income from surplus energy is directly tied to LMPs. By analyzing these scenarios, the study provides insights into how sensitive the financial outcomes are to changes in electricity prices, which is essential for making informed investment decisions.

Political risk is also a major consideration, especially given the current regulatory environment in Mexico. Scenarios 2, 3, and 4 incorporate the possibility that net-metering contracts could be transitioned to net-billing after year 7, reflecting potential changes in government policy. This shift reduces the financial benefits of solar energy projects, as net-billing results in lower income from surplus energy compared to net-metering. By including this risk in the analysis, the study highlights the importance of monitoring regulatory developments and being prepared for potential policy shifts that could affect the long-term viability of solar investments.

While credit risk was identified as a potential issue, it primarily impacts investors rather than the client and was not the focus of this analysis. Instead, the study concentrated on risks more relevant to the client's perspective, such as consumption risk. The PV plant was designed based on the client's current energy consumption patterns, with an expected yearly generation covering 86% of the total consumption. This design provides a buffer in case of decreased energy consumption, which could otherwise reduce the financial benefits of solar investment. Additionally, the natural degradation of solar panels over time will gradually reduce energy generation, further mitigating the impact of any potential decrease in consumption.

4. Case study

In this chapter, we present a detailed analysis of the client's historical energy consumption data and the applicable tariff prices. This information is critical for accurately modeling the financial impact of various solar energy procurement schemes. By understanding the client's energy usage patterns and the associated costs, we can effectively evaluate the potential savings and benefits of installing a photovoltaic system. The data used in this analysis has been extracted from the client's previous electricity bills, providing a comprehensive basis for our financial models.

4.1. Historical Consumption Data

To accurately model and analyze the solar energy procurement schemes, we first gather historical consumption data from a client based in Querétaro. This data, extracted from previous electricity bills, provides detailed monthly consumption figures for both 2023 and 2024. The historical data includes energy usage broken down into base, intermediate, and peak periods, as well as the maximum demand in kW for each period.

	Consumption	kWh Base	kWh Intermedia	kWh Punta	kW Base	kW Intermedia	kW Punta
2024	**January**	1040	16.350	2102	136	136	84
	February	1280	16.543	1868	138	97	86
	March	1680	17.358	1306	139	138	87
	April	4880	24.407	1739	110	123	65
2023	**May**	1630	18.748	5440	72	94	127
	June	108	20.050	400	10	134	5
	July	875	19.066	2400	67	122	72
	August	595	19.490	1840	73	144	0
	September	1848	18.862	5840	72	124	88
	October	1732	17.353	4800	57	65	2
	November	3175	17.847	2320	88	123	118
	December	2230	13.174	1760	89	135	123

Figure 6. Consumption Data

4.2. Hourly Consumption Curve

Using the historical monthly consumption data, we derive an hourly consumption curve. This process involves dividing the total monthly consumption for each period by the number of hours in that period. The resulting hourly consumption curve is essential for comparing the client's energy consumption against solar energy generation on an hourly basis, ensuring precise calculations of excess energy and potential savings.

To accurately calculate the number of hours in each period for each month, we use the official calendar provided by (Comisión Federal de Electricidad (CFE), 2024) for the central region. This calendar differentiates between periods based on seasonal changes and day types (weekdays, Saturdays, Sundays, and holidays). Using this information, the model calculated the number of hours in each period for each month, as shown in Figure 7:

	Base	Intermedio	Punta
January	259	389	96
February	228	356	88
March	246	397	100
April	251	427	42
May	242	456	46
June	236	440	44
July	256	446	42
August	242	456	46
September	237	441	42
October	255	442	48
November	240	384	96
December	261	389	94

Figure 7. Tariff Periods Consumption Curve

Now that the historical consumption data from the client and the amount of hours in each period in each month are compiled, the following formula is applied to every period and month:

$$Average\ Hourly\ Consumption = \frac{Monthly\ Consumption\ in\ Each\ Period}{Number\ of\ Hours\ in\ Each\ Period}$$

The average hourly consumption values are compiled to form a comprehensive hourly consumption curve for each period. Figure 8 shows the results of the calculation:

	Base	Intermedio	Punta
January	4,0	42,0	21,9
February	5,6	46,5	21,2
March	6,8	43,7	13,1
April	19,4	57,2	41,4
May	6,7	41,1	118,3
June	0,5	45,6	9,1
July	3,4	42,7	57,1
August	2,5	42,7	40,0
September	7,8	42,8	139,0
October	6,8	39,3	100,0
November	13,2	46,5	24,2
December	8,5	33,9	18,7

Figure 8. Hourly Consumption Curve

4.3. Applicable Tariff Prices

The applicable tariff prices for the region in question, Bajío, have been extracted directly from (Comisión Federal de Electricidad (CFE), 2024). The tariffs are specifically for the Gran Demanda Media Tension Horaria (GDMTH) rates. These prices are incorporated in the model to accurately calculate the current costs and potential cost savings, and financial impact of the different energy procurement schemes mentioned.

Figure 9 outlines the fixed charges and variable tariffs for base, intermediate, and peak periods for the years 2023 and 2024 (Comisión Federal de Electricidad (CFE), 2024):

Year	Month	Fijo ($)	Base ($/kWh)	Intermedia ($/kWh)	Punta ($/kWh)
2024	**January**	362,6	1,0702	1,9081	2,1752
	February	362,6	1,0753	1,918	2,1867
	March	362,6	1,0865	1,9398	2,2119
	April	362,6	1,0865	1,9399	2,212
	May	362,6	1,0865	1,9399	2,212
2023	**June**	304,99	1,0871	1,9422	2,2148
	July	304,99	1,0999	1,9672	2,2438
	August	304,99	1,0908	1,9494	2,2232
	September	304,99	1,0818	1,9319	2,203
	October	304,99	1,0832	1,9346	2,2061
	November	304,99	1,0711	1,9111	2,1789
	December	304,99	1,0643	1,8977	2,1635

Figure 9. Electricity Tariffs

Additionally, the distribution and capacity charges are also critical components of the total electricity costs. These charges for the years 2023 and 2024 are as Figure 10 shows (Comisión Federal de Electricidad (CFE), 2024):

Year	Month	Distribution ($/kW)	Capacity ($/kW)
2024	**January**	101,75	401,05
	February	101,75	403,37
	March	101,75	408,46
	April	101,75	408,47
	May	101,75	408,47
2023	**June**	101,35	409,31
	July	101,35	415,15
	August	101,35	411
	September	101,35	406,92
	October	101,35	407,55
	November	101,35	402,06
	December	101,35	398,94

Figure 10. Distribution and Capacity Tariffs

4.4. Current Electricity Bills

This subchapter provides a detailed breakdown of the client's current electricity bills. The data presented here has been extracted from the model, emulating the functioning of electricity bills through the formulas mentioned earlier, offering a comprehensive view of their monthly expenditures. Figure 11 represents the client's historical consumption data:

	Distribution (kW)	Capacity (kW)	Consumption (kWh)
January	47	47	19492
February	47	47	19691
March	49	49	20344
April	75	65	31026
May	62	62	25818
June	50	5	20558
July	54	54	22341
August	53	0	21925
September	64	64	26550
October	58	2	23885
November	56	56	23342
December	41	41	17164

Figure 11. Consumption Data

Figures 12 and 13 summarize the client's electricity expenses for each month, divided into the four main cost components: energy, distribution, capacity, and transmission.

Spending	Energy	Distribution	Capacity	Transmission
January	$36.882,71	$4.782,25	$18.849,35	$3.426,69
February	$37.190,61	$4.782,25	$18.958,39	$3.461,68
March	$38.385,11	$4.985,75	$20.014,54	$3.576,48
April	$56.495,93	$7.631,25	$26.550,55	$5.454,37
May	$50.173,52	$6.308,50	$25.325,14	$4.538,80
June	$39.944,44	$5.067,50	$2.046,55	$3.614,10
July	$43.854,17	$5.472,90	$22.418,10	$3.927,55
August	$42.733,52	$5.371,55	$-	$3.854,42
September	$51.304,18	$6.486,40	$26.042,88	$4.667,49
October	$46.036,50	$5.878,30	$815,10	$4.198,98
November	$42.563,19	$5.675,60	$22.515,36	$4.103,52
December	$31.181,45	$4.155,35	$16.356,54	$3.017,43
TOTAL	**$516.745,33**	**$66.597,60**	**$199.892,50**	**$47.841,51**

Figure 12. Yearly Spending Table

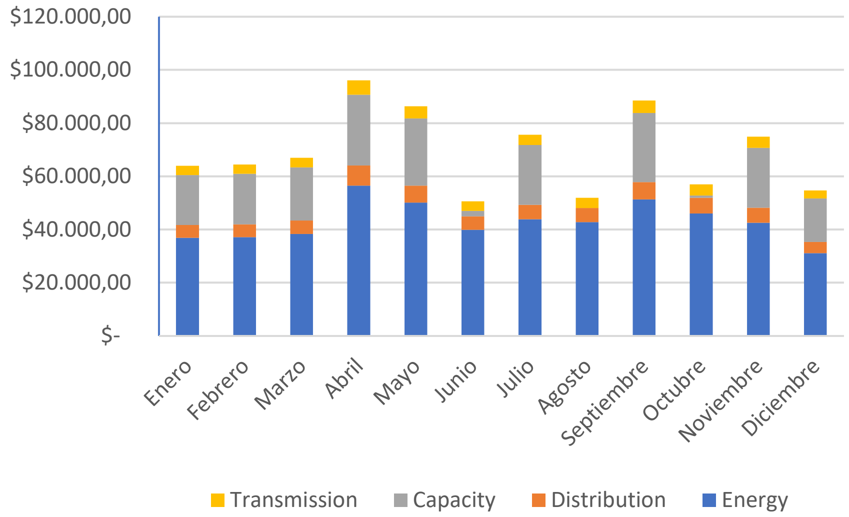

Figure 13. Yealy Spending Distribution

The total annual expenditure for energy, distribution, capacity, and transmission costs is 898.186 MXN. Knowing their annual consumption is 272.136 kWh and their total annual costs, we can deduce that their average price is 3,3005 $/kWh. Figure 14 portrays how the costs are distributed among the four components:

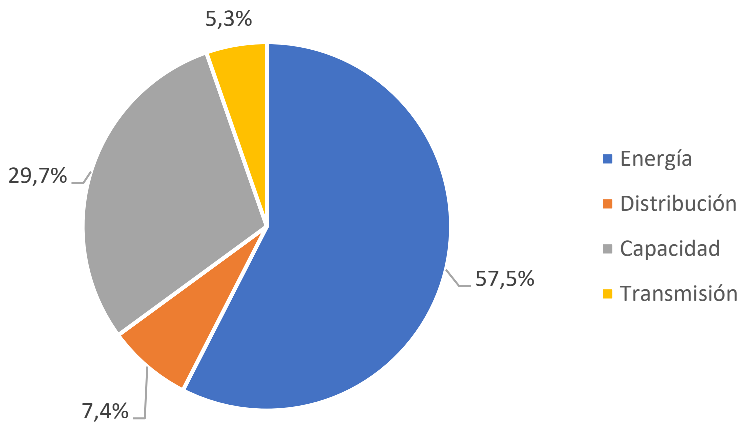

Figure 14. Yearly Spending Breakdown

4.5. System Design and Specifications

4.5.1. System Design

The photovoltaic (PV) system designed comprises 234 solar panels with a capacity of 555 Wp, adding to a total installed capacity of 129,87 kWp. The setup includes a single 100 kW inverter, ensuring that all of the energy generated by the panels is converted and that there is no cut out energy.

