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Designing an optimal electricity supply portfolio based on the Markowitz model: The case of a user in Mexico

Diseño de un portafolio óptimo de suministro eléctrico a partir del modelo de Markowitz: el caso de un usuario en México

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Abstract

The Energy Reform in Mexico, which was started in 2013, opened the possibility that electrical energy consumers could choose the supply from any supplier participating in the market. The objective of this work is to validate that Markowitz Model is useful in the construction of an optimal portfolio of electricity supply, from the options available in the Mexican Electricity Market. A hypothetical case, based on real information, was built and the results obtained in the case of study shows that the use of this methodology allows to mitigate risks, from the diversification of supply options, as is the case of the diversification of investment alternatives. This approach constitutes an alternative for consumers of electrical power to plan and design optimal portfolios of electricity supply.

JEL Code: C6, G0, Q4
Keywords: Markowitz model; Optimal portfolio of energy supply

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Resumen
La Reforma Energética de México, promulgada en el año 2013, abrió la posibilidad para que consumidores de energía eléctrica pudieran elegir entre diferentes opciones de suministro. Por lo anterior, el objetivo de este trabajo es validar que el Modelo de Markowitz es útil en la construcción de un portafolio óptimo de suministro de energía eléctrica, a partir de las opciones disponibles en el mercado eléctrico mexicano. Se construyó un caso hipotético, a partir de información real, y los resultados obtenidos en el caso de estudio muestran que el uso de esta metodología permite mitigar los riesgos, a partir de la diversificación de opciones de suministro, tal y como ocurre con la diversificación de alternativas de inversión. Este enfoque constituye una alternativa objetiva para que los usuarios de energía eléctrica planeen y diseñen portafolios óptimos de suministro.

Código JEL: C6, G0, Q4
Palabras clave: Modelo de Markowitz; Portafolio óptimo de suministro eléctrico

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Introduction

As a result of the Energy Reform [*Cámara de Diputados del H. Congreso de la Unión*, (2013)] in Mexico, the Electricity Industry Law [*Cámara de Diputados del H. Congreso de la Unión* (2014)] was passed, creating a Wholesale Electricity Market that allows a user to access the supply of electricity, and its associated services, from any duly accredited generator.

In parallel, and for several years, the Legacy Interconnection Contracts would coexist. These were permits obtained by energy generators before the decree of the Electric Industry Law in 2014, under the modality of self-supply or cogeneration, schemes with which they have the possibility of selling electric energy to third parties.

Although this scenario opened up opportunities for a company to contract an energy supply service that offers savings compared to its current supplier, there is also a risk that the savings will not be as expected, given the price volatility over five- or ten-year periods, typical of electricity supply contracts.

The generation of electricity is done through sources such as natural gas, water, sun, wind, geothermal elements of the earth, among others. Each of these sources has triggered a particular process of energy generation with its own cost structure, which translates into a price dynamic for each alternative. The generation process through a combined cycle, from natural gas, would have a relatively low initial investment cost, compared to the operating expense that would be linked to the cost of natural gas, which is the generation fuel.

In wind or solar generation, the cost of the initial investment is high while operating expenses are low. This translates into a generation cost that is dependent on the cost of financing the initial investment, which would be relatively stable.

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It should be noted that at least in the first few years after the Energy Reform, the Federal Electricity Commission will continue to be a multi-user supplier simply because it offers energy and backup power, as well as a guarantee of continuity of supply.

It is possible to think that a direct solution for a user would be to choose the lowest cost option, however, this alternative could have a risk associated with volatility in fuel prices, which is what would happen, for example, if the energy supply of a supplier that has a combined cycle generation plant were selected, since its rate is fundamentally linked to the cost of gas.

In terms of this context, the objective of this research work is to propose an analysis methodology based on the Markowitz Model (1952), which allows choosing electricity supply options at the lowest cost and with the least risk.

Review of the Literature

Awerbuch and Berger (2003) utilized the Markowitz Model (1952) to evaluate electricity generation projects in the European Union, including both conventional (coal, oil, gas, and nuclear) and renewable (in this case, wind) technologies.

For his part, Awerbuch (2006) analyzes the case of the European Union and adds two more case studies, one in the United States and one in Mexico. He concludes that the Markowitz Model is a better alternative for planning a mix of power generation sources than a lower cost analysis, considering each option separately. The Markowitz Model helps identify the least risky mix.