The PV panels are mounted using a coplanar structure on the client's roof, with a 4º inclination. This method involves installing the panels flat against the roof surface, which minimizes structural modifications and optimizes the use of existing space. The coplanar installation is the most cost-efficient solution available due to its small size. The panels are oriented towards the east following the building's orientation.

Figure 15. PV Plant Design

The PV array is divided into three sections, each connected to the inverter. These sections, referred to as strings, are arranged as follows:

- Central Unit: Comprising 3 strings, each with 26 PV modules.
- Left Unit: Also comprising 3 strings, each with 26 PV modules.
- Right Unit: Similarly, 3 strings with 26 PV modules each.

This system design yields a performance Index of 1804 kWh/kWp. The cost determined for the PV plant is 0,75 USD/Wp, which amounts to a total of 97.500 USD or 1.950.000 MXN.

4.5.3. Energy Generation by Period

To provide a comprehensive understanding of the system's performance, the energy generation for each tariff period (base, intermediate, peak) is detailed monthly. This information will be summarized in Figure 16:

	kWh Base	kWh Intermedia	kWh Punta
January	2724	13397	0
February	2768	14744	30
March	3124	18693	137
April	3850	18970	3
May	3387	20119	0
June	2110	18845	0
July	3104	18841	0
August	2232	19111	0
September	2569	16019	0
October	3460	14625	0
November	2279	14227	0
Dicember	1942	12916	0

Figure 16. Energy Generation in each Tariff Period

The total annual energy yield is 234.226 kWh

4.5.4. Long-Term Energy Generation

Solar panels typically experience a decrease in efficiency over time. For this installation, the panels have an expected degradation rate of 2% in the first year and 0,55% annually for the remaining years, according to the panels' data sheet. This degradation rate is factored into the financial and energy production models to provide accurate long-term performance projections.

To assess the long-term viability and financial return of the PV system, we project the annual energy generation over 25 years, considering the annual degradation rates of the panels. The total production over 25 years will be 5.408,4 MWh. Figure 17 portrays the solar panels' degradation curve.

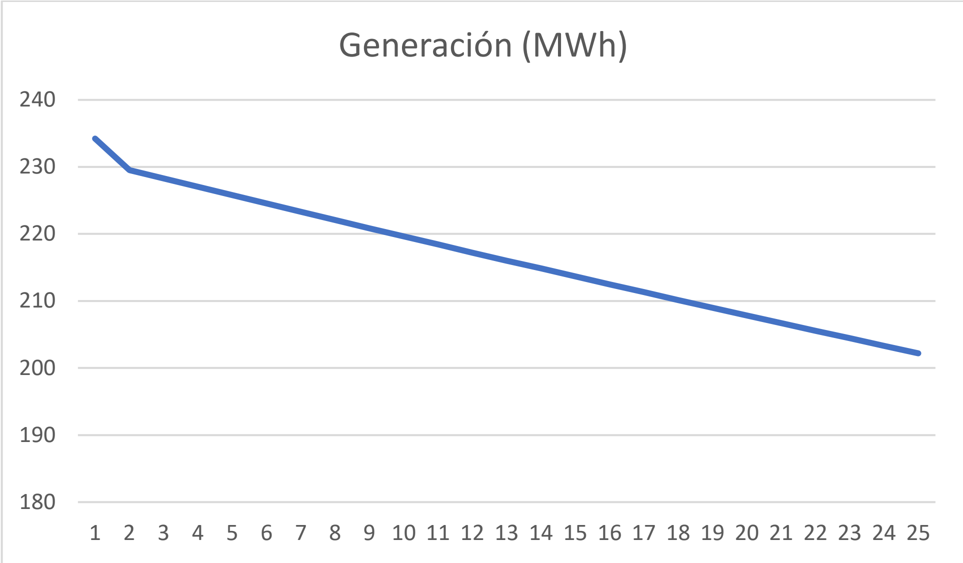

Figure 17. Solar Panels' Degradation Curve

5. Results

5.1 Impact on Billing under Net Metering

5.1.1 First year

The implementation of a photovoltaic system significantly impacts the client's electricity billing under the net metering scheme. Net metering allows the energy generated by the solar panels to offset the client's energy consumption. Any excess energy produced is fed back into the grid and credited to the client's account for future use. This reduces the overall energy costs by lowering the amount of electricity that needs to be purchased from the utility.

To evaluate the impact on billing, we utilized several key data points:

- Historic Consumption Data: The client's monthly energy consumption for each period (base, intermediate, and peak).
- Solar Generation Data: The monthly energy generation from the PV system for each period, obtained from our plant simulation.
- Applicable Tariff Prices: Distribution, capacity, energy, and transmission charges as per the Bajío region tariff schedule.

These data points were input into the formulas discussed earlier to calculate the adjusted multiplying factor for capacity, distribution, energy, and transmission under the net metering scheme. These results will be multiplied by the applying tariff prices mentioned earlier to calculate the new electricity bill.

	Distribution (kW)	Capacity (kW)	Consumption (kWh)
January	5	5	2102
February	4	4	1838
March	2	2	1169
April	4	4	1736
May	13	13	5440
June	0	0	400
July	5	5	2400
August	4	0	1840
September	14	14	5840
October	17	2	7188
November	14	14	5940
December	4	4	2018

Figure 18. Energy and Power Parameters

The data shows a significant decrease in all categories: energy, distribution, capacity, and transmission. The new electricity bills will be the ones portrayed in Figure 19:

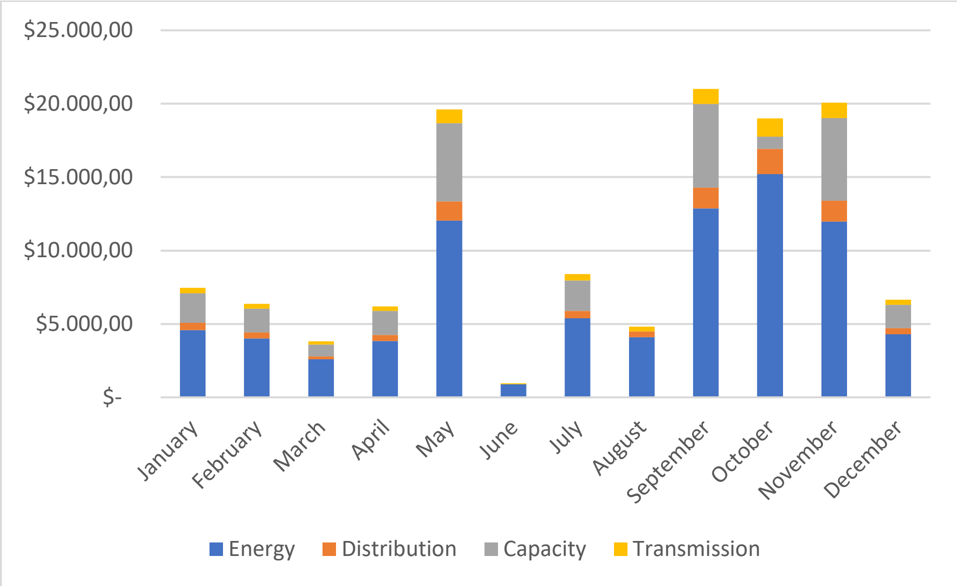

Figure 19. New Monthly Electricity Bill

The new annual costs amount to $81.755 MXN in energy costs, 8.727 MXN in distribution charges, 27.191 MXN in capacity charges, and 6.664 MXN in transmission charges, adding a grand total of 124.339 MXN.

Now that we know the current costs and the new costs, we can calculate the savings in each of the four components for every month. Figure 20 below portrays the savings, divided by month and bill component:

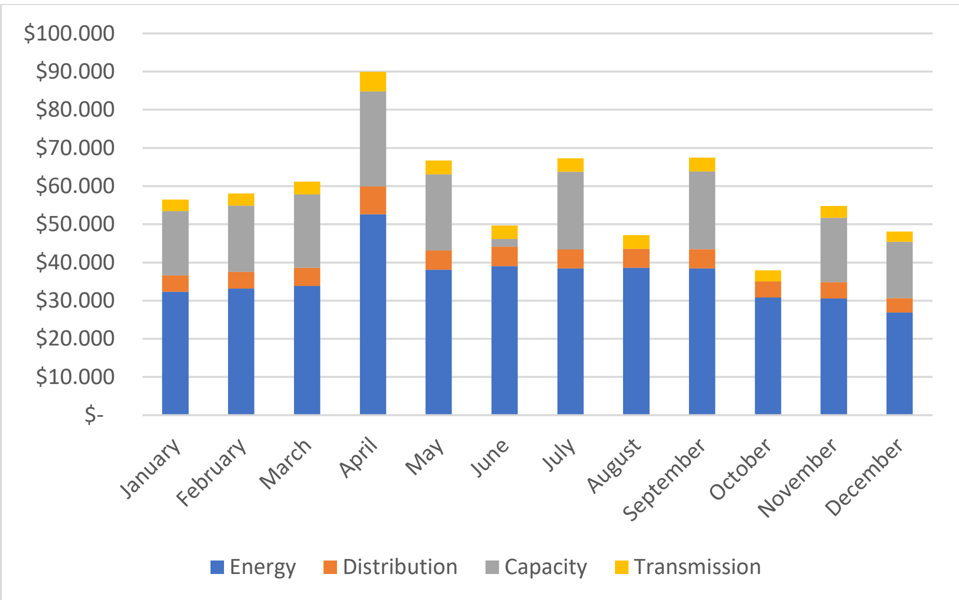

Figure 20. Monthly Savings

The total annual savings amount to 433.003 MXN in energy costs, 57.870 MXN in distribution charges, 172.701 MXN in capacity charges, and 41.177 MXN in transmission charges, adding a grand total of 764.102 MXN. This represents an 84,80% reduction in the electricity bill.

5.1.2. Long-Term Financial Projections Under Net Metering for 24 Years

In this section, we analyze the financial performance of the photovoltaic (PV) system from year 2 through year 25, under the assumption that the net metering scheme remains applicable throughout this period. The financial outcomes presented here are built on the initial savings observed in the first year, providing a comprehensive view of the system's profitability over its operational life.

The energy savings generated by the PV system grow steadily each year, as electricity prices rise at an inflation rate of 6,9%. For instance, while the energy savings in the second year are projected to be 738.310 MXN, these savings increase significantly over time, reaching 3.017.424 MXN by the 25th year. Cumulatively, the savings grow substantially, illustrating the strong financial returns of maintaining net metering throughout the period.

The model accounts for maintenance costs, which start at 27.500 MXN in the first year and increase by 4,98% annually. By the 25th year, maintenance costs are projected to rise to 88.285 MXN. Even with these rising costs, the savings from reduced energy bills continue to far exceed the expenses, ensuring that the PV system remains a highly profitable investment.

The cumulative savings, inclusive of the first year, demonstrate the system's ability to generate substantial returns over its 25-year operational life. Figure 21 illustrates the progression of savings.

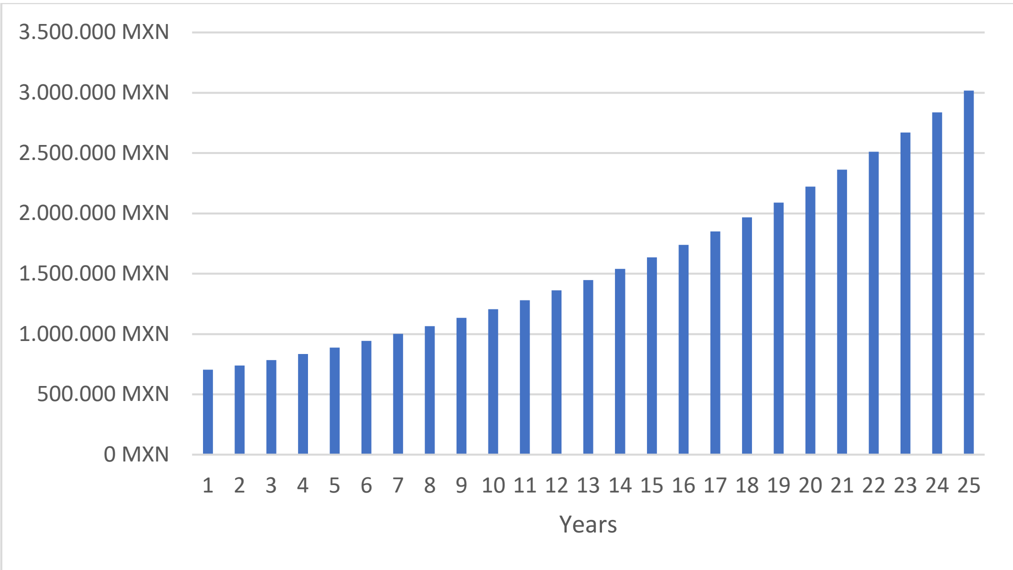

Figure 21. Scenario 1 Lifetime Savings

5.1.3 Long-Term Financial Projections with Transition to Net Billing and PML deflation

In this analysis, we evaluate the financial performance of a PV system from year 2 through year 25 under a scenario where the net metering scheme is operational until year 6, after which it transitions to a net billing scheme.

With net billing, the credit for surplus energy is based on the LMP rather than the retail electricity rate. The LMP is expected to decrease by 5,98% annually, which diminishes the income generated from selling excess energy back to the grid. For example, in year 7, total savings drop to 561.827 MXN, supplemented by an additional income of 113.578 MXN from selling surplus energy, resulting in combined savings and income of 675.405 MXN. This represents a significant decline compared to the previous year under net metering.

As the years progress, the decreasing LMP further reduces the income from surplus energy. In year 25, income from energy sales declines to just 33.896 MXN, while the savings reach 1.690.781 MXN, leading to combined savings and income of 1.724.677 MXN. Figure 22 shows this scenario’s lifetime savings

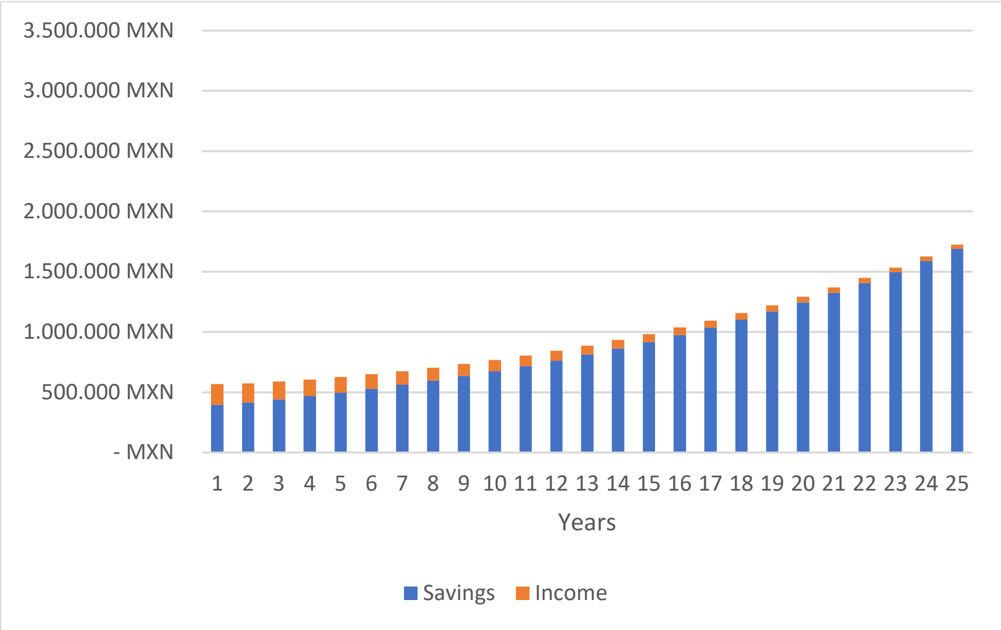

Figure 22. Scenario 2 Lifetime Savings

The financial impact of transitioning from net metering to net billing is evident in the reduced overall returns. While the savings from reduced energy bills remain substantial, the income generated from selling surplus energy decreases each year due to the deflationary trend in LMPs.

5.1.4 Long-Term Financial Projections with Transition Net Billing and constant LMP

In this analysis, we evaluate the financial performance of a photovoltaic (PV) system from year 2 through year 25 under a scenario where the net metering scheme is operational until year 6, after which it transitions to a net billing scheme. Starting in year 7, the income from surplus energy is determined by the Local Marginal Prices (LMPs), which are expected to remain constant throughout the entire period set at 389,5 MXN/MWh.

In year 7, after transitioning to net billing, the total savings drop to 561.827 MXN, supplemented by an additional income of 38.281 MXN from selling surplus energy, resulting in combined savings and income of 600.108 MXN. This represents a significant decline compared to the previous year under net metering. Over time, while savings from reduced electricity bills continue to grow, the income from selling surplus energy tends to decrease each year, reaching 34.664 MXN in year 25. This decrease is caused by the panels' efficiency loss over the years

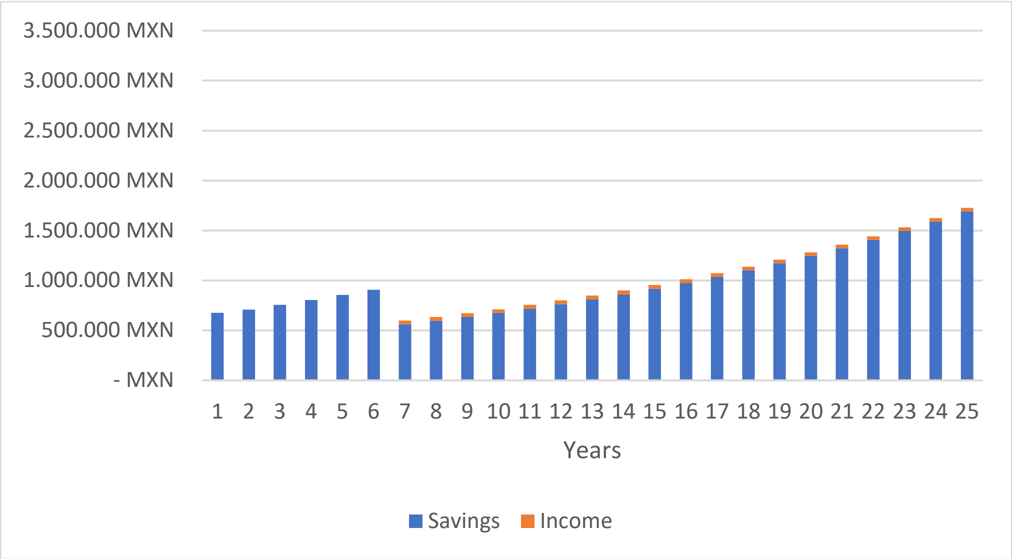

Figure 23. Scenario 3 Lifetime Savings

Adding up the yearly numbers from Figure 23 results in a grand total of savings and income reaching 24.974.646 MXN, of which only 692.441 MXN corresponds to the income generated from excess energy.

5.1.5 Long-Term Financial Projections with Transition to Net Billing and PML Inflation

This analysis examines a scenario where the net metering scheme transitions to a net billing scheme in year 7, with LMPs experiencing an annual inflation rate of 10,31%.

In year 7, the income from surplus energy is 296.217 MXN under the current scenario, compared to only 113.578 MXN in the deflationary scenario. This difference grows over time as the compounding effect of LMP inflation becomes more pronounced.

By year 25, the income from energy sales under the current scenario reaches 1.568.195 MXN, significantly higher than the 33.896 MXN generated under the deflationary scenario. This results in a total combined savings and income of 3.258.976 MXN in year 25 under the current scenario, compared to 1.724.677 MXN in the deflationary scenario.

The comparison between the two scenarios highlights the substantial impact of LMP inflation on long-term financial returns. In the current scenario, the system generates significantly higher income from energy sales each year. This trend continues, with the difference in income widening each year, highlighting the financial impact of LMP.