DeLaquil, Awerbuch, and Stroup (2005) used the Markowitz Model in the planning of electricity in the State of Virginia in the United States. At the time of the analysis, the mix of generation sources was dominated by hydrocarbons, mainly natural gas, which at that time had high volatility and high cost.

Awerbuch, Jansen, Bursken, and Drennen (2005) utilize the Markowitz Model to show that including geothermal and renewable generation in the mix of electricity generation in the western region of the United States—the generation tradition of which is of fossil origin—favors risk reduction in the cost of electricity.

Woo, Horowitz, Horii, and Karimov (2004) propose the use of the Markowitz Model for the purchase of energy coverages, for an electricity trader who wants to keep costs and risks low.

Lesser, Lowengrub, and Yang (2007) submitted an analysis of electric power generation mixes for the year 2020 to the California State Energy Commission. The analysis used an optimization study based on the Markowitz Model. This work concludes that the involvement of non-fuel technologies can help reduce the cost and risk of the generation portfolio in California. The use of the Markowitz Model makes it possible to analyze the interrelationship of cost and risk of electricity generation alternatives.

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Huisman, Mahieu, and Schlicther (2007) propose using the Markowitz Model as a measure of coverage in day-ahead energy markets, selecting the appropriate peak and off-peak contracts, which provide coverage in price and volume, depending on the aversion or propensity to risk of the buyer.

Beltrán (2009) used the Markowitz Model to evaluate the electric power generation portfolio of Mexico. The study compares the costs and variance of different generation options, including hydropower, combined cycle, coal, nuclear, wind, fuel oil, and geothermal, among others. The author concludes that using lower cost methods to analyze each generation option separately may entail missing opportunities for lower risk, which does not occur if they are analyzed as a portfolio.

On the other hand, Roques, Hiroux, and Saguan (2010) used the Markowitz Model to analyze the effect of the geographical diversity of wind generation fields located in five European countries (Austria, Denmark, France, Germany, and Spain). It was concluded that the Markowitz Model is a tool that can help in the best planning of a wind generation system.

In order to optimize the generation mix in Belgium, Delarue, De Jonghe, Belmans, and D'haeseleer (2009) suggest a model in which the initial cost is distinguished from the variable cost of operation (including maintenance, fuels, and operation in general), unlike other models in which a levelled cost is used. In this way, a portfolio of alternatives is analyzed with sources such as nuclear, coal, gas, oil, and wind. It was concluded that by adding wind generation to the portfolio its risk decreases.

Roques, Newbery, and Nuttall (2007) use simulation techniques and the Markowitz Model to assess the impact of fuel price, electricity, and CO2 emission risks to demonstrate the usefulness of diversification for an investor.

Liu and Wu (2010) made an analysis from the perspective of a generator, using the Markowitz Model. The approach suggests that there are two ways of managing risk in energy trade, through diversification and through hedging. The study concluded that by using the Markowitz Model it is possible to control risk by making the relevant allocation in the different marketing options, through the wholesale market and through bilateral contracts. The optimal solution would be the one that gives the best rate of return for a given level of risk.

Rodoulis (2010) utilizes the Markowitz Model to analyze the feasibility of using natural gas, wind energy, and coal, together with oil, which until then was the main source of electricity generation in Cyprus. The objective was to determine which generation portfolio mix would give the best cost-risk ratio for the island. It was concluded that the planned diversification of power generation sources helps to reduce the portfolio risk generated by oil price fluctuations.

Yan (2011) uses the Markowitz Model to develop the proposal for an energy portfolio, considering social cost as a fundamental element for consumers and regulators, in the case of the United States.

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Cucchiella, D'Adamo, and Gastaldi (2012) applied the Markowitz Model to analyze different renewable energies in the Italian market. They concluded that it is possible to diversify the sources of energy generation with renewable ones, mitigating portfolio return risk.

Ziegler, Schmitz, and Weber (2012) analyzed the German domestic market through the Markowitz Model to find the optimal generation portfolio. For the analysis they used the average net present value, based on the modeling of fuel prices.

Lüttgens and Antons (2013) combine a qualitative management model of technology portfolios with the Markowitz Model to evaluate an energy generation portfolio, highlighting the value from a holistic perspective, not purely qualitative and not purely in risk evaluation.