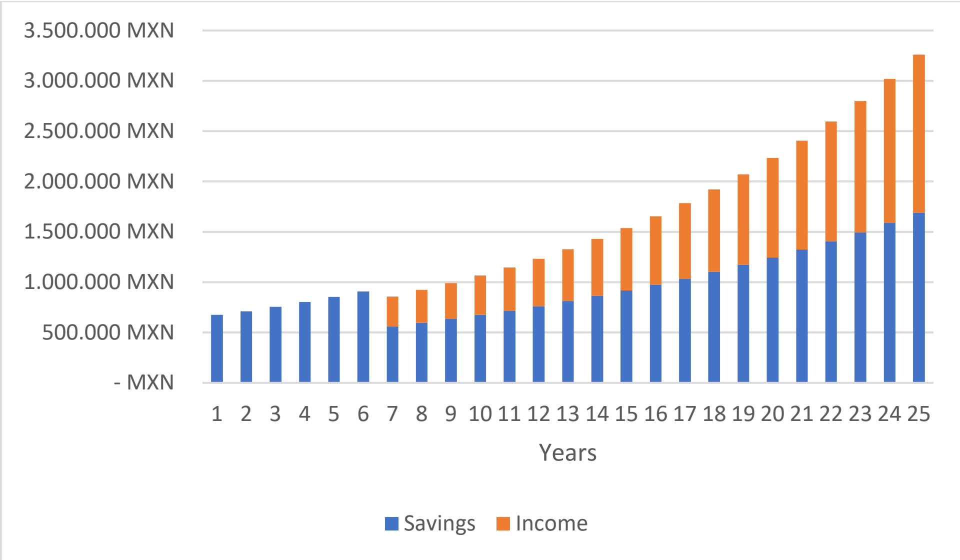

Figure 24. Scenario 4 Lifetime Savings

5.2. Impact on Billing under Net Billing

5.2.1 First year

To assess the impact on billing under the net billing scheme, we utilized hourly data for both energy consumption and generation. Hourly consumption data was obtained by assuming a constant consumption throughout each period, due to the CFE only stating the monthly consumption in each tariff period. The hourly solar generation data, derived from PV system simulations, provided a clear picture of how much energy the system produced at different times of the day. This detailed information was crucial for accurately calculating the interaction between energy generated and consumed.

The analysis also took into consideration the applicable tariff prices for distribution, capacity, energy, and transmission as specified in the Bajío region's tariff schedule. Furthermore, LMPs specific to the Querétaro Industrial node were applied, reflecting the hourly cost of electricity in 2023 and 2024. By comparing the hourly generation with consumption and applying the relevant tariffs and LMPs, we could precisely determine the financial outcomes under the net billing scheme, including the revenue generated from any surplus energy fed back into the grid.

	Distribution (kW)	Capacity (kW)	Consumption (kWh)
January	24	24	10.167
February	23	23	9.824
March	21	21	8.781
April	39	39	16.398
May	33	33	13.813
June	21	5	8.789
July	26	26	10.688
August	25	0	10.275
September	38	38	15.799
October	35	2	14.508
November	31	31	12.812
December	22	22	9.150

Figure 25. Energy and Power Parameters

The data shows a significant decrease in all categories: energy, distribution, capacity, and transmission. Figure 26 portrays the new electricity bills:

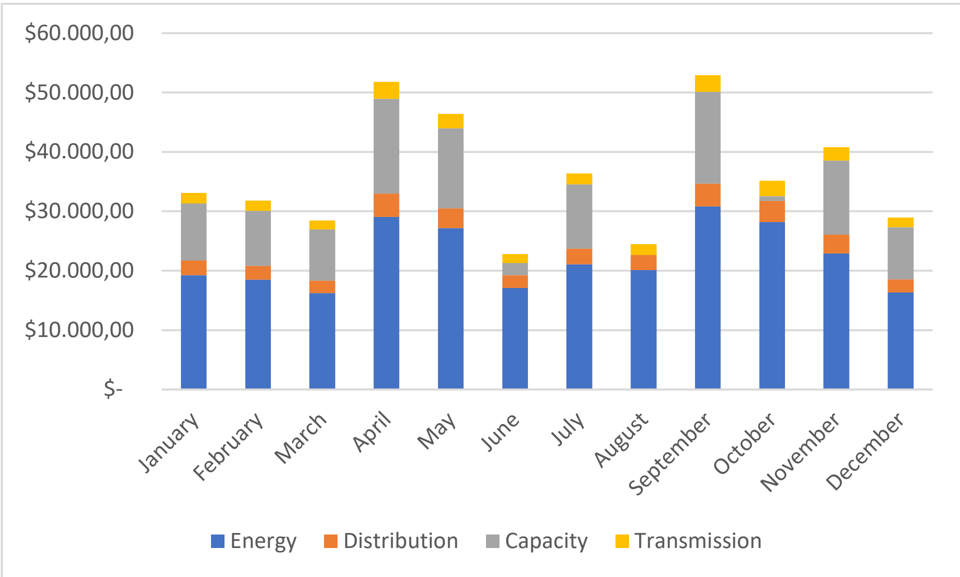

Figure 26. New Electricity Bill

The new annual costs amount to 266.776 MXN in energy costs, 34.312 MXN in distribution charges, 107.249 MXN in capacity charges, and 24.788 MXN in transmission charges, adding a grand total of 433.125 MXN.

Now that we know the current costs and the new costs, we can calculate the savings in each of the four components for every month. Figure 27 portrays the savings, divided by month and bill component:

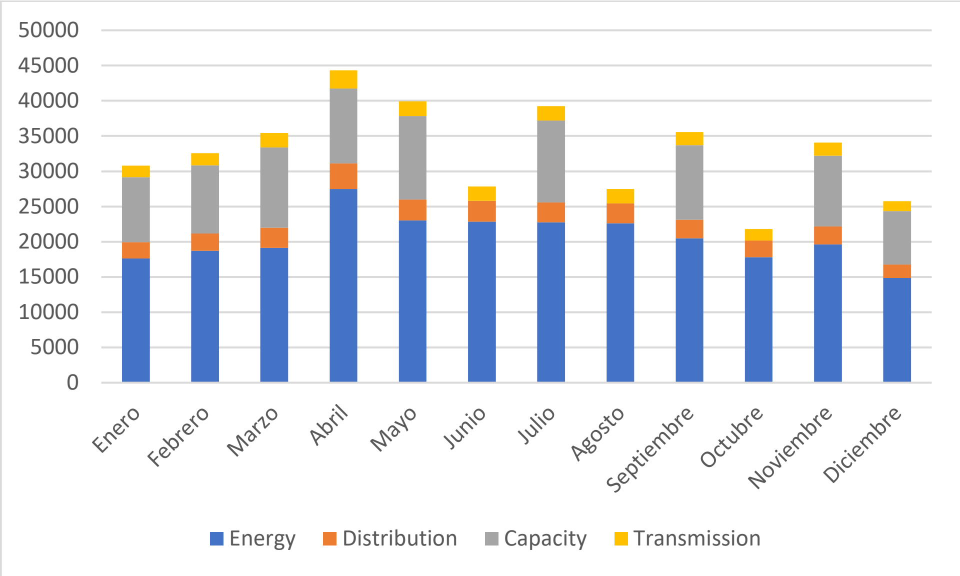

Figure 27. Monthly Savings

The total annual savings amount to $264.918 in energy costs, $32.285 in distribution charges, $92.643 in capacity charges, and $23.053 in transmission charges, adding a grand total of $349.899. This represents a 47,52% reduction in the electricity bill.

The energy injected into the grid, as calculated in this analysis, is an approximation. This approximation is based on dividing the monthly consumption data into hourly values using an arithmetic approach. Specifically, the consumption data for each period (base, intermediate, and peak) have been divided by the number of hours in each period and month.

This method assumes a constant consumption curve throughout each period, which does not accurately reflect real-world consumption patterns. In reality, energy usage fluctuates due to various factors such as operational changes, equipment usage, and external conditions. However, for the purposes of this analysis, maintaining constant consumption curves provides a simplified yet effective way to estimate the amount of excess energy that could be injected into the grid.

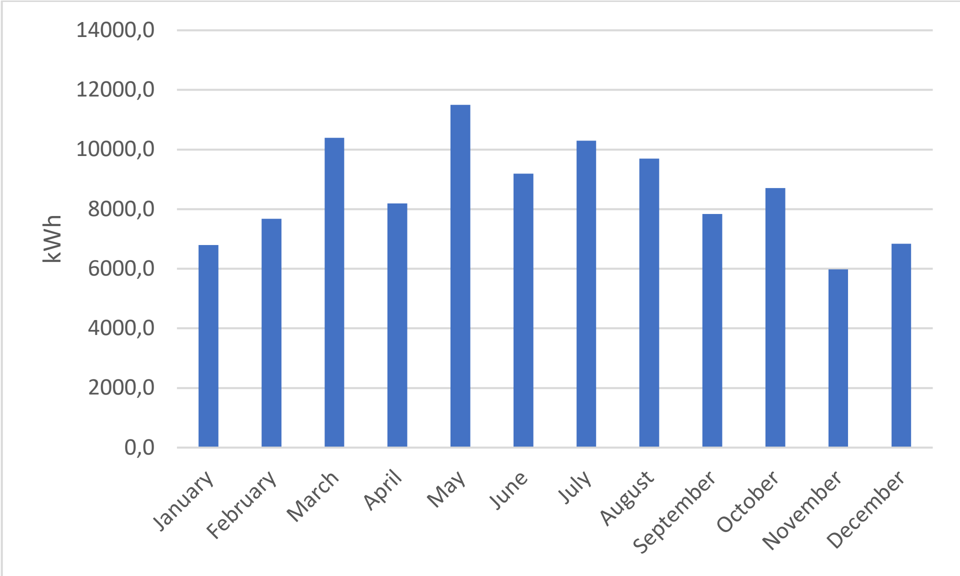

Figure 28. Monthly Excess Energy (kWh)

The revenue from excess energy is directly influenced by the LMPs, which are the prices at which the energy is sold back to the grid. LMPs fluctuate hourly based on supply and demand dynamics within the local electricity market. For this analysis, we extracted the LMPs corresponding to Querétaro Industrial for each hour of 2023 and 2024. By multiplying the excess energy for each hour by the corresponding LMP, we calculated the total income generated from the excess energy.

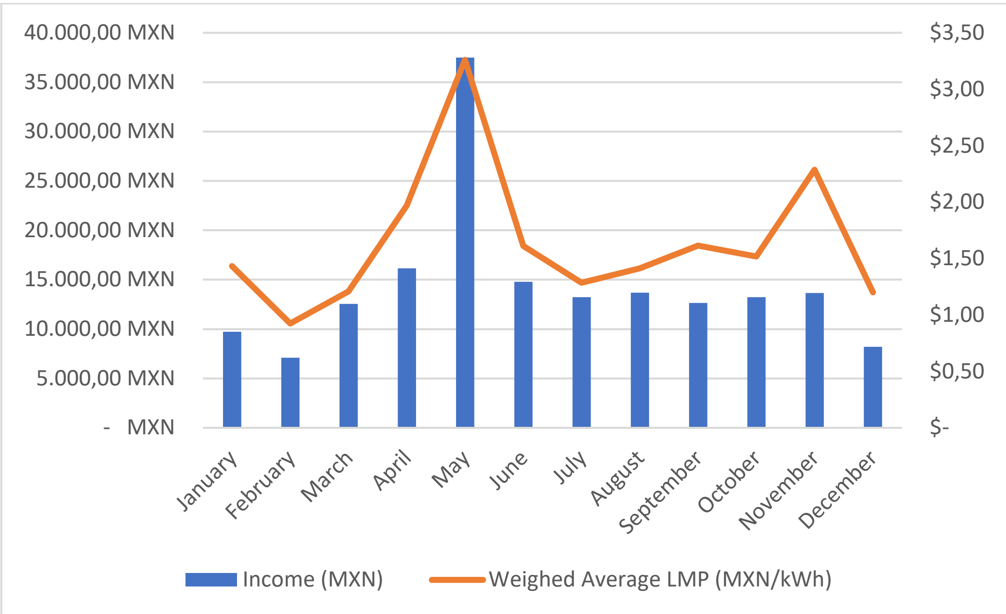

Figure 29. Monthly Income and Average LMPs

The monthly income varies, reflecting the fluctuations in both the quantity of excess energy and the LMPs. As shown in Figure 29, the highest income was recorded in May, with 37.498 MXN, due to the high volume of excess energy generated and the highest average LMPs. Overall, the total income from the excess energy injected into the grid amounts to 18.474 MXN annually.

The LMPs exhibit notable fluctuations throughout the year, as evidenced by the monthly data. In January, the LMP starts at 1,43 MXN/kWh and drops to its lowest point in February at 0,92 MXN/kWh. The peak is observed in May, where the LMP sharply rises to $3,26. The rest of the year stays relatable stable, between de $2 and $1,50 marks, except in November, where we see a slight increase in price.

5.2.2 Long-Term Financial Projections Under Continuous Net Billing with LMP Deflation

Under continuous net billing, the financial returns are largely driven by self-consumption savings. For example, in year 2, the system generates 413.704 MXN in savings from self-consumption. This figure grows steadily, reaching 1.690.781 MXN by year 25, as electricity tariff prices inflate by 6,9% annually. However, the income from selling excess energy to the grid declines each year mainly due to the 5,98% annual deflation in LMPs. In year 2, the income from selling excess energy is 158.917 MXN, but it drops to 33.896 MXN by year 25.

The total savings, which combine self-consumption savings and income from excess energy, increase over time but at a slower rate due to LMPs' constant deflation. For instance, total savings in year 2 are 572.622 MXN, while by year 25, they reach 1.724.677 MXN.

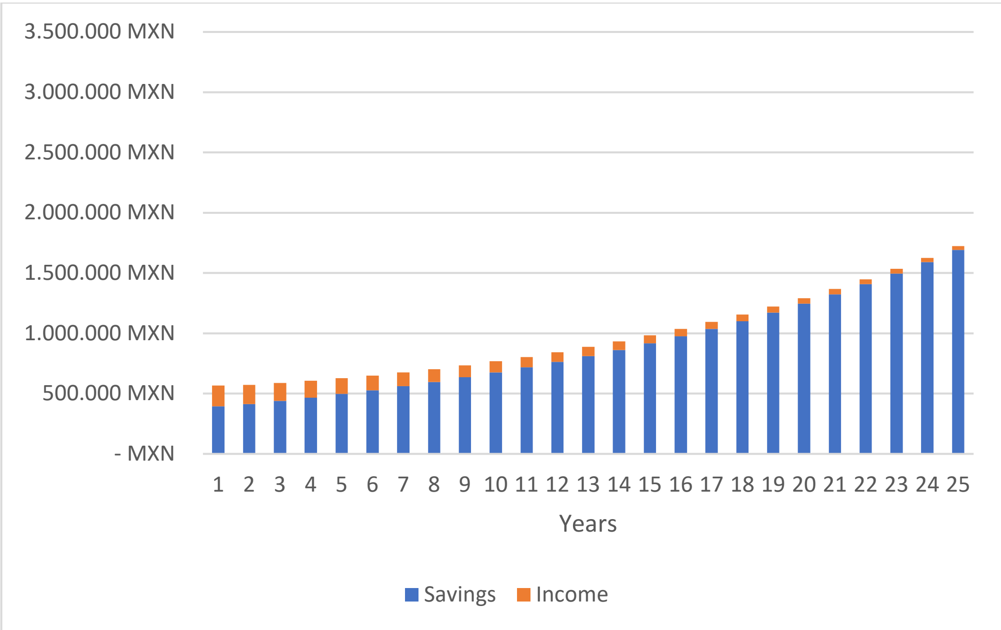

Figure 30. Scenario 5 Lifetime Savings

As shown in Figure 31, LMPs decrease steadily from 1,67 MXN/kWh in year 1 to $0,38 MXN/kWh in year 25, reducing the income generated from selling surplus energy. In contrast, maintenance costs rise significantly, starting at $27,500 in year 1 and reaching over $88,000 by year 25 due to inflation.

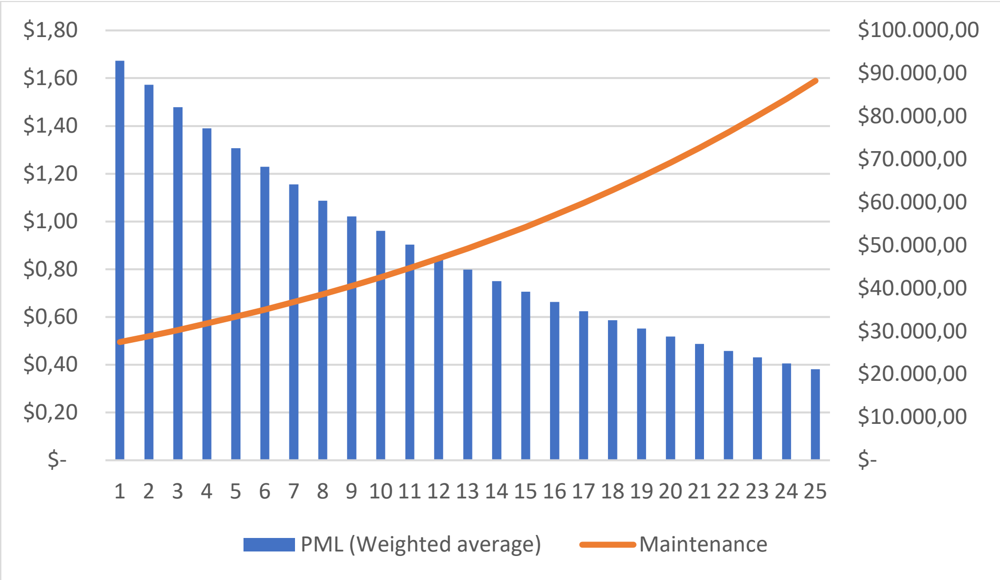

Figure 31. PMLs and Maintenance Costs Trend

Operating under continuous net billing with a 5,98% deflation in LMPs results in reduced income from excess energy sales, making self-consumption the primary source of financial returns. This highlights the importance of market conditions in the long-term financial planning of solar energy investments.

5.2.3 Long-Term Financial Projections Under Continuous Net Billing and Constant LMP

This scenario explores the financial outcomes of a PV system operating under a continuous net billing scheme with a fixed LMP of 389,5 MXN/MWh.

While maintaining a constant LMP provides predictability in income generation, the low price significantly impacts the financial performance. Even though the PV system consistently generates savings throughout its lifetime, the overall financial benefits are comparatively modest. For instance, in the second year, the client achieves savings of 413.704 MXN, with an additional income of 39.352 MXN from selling excess energy. By year 25, the savings grow to 1.690.781 MXN, and income from energy sales reaches 34.664 MXN. The income diminishes each year due to the solar panels’ degradation. The total savings and income adds up to approximately 22.318.042 MXN over the 25-year period. This is the lowest financial benefit among the scenarios where the client invests directly.

Figure 32. Scenario 6 Lifetime Savings

An important insight is that despite the LMP remaining constant, it is set at an exceptionally low level compared to other models. Notably, in the deflationary scenario, the LMP only reaches this auction-based price by the 25th year leading to reduced financial returns.

5.2.4 Long-Term Financial Projections Under Continuous Net Billing with LMP Inflation

Savings from self-consumption remain the same as in the previous section since the inflation on tariff prices does not vary. Meanwhile, income from selling excess energy to the grid increases due to the 10,31% annual inflation in LMPs. In year 2, the income is 186.447 MXN, which grows to 1.568.195 MXN by year 25. By year 25, selling the electricity generated has become more profitable than consuming it.

The total savings, which include both self-consumption savings and income from excess energy, show a consistent upward trend. For instance, total savings in year 10 amount to 1.066.130 MXN, and by year 25, they reach 3.258.976 MXN.

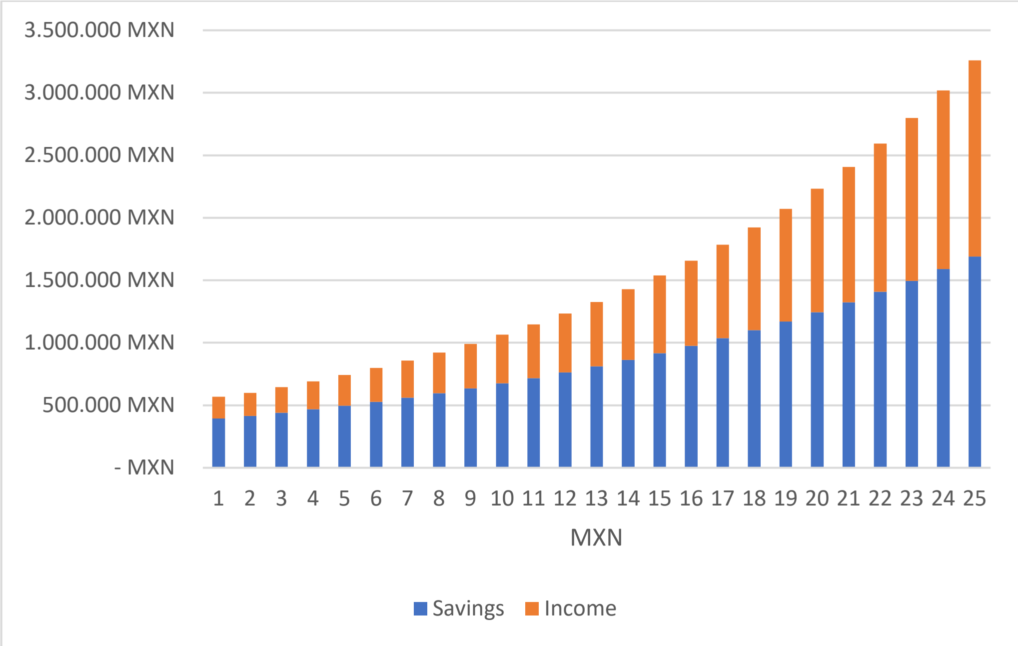

Figure 33. Scenario 7 Lifetime Savings

Figure 34 illustrates the relationship between the inflating Local Marginal Prices (LMPs) and the rising maintenance costs over the 25-year period. As shown, the LMPs increase from approximately 1,67 MXN/kWh to 17,62 MXN/kWh. This steady rise in LMPs effectively offsets the concurrent inflation in maintenance costs, which grow from 27.500 MXN in year 2 to 88.286 MXN by year 25. The alignment of these two trends suggests that the additional income generated by the inflating LMPs covers the increasing operational expenses and even increases the benefit.