In an analysis of the case of Albania, where 100% of electricity was generated by hydraulic sources, Tola (2015) compared wind and photovoltaic sources in the same portfolio. This comparison made it possible to visualize how the diversification of energy generation sources had an effect on risk reduction, the way it happens when considering a portfolio of financial assets.

Similarly, De Llano Paz, Calvo Silvosa, and Portos García (2012) used the Markowitz Model in a case in Spain.

Kumar, Mohanta, and Reddy (2015) analyzed information from the Indian electricity market with the aim of optimizing a portfolio of electricity generation alternatives that represents the lowest price, given a certain level of risk and a certain level of CO_2 emissions. In line with other studies, it is concluded that considering different electricity generation options reduces the risk associated with variations in fuel prices for certain technologies.

A study carried out in the United Kingdom by Adams and Jamasb (2016) analyzed the generation portfolio that should be in place to ensure the supply of electricity. Using the Markowitz Model, they analyzed the portfolio that includes generation through gas (combined cycle), nuclear, coal, and wind, considering the investment, fuel, and, CO_2 bonus costs. It was concluded that a diversified mix can mitigate the risk associated with the uncertainty of electricity price, fuel costs, and carbon offset costs. This study proved that considering a portfolio of wind and photovoltaic sources as a complement to hydraulic generation may be adequate to reduce the risk.

Finally, Gökgöz and Atmaca (2016) compared methodologies, based on the Markowitz Model, in an analysis to maximize return and minimize risk in the electricity market in Turkey. The price information for the day-ahead was analyzed and compared with the generation cost of that same hour to calculate the return; this was done on an hourly basis. Each of the 24 hours of the day is considered an asset in the study. With the proposed methodologies, the hours with the most weight in the optimal portfolio are obtained. The authors recognized that the Markowitz Model was valuable to support investment decision making and to define regulations in an electricity market.

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This literature review showed different areas within the electricity sector in which the Markowitz Model has been used. By virtue of the above, the objective of this work was to use these concepts to conform an optimal portfolio of electrical energy supply from the perspective of a user in Mexico. With this approach it is intended that users, instead of only making decisions based on the minimization of costs, consider, at the same time, the relevant risk considerations in order to strengthen the decision-making process on the supply of electricity.

Methodological Framework

The Markowitz Model (1952) proposes, as an analysis and decision strategy, an essentially statistical and mathematical methodology, also known as media-variance analysis, to seek the best investment strategy, from the perspective of an investor, to balance profits and mitigate risks.

Markowitz (1952) defines that the expected yield from an investment portfolio is given by:

$$E(R_P) = E\left(\underset{\sim}{\mathbf{w}}^{\mathrm{T}}\underset{\sim}{\mathbf{R}}\right) = \underset{\sim}{\mathbf{w}}^{\mathrm{T}}E\left(\underset{\sim}{\mathbf{R}}\right) = \begin{pmatrix} w_1 & w_2 & \cdots & w_n \end{pmatrix}\begin{pmatrix} E(R_1) \\ E(R_2) \\ \vdots \\ E(R_n) \end{pmatrix} \quad (1)$$

Where $\underset{\sim}{\mathbf{w}}$ is the weighting vector, the elements of which represent the ratio to be invested in each of the n financial instruments that make up the portfolio, while $E(\underset{\sim}{\mathbf{R}})$ is the expected yield vector, in which each element represents the expected yield of each instrument in the portfolio.

The standard deviation of portfolio yields, which is normally a measure of portfolio volatility, is given by:

$$\sigma_P = \sqrt{Var(R_P)} = \sqrt{\underset{\sim}{\mathbf{w}}^{\mathrm{T}}Var(\underset{\sim}{\mathbf{R}})\underset{\sim}{\mathbf{w}}} \quad (2)$$

Where $Var(\underset{\sim}{\mathbf{R}})$ is the matrix of variances and covariances of the yields associated with the instruments that make up the portfolio.