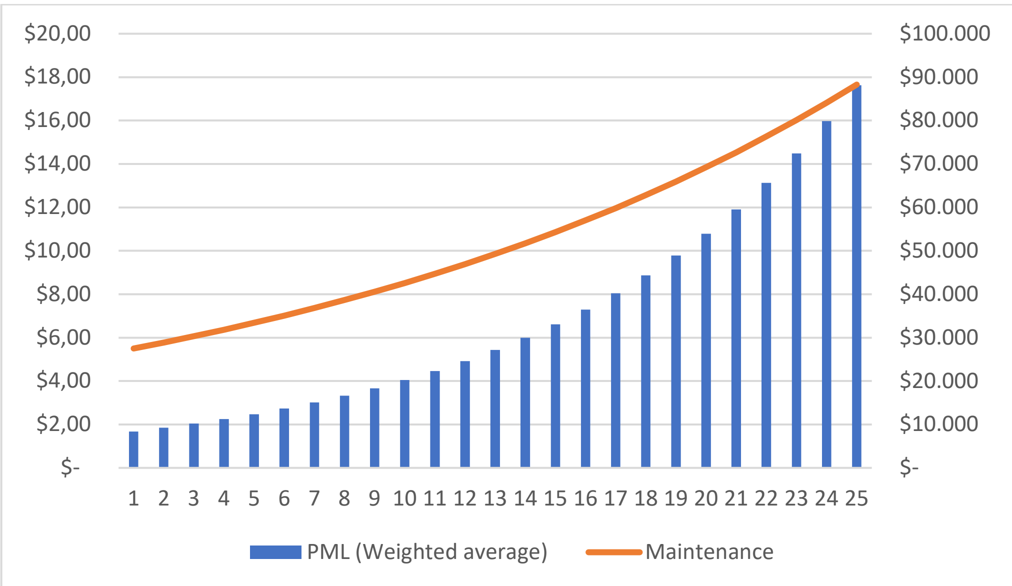

Figure 34. LMPs and Maintenance Costs Trend

5.3 PPA's Impact on billing

5.3.1. First year

In this arrangement, an investment fund finances the PV installation and sells the generated electricity to the client at a discounted rate of 30% below the standard price charged by the CFE. The PPA follows a pay-as-produced model, meaning the client only pays for the actual energy produced by the PV system.

The client agrees to purchase the electricity generated by the PV system at a rate of 2,138 MXN/kWh, which is 30% lower than the CFE's rate of 3,054 MXN/kWh. CFE's average rate was calculated using the client's historical consumption data and the applicable tariff prices mentioned earlier.

Under this arrangement, the client will now pay two separate electricity bills each month: one to the CFE for any additional energy consumed that is not covered by the photovoltaic system, and one to the investment fund for the electricity generated by the PV system under the PPA. This dual billing system ensures that the client benefits from reduced electricity costs through the discounted PPA rate while maintaining a connection to the grid for any supplementary energy needs.

The new electricity bill from the CFE will remain the same as detailed in the net metering chapter. The difference is the addition of a new bill from the investment fund under the PPA, which covers the electricity generated by the photovoltaic system. Figure 35 illustrates the current CFE bill, the new CFE bill, the additional PPA bill, and the resulting savings for each month:

	CFE – current bill	**CFE - new bill**	**PPA bill**	**Savings**
January	$63.941	$7.456	$34.468	**$22.018**
February	$64.393	$6.362	$37.505	**$20.526**
March	$66.962	$5.798	$46.940	**$14.224**
April	$96.132	$6.186	$48.796	**$41.150**
May	$86.346	$19.622	$50.255	**$16.468**
June	$50.673	$956	$44.801	**$4.915**
July	$75.673	$8.390	$46.918	**$20.365**
August	$51.959	$4.820	$45.630	**$1.509**
September	$88.501	$21.008	$39.739	**$27.754**
October	$56.929	$19.011	$38.667	**$-749**
November	$74.858	$20.064	$35.290	**$19.504**
December	$54.711	$6.653	$31.767	**$16.291**

Figure 35. Scenario 8 - First Year Results

By comparing the current CFE bill with the new CFE bill and the additional PPA bill, we observe substantial monthly savings. For instance, in January, the total savings amount to 22.018 MXN, while in April, the client saves as much as 41.150 MXN. Even though some months, such as October, may show a minor negative saving, the overall financial benefit is clear. The client consistently benefits from reduced electricity expenses, with an average significant reduction across most months, confirming the effectiveness of this scheme in lowering overall energy costs.

The total yearly savings in the PPA scheme went up to 204.022 MXN, representing a 24,55% reduction in the annual electricity bills.

While the annual savings under this combined net metering and PPA scheme are the lowest among the three schemes compared, it is important to note that the client does not have to invest any money out of pocket. Given this financial arrangement, achieving a 25% decrease in electricity bills represents a significant benefit. This reduction provides substantial financial relief without any upfront investment, making the scheme a highly attractive and cost-effective option for the client.

5.3.2 Long-Term Financial Projections

This chapter analyzes the financial performance of a PV system operating under a continuous net metering scheme from year 2 to year 25. The analysis incorporates PPA payments for the first 10 years, where the PPA tariff price is adjusted annually based on the INPC, with an average increase of 4,98%. From year 11 onwards, maintenance costs are borne by the client.

During the first 10 years, the PV system consistently generates savings by offsetting electricity costs through net metering. In year 2, for instance, the system produces 229,54 MWh, resulting in savings of 680.631 MXN. After deducting the PPA costs of 515.159 MXN, the adjusted savings for year 2 stand at 194.342 MXN.

The PPA tariff, which escalates yearly in line with the INPC, results in growing PPA costs—rising from 500.729 MXN in year 1 to 727.253 MXN by year 10. Despite these increasing costs, the savings continue to outpace the PPA payments, ensuring positive financial returns. By year 10, the savings reach 1.115.157 MXN, with an adjusted savings after PPA costs of 430.492 MXN, demonstrating the system's robust performance under net metering.

From year 11 onwards, the client is no longer responsible for PPA payments but must cover the maintenance costs directly. These costs begin at 44,709 MXN in year 11, escalating to 88,286 MXN by year 25 due to inflation. Simultaneously, the savings from self- consumption continue to grow, driven by the increasing electricity prices.

For example, in year 11, the system generates 218,43 MWh, leading to savings of 1.186.113 MXN. After accounting for maintenance costs, the adjusted savings are 1.141.404 MXN. By year 25, the system's savings grow to 2.811.396 MXN, with maintenance costs reducing this to 2.723.110 MXN.

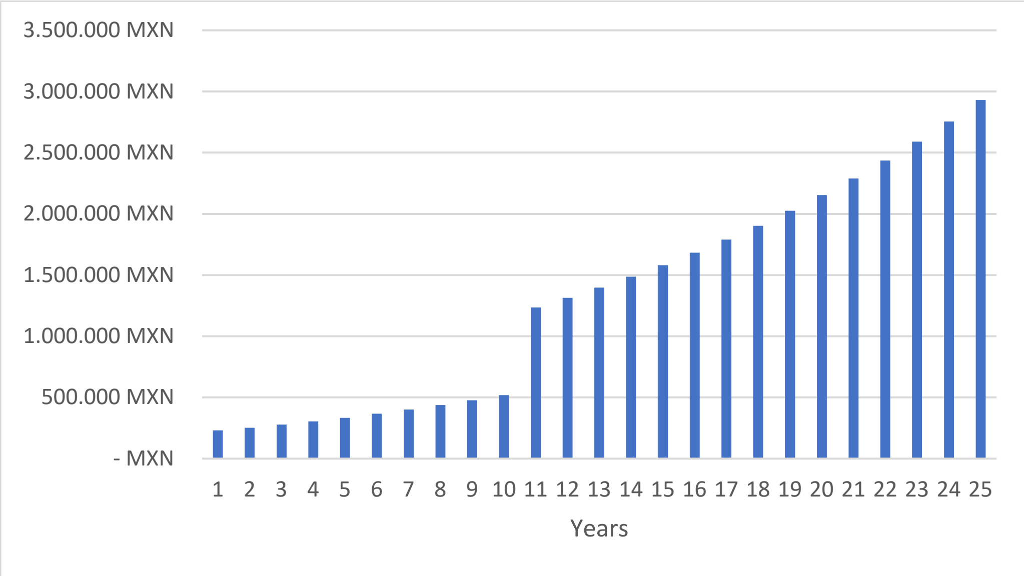

Figure 36. Scenario 8 Lifetime Savings

Figure 36 illustrates the yearly savings. Over the 25-year period, the total savings amount to 36.993.952 MXN, with PPA payments totaling 6.043.689 MXN. After deducting the PPA costs, the adjusted savings for the first 10 years are 30.332.520 MXN. This analysis confirms that the PV system remains a financially sound investment, providing substantial savings and financial stability over its operational life.

5.4. Leasing's impact on billing

5.4.1. First year

In this scenario, the client enters into a financial leasing agreement for the PV system, paying a fixed monthly fee regardless of the actual energy produced by the system. Unlike a PPA, where payments are made based on the actual energy generated, financial leasing provides predictability with a set monthly cost. This analysis compares the client's current electricity bills from the CFE with the new bills after applying the PV system under the leasing model.

The financial leasing model ensures that the client has a steady monthly expense, which simplifies budgeting and financial planning. Each month, the client pays the leasing company a fixed fee of 34.430 MXN. This fee is not tied to the PV system's production, meaning the client's savings are determined by the difference between the reduced CFE bill and the leasing cost.

The new electricity bill will remain the same as detailed in the net metering chapter. Figure 37 portrays the current CFE bill, the new CFE bill, the additional PPA bill, and the resulting savings for each month.

	CFE - current bill	**CFE - new bill**	**Leasing bill**	**Savings**
January	$63.941	$7.456	$34.430	**$22.055**
February	$64.393	$6.362	$34.430	**$23.600**

March	$66.962	$5.798	$34.430	**$26.733**
April	$96.132	$6.186	$34.430	**$55.515**
May	$86.346	$19.622	$34.430	**$32.293**
June	$50.673	$956	$34.430	**$15.286**
July	$75.673	$8.390	$34.430	**$32.853**
August	$51.959	$4.820	$34.430	**$12.709**
September	$88.501	$21.008	$34.430	**$33.063**
October	$56.929	$19.011	$34.430	**$3.488**
November	$74.858	$20.064	$34.430	**$20.363**
December	$54.711	$6.653	$34.430	**$13.628**

Figure 37. Scenario 9 - First Year Results

Figure 37 illustrates the significant impact of adopting a financial leasing model for a PV system on the client's electricity costs over the first year. Notably, the total savings amount to 291.585 MXN, representing a 35,1% reduction in electricity expenses compared to the current billing scenario without PV intervention. These savings already discounted the leasing bill paid to the investment fund. Particularly in months with higher initial electricity consumption, such as April and September, the savings are more pronounced, with reductions of 55.515 MXN and 33.063 MXN respectively.

In contrast with the PPA model, the table also reveals that while the leasing model consistently delivers cost savings throughout the year, the extent of savings varies by month. For instance, in October the savings drop to just 3.488 MXN.

5.4.2 Long-term financial projections

This chapter provides an analysis of the financial performance of a PV system under a financial leasing arrangement over a 25-year period, with a consistent net metering scheme applied throughout. The leasing agreement is set for a duration of 10 years, with the monthly leasing fee indexed to the INPC, which has an average increase of 4.98%. During this period, the investment fund covers all maintenance costs, ensuring that the client only needs to pay the set leasing fee. After the 10-year leasing period ends, the responsibility for maintenance costs shifts to the client, who continues to benefit from the savings generated by the PV system.

Starting in year 2, the PV system generates 229,54 MWh, leading to savings of 738.310 MXN. After accounting for the leasing costs of 433.741 MXN, the adjusted savings for year 2 stand at 304.570 MXN. The leasing costs, which increase annually in line with the INPC, rise from 413.165 MXN in year 1 to 639.858 MXN by year 10. Despite these rising costs, the savings consistently exceed the leasing payments, ensuring a positive financial return each year. By year 10, the savings amount to 1.204.756 MXN, with adjusted savings after leasing costs reaching 564,899 MXN, illustrating the system's strong financial performance under the leasing arrangement.

From year 11 onward, with the leasing contract concluded, the client assumes responsibility for the maintenance costs. These costs start at 44.709 MXN in year 11, increasing to 88,286 MXN by year 25, due to inflation. Despite this new financial responsibility, the savings from self-consumption continue to grow, fueled by increasing electricity prices. For example, in year

11, the system generates 218,43 MWh, resulting in savings of 1.280.800 MXN. After deducting the maintenance costs, the adjusted savings are 1.236.091 MXN. By year 25, the system's savings grow to 3.017.424 MXN, with maintenance costs reducing this to 2.929.138 MXN.

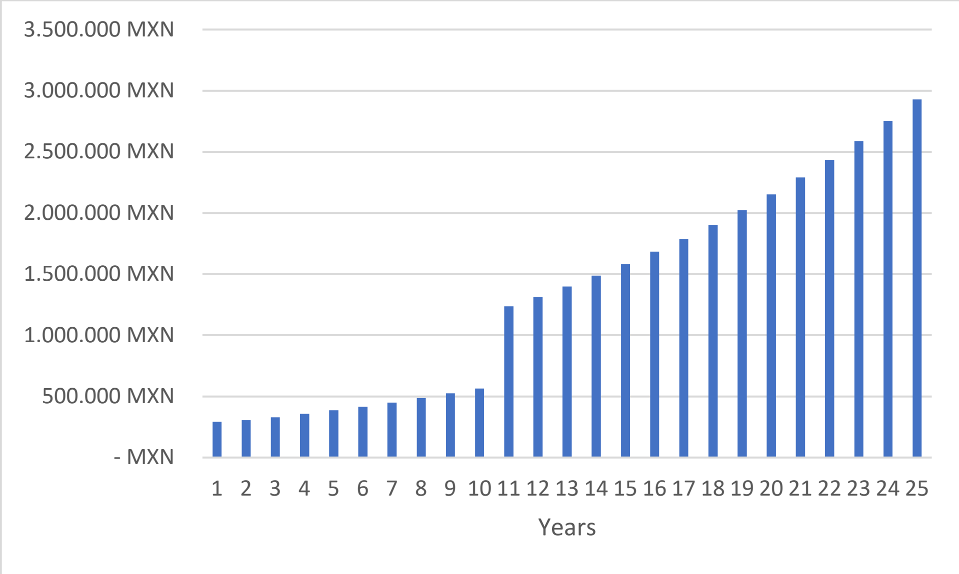

Figure 38. Scenario 9 Lifetime Savings

Over the 25-year period, the total savings amount to 39.829.518 MXN. The leasing costs incurred during the first 10 years total 5.191.900 MXN, resulting in adjusted savings of 33.674.306 MXN. This analysis confirms that the PV system, under a financial leasing arrangement, remains a financially viable investment. The system not only covers its costs but also provides substantial savings, contributing to long-term financial stability for the client. As the graphs show, the increasing savings and relatively stable maintenance costs after the leasing period further underscore the financial soundness of this approach.

5.5. Economic Ratios

The purpose of this chapter is to provide a comprehensive comparison of the financial benefits obtained from the different solar energy schemes analyzed in this study. By examining the key metrics such as Net Present Value (NPV), Internal Rate of Return (IRR), and the payback period, we aim to highlight the economic advantages and feasibility of each scheme for the client.

Scenario 1 represents a pure net-metering scheme, where the client benefits from retail rate offsets for surplus energy. Scenarios 2, 3, and 4 begin as net-metering but transition to net billing in year 7, with each scenario reflecting different trends in Local Marginal Prices (LMPs): a deflation rate of 5,98%, a constant LMP, and an inflation rate of 10,31%, respectively. Scenarios 5, 6, and 7 are strictly net billing from the start, with Scenario 5 assuming a 5,98% deflation in LMPs, Scenario 6 holding LMPs constant, and Scenario 7 assuming a 10,31% inflation rate.

The Internal Rate of Return (IRR) is highest in Scenario 1, at 45%, due to the full benefit of net metering. In Scenarios 2, 3, and 4, the IRR slightly decreases to 42%-44% due to the transition to net billing after year 6. Scenario 5, with a deflating LMP under net billing, sees a reduced IRR of 34%, while Scenario 6 with constant LMPs has the lowest IRR at 29%. Scenario 7 benefits from increasing LMPs, achieving an IRR of 38%. All IRRs obtained are shown in Figure 39.

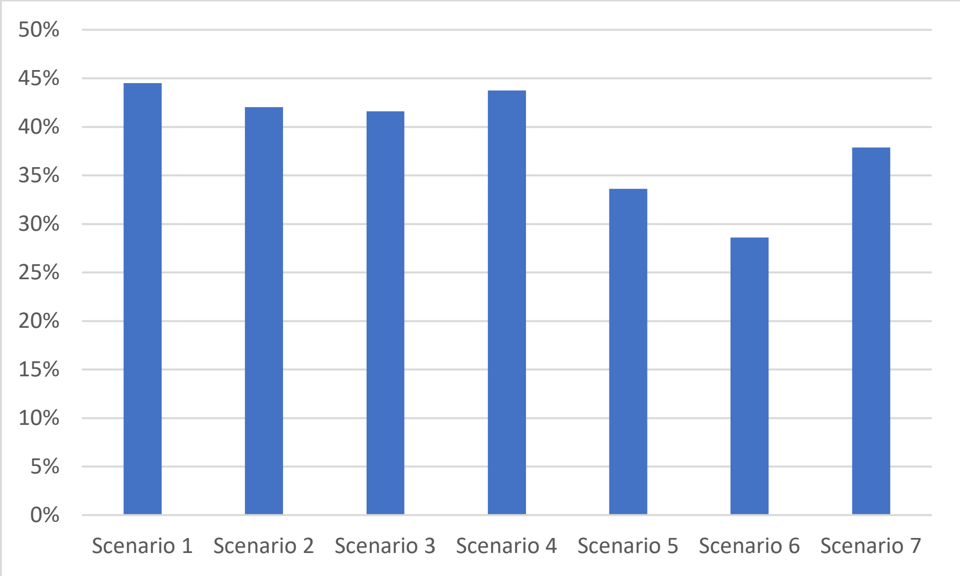

Figure 39. IRRs Comparison

Notably, the payback period remains consistent at 2,5 years across all net metering scenarios due to the investment being recovered while the net-metering is still applicable. The payback period extends to 3-4 years in the net billing-only scenarios, reflecting the reduced financial benefits due to lower or constant LMPs. Figure 40 compares the payback period of each self-finance scenario.

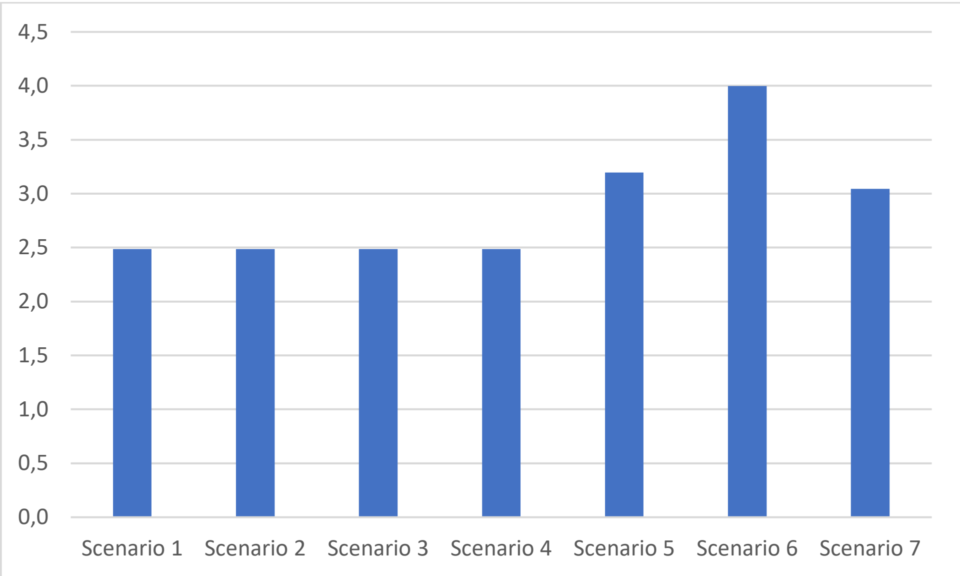

Figure 40. Payback Period Comparison

5.6. Total Savings and NPV

In this chapter, we will compare the Net Present Value (NPV) and total savings of nine different scenarios that examine the financial performance of a PV system under varying conditions. Scenarios 1 through 7 involve different configurations of net metering and net billing schemes, with adjustments based on LMP trends. Scenarios 8 and 9 introduce financing options where the client does not invest capital upfront; Scenario 8 represents a PPA model, and Scenario 9 represents a leasing model.

The NPV was calculated using a discount rate of 4,98% (in line with the INPC) and assuming the client has the enough disposable capital to invest upfront. NPV reveals distinct financial outcomes across the nine scenarios.