From this context, it is clear that the main objective of the analysis of an investment portfolio, based on these ideas, is to maximize its return, assuming a certain level of risk or volatility or to minimize the volatility by accepting a certain level of return. These ideas are expressed below as quadratic programming models:

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$$\begin{aligned} &Max\ E(R_P) \equiv Max\ \underset{\sim}{\mathbf{w}}^{\mathrm{T}} E(\underset{\sim}{\mathbf{R}}) \\ &\text{Sujeto a:} \\ &\sigma_P = \sqrt{Var(R_P)} = \sqrt{\underset{\sim}{\mathbf{w}}^{\mathrm{T}} Var(\underset{\sim}{\mathbf{R}}) \underset{\sim}{\mathbf{w}}} = \sigma \\ &\underset{\sim}{w}^T \underset{\sim}{1} = 1 \end{aligned} \quad (3)$$

$$\begin{aligned} &Min\ \sigma_P = \sqrt{Var(R_P)} = \sqrt{\underset{\sim}{\mathbf{w}}^{\mathrm{T}} Var(\underset{\sim}{\mathbf{R}}) \underset{\sim}{\mathbf{w}}} \\ &\text{Sujeto a:} \\ &E(R_P) = \underset{\sim}{\mathbf{w}}^{\mathrm{T}} E(\underset{\sim}{\mathbf{R}}) = \mu \\ &\underset{\sim}{w}^T \underset{\sim}{1} = 1 \end{aligned} \quad (4)$$

According to the Markowitz Model (1952), the diversification of an investment portfolio makes it possible to reduce the variance of the expected yield of the portfolio, given the correlation between the yields of the instruments considered. However, the portfolio that reduces the yield variance is not, as a matter of principle, the portfolio that maximizes the return of the investment. These ideas can best be understood in terms of the efficient frontier, which shows the relationship between the expected return of a portfolio and its level of risk, measured from the standard deviation, as shown in Figure 1.

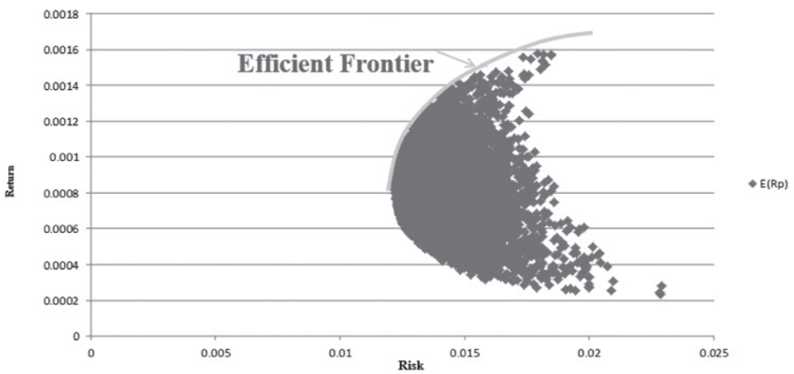

Figure 1. Efficient Frontier and possible portfolios formed from a set of investment alternatives.

Source: own elaboration

This graph illustrating the relationship between Yield and Risk was constructed by simulating a portfolio of three assets to which different weights were assigned. The blue portion of Figure 1 represents the different portfolios, constructed from different ratios assigned to

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the instruments that make it up. The efficient frontier corresponds to the upper perimeter of the graph and represents the optimal set of portfolios in which to invest, since it is guaranteed that the more the assumed risk, the greater the reward in return. In other words, the efficient frontier represents the maximum return in the set of portfolios given a certain level of risk.

From this graph it can be observed that it is possible to maximize the performance of the portfolio conditioned to assume a certain level of risk.

A variant in the application of these ideas is the use of the Markowitz Model in the planning of an electric power generation portfolio, in a country or in a region. The argument is that the usual method of planning a generation portfolio analyzes the cost of each generation source separately. In such an analysis, the selected generation source will always be the one with the lowest cost. The costs of traditional technologies, based on coal and gas, for example, depend on fuel prices and, as these are volatile, the costs of these technologies become high risk.

Instead of analyzing each generation source separately, the entire portfolio of alternatives is analyzed using the Markowitz Model. Thus, there is an opportunity to consider the correlations between the various generation sources. Renewable sources of generation (such as solar or wind) are characterized by having a high initial investment but a low operating cost, resulting in a predictable cost of energy. Conversely, traditional sources of generation have a high operating cost and a relatively low initial cost, resulting in a volatile cost dependent on the price of fuels. The Markowitz Model has made it possible to include renewable generation sources in the optimal portfolios, because their inclusion mitigates the risk of the cost of energy of the entire portfolio.