Scenario 1 yields the highest NPV of approximately 16,12 million MXN, demonstrating its financial robustness when the client invests capital upfront. Scenario 4 follows closely with an NPV of 15,58 million MXN, while Scenario 7 achieves a strong NPV of 14,89 million MXN. These figures highlight the benefits of investing in scenarios where energy prices or LMPs are expected to rise over time. On the other hand, scenarios reflecting lower or constant LMPs, such as Scenario 6 and Scenario 5, show significantly lower NPVs of 8,53 million MXN and 9,36 million MXN, respectively.

The financing scenarios, represented by Scenario 8 and Scenario 9, demonstrate NPVs of 13,75 million MXN and 14,29 million MXN, respectively, which are only slightly lower than Scenario 1's NPV of 16,12 million MXN, where net metering is consistently applied throughout the 25 years. This minimal difference in NPV highlights that while the client achieves nearly the same financial benefit, they do so without the need for any upfront capital investment. This is a significant advantage for companies looking to improve their cash flow or those who prefer to allocate their capital to other areas of their business. The ability to avoid a large initial expenditure while still securing substantial long-term savings makes financing options like PPA and leasing particularly attractive in the current economic environment. Figure 41 shows the NPV result of each scenario.

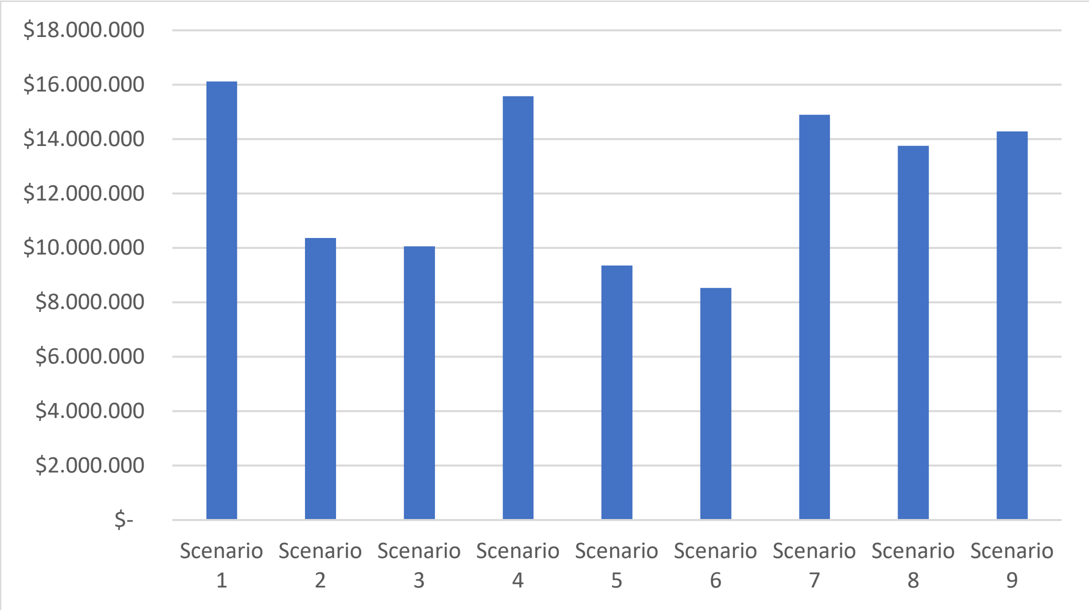

Figure 41. NPVs Comparison

When analyzing total savings, Scenario 1 again stands out with 36,77 million MXN, making it the most beneficial option for clients who can invest directly. Scenario 4 follows closely with 36,09 million MXN, and Scenario 7 delivers 35,24 million MXN, further reinforcing the financial advantages of scenarios with rising LMPs or continuous net metering.

Scenarios involving financing show promising savings. Scenario 9 yields 33,67 million MXN while Scenario 8 yields 32,95 million MXN. While these figures are slightly lower than the best investment scenarios, they highlight the attractiveness of these financing options for clients who may want to avoid initial expenditure while still reaping considerable financial benefits over the long term. Figure 42 shows total savings for all 9 scenarios.

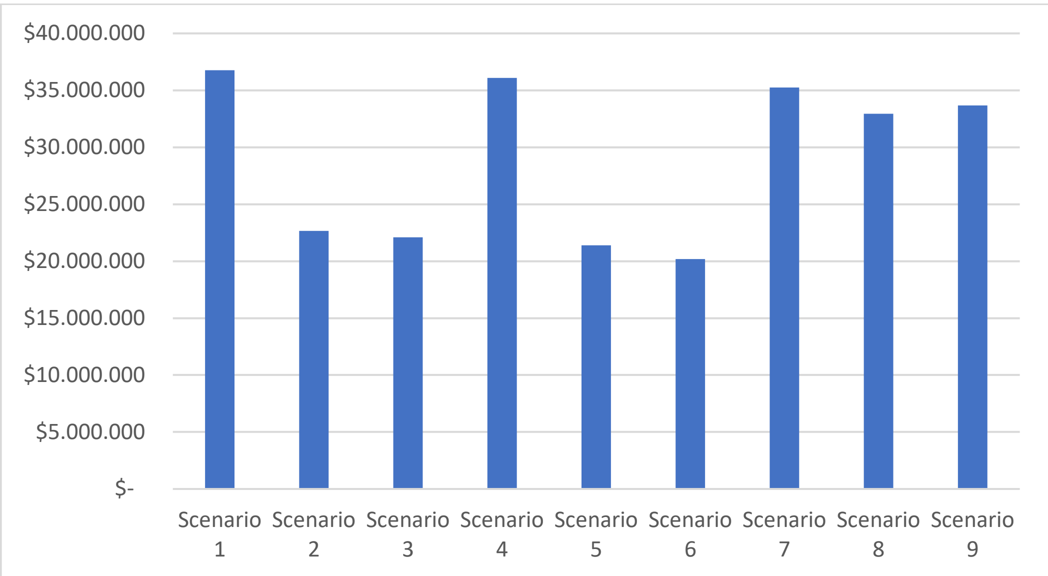

Figure 42. Total Savings Comparison

6. Conclusion

The primary goal of this research is to evaluate the financial viability and overall performance of various solar energy procurement models available to large industrial consumers in Mexico. The analysis focused on three main financing schemes: self-financed solar energy systems (Scenarios 1 to 7), PPA (Scenario 8), and leasing options (Scenario 9). Specifically, the study aimed to identify the most cost-effective and practical model that aligns with Mexico's evolving energy market conditions, considering factors such as LMPs, tariff inflation, and political risks associated with each procurement model.

To evaluate the financial viability of solar energy investments, several key risks were considered. Volumetric risk refers to the variability in solar energy production due to changes in solar irradiance. To address this, data from Meteonorm was used to provide accurate projections of energy generation. Price fluctuation risk was also analyzed through different scenarios with varying trends in LMPs, highlighting the impact on financial outcomes, particularly in net-billing schemes. Political risk was considered by incorporating scenarios where net-metering could shift to net-billing due to potential regulatory changes, which would reduce financial returns. Credit risk, though more relevant to investors, was acknowledged but not a focus, as the analysis centered on the client's perspective. Finally, consumption risk was addressed by designing the PV plant to cover 86% of the client's energy needs, providing a buffer against reduced consumption. Also, the expected degradation of solar panels over time will increase the buffer over time.

In terms of Net Present Value, Scenario 1, which applied net-metering throughout the 25-year project lifespan, delivered the highest NPV at 16,12 million MXN. This reflects the substantial financial benefits of maintaining a consistent net-metering approach over the long term. On the other hand, Scenario 6, representing net billing with constant LMPs, yielded the lowest NPV at 8,53 million MXN.

Regarding total savings, Scenario 1 again achieved the highest result, with total savings of 36,77 million MXN, emphasizing the strong financial returns of continuous net-metering. In contrast, Scenario 6 resulted in the lowest total savings at 20,12 million MXN.

On the other hand, the financing options—PPA (Scenario 8) and leasing (Scenario 9)—while slightly less profitable for the consumer in terms of NPV compared to Scenario 1, offered the advantage of requiring no upfront investment. The financial benefits from these scenarios were relatively close to those achieved under continuous net-metering, demonstrating that financing schemes can be a viable alternative for clients without the capital to invest in solar energy projects.

The payback period analysis across the seven scenarios shows varying levels of investment recovery time. Scenarios 1 through 4, which maintain net metering throughout the project or transition from net metering to net billing after six years, all display the shortest payback period of 2,5 years. On the other hand, Scenario 6, which represents a constant LMP under a net billing scheme, exhibits the longest payback period of 4,0 years, highlighting the slower rate of investment recovery when net-billing is applied and electricity prices are stable.

The Internal Rate of Return greatly varies across the seven scenarios. Scenario 1, which maintains net metering throughout the project's 25-year duration, achieves the highest IRR at 45%, indicating the most efficient capital investment return under stable and favorable conditions. Close behind, Scenario 4, which transitions to net billing with a 10.31% increase in LMP, yields an IRR of 44%, showing that rising electricity prices can closely match the returns of continuous net metering. The lowest IRR is found in Scenario 6, at 29%, where the constant LMP under net billing results in the least favorable investment conditions, significantly reducing the efficiency of capital returns.

The findings suggest that for companies with the ability to finance solar energy systems upfront, net-metering offers the highest financial returns, particularly when it can be maintained over the long term. However, in scenarios where capital investment is a barrier, financing through PPA or leasing can still provide substantial savings with lower financial risk. The results emphasizes the importance of LMP trends and tariff inflation in determining the financial outcomes of solar energy investments, which should be a key consideration for companies in decision-making processes. Moreover, this study highlights the potential for significant cost savings and environmental benefits, reinforcing the value of solar energy adoption in Mexico's industrial sector.

Based on the findings, companies that have sufficient capital should prioritize self-financed net-metering schemes to maximize their financial returns. However, for those unable to invest upfront, PPA and leasing offer viable alternatives that still deliver considerable savings. It is recommended that companies continuously monitor LMP trends and policy developments to optimize their energy strategies. Further research could explore new financing models and assess the impact of emerging energy technologies on long-term financial viability.

This study assumed stable energy consumption patterns and did not fully explore the impact of potential future regulatory changes that could alter the financial landscape for solar energy projects. Additionally, the analysis was based on current and historical LMP and tariff data, which may not fully capture future market dynamics or external factors such as geopolitical events or technological advancements that could affect energy prices. Further research could be focused on the investor’s perspective and their return on each of the available financing schemes.

This research provides valuable insights into the financial benefits of various solar energy procurement models in Mexico, offering a clear guide for industrial consumers navigating the complexities of the energy market. By understanding the financial implications of each model, companies can make informed decisions that contribute not only to their financial stability but also to the broader goal of sustainable energy adoption in Mexico.

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