Description of the context to be studied

Today, practically all users receive electricity from the transmission and distribution networks of the new State Productive Enterprises: CFE-Transmission and CFE-Distribution. The energy they consume is fully or partially generated by one of the CFE-Generation companies. At least in the short-term, the Federal Electricity Commission (CFE for its acronym in Spanish) will continue to provide part of the energy consumption and other services that users require.

As mentioned above, there are generators that have Legacy Interconnection Contracts, which are generation permits granted by the CFE before the issuance of the Electricity Industry Law (2014). These suppliers have self-supply or cogeneration permits that may be offered, fully or partially, to third parties through private contracts.

Finally, a user registered as Qualified User Participating in the Market may also have access to the wholesale market, and purchase electricity and other services in the auctions of the market itself.

Basically, there are two types of contracts: pay as you use and take or pay. In a pay as you use contract, users pay what they consume. The price of electricity is agreed and paid as much as it is consumed.

In a take or pay contract, the rate paid is normally lower, but the users buy the agreed capacity and it is fully liquidated, whether it is consumed or not.

Both types of contract, with their respective adaptations, are the types of contract to which a user will be able to access, either under the regime of the new Electric Energy Law or under the previous law, with generators with legacy permits.

Supply Portfolio from the Markowitz Model

The Markowitz Model (1952) was used to optimize a portfolio of electricity supply alternatives. The model considers the perspective of a user who currently has electricity supply from the CFE.

The user is presented with energy supply options which, in general terms, can be grouped as follows:

a) Continue the basic user contract with CFE, under the current conditions.
b) Establish a coverage contract with a generator that has a Legacy Interconnection Contract. In this case there are generators that have technologies based on natural gas or renewable technologies (such as photovoltaic or wind).
c) Establish a bilateral contract under the new Electricity Industry Law (2014), which could be based on technologies reliant on natural gas, renewable technologies, or others.
d) Establish a contract with a supplier or with a marketer, under the Qualified User scheme, based on the Electricity Industry Law (2014).
e) Participate directly in the Wholesale Electricity Market, under the scheme of Qualified User Market Participant.
f) Have a combination of two or more of the above options.

In the case of a portfolio with *n* electricity supply options, the expected cost per kW-h is given by:

$$E(C_P) = E(\underset{\sim}{\mathbf{w}}^{\mathrm{T}}\underset{\sim}{\mathbf{C}}) = \underset{\sim}{\mathbf{w}}^{\mathrm{T}}E(\underset{\sim}{\mathbf{C}}) = \begin{pmatrix} w_1 & w_2 & \cdots & w_n \end{pmatrix}\begin{pmatrix} E(C_1) \\ E(C_2) \\ \vdots \\ E(C_n) \end{pmatrix} \quad (5)$$

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Where $\underset{\sim}{\mathbf{w}}$ is the vector of weights, the elements of which represent the ratio of the total supply that each of the n suppliers will supply, while $E(\underset{\sim}{\mathbf{C}})$ is the vector of expected costs, where each element represents the expected cost of the corresponding supplier.
The standard deviation of the portfolio costs is described by:

$$\sigma_P = \sqrt{Var(C_P)} = \sqrt{\underset{\sim}{\mathbf{w}}^{\mathrm{T}} Var(\underset{\sim}{\mathbf{C}}) \underset{\sim}{\mathbf{w}}} \quad (6)$$

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Where is the $Var(\underset{\sim}{\mathbf{C}})$ matrix of variances and covariances of the costs of the different supply alternatives.

The objective is to minimize the cost of the project subject to an appropriate level of risk for the user, which is equivalent to:

$$\begin{aligned} &Min\ E(C_P) \equiv Min\ \underset{\sim}{\mathbf{w}}^{\mathrm{T}} E(\underset{\sim}{\mathbf{C}}) \\ &\text{Sujeto a:} \\ &\sigma_P = \sqrt{Var(C_P)} = \sqrt{\underset{\sim}{\mathbf{w}}^{\mathrm{T}} Var(\underset{\sim}{\mathbf{C}}) \underset{\sim}{\mathbf{w}}} = \sigma \\ &\underset{\sim}{w}^T \underset{\sim}{1} = 1 \end{aligned} \quad (7)$$

Or, minimize the risk of the portfolio subject to an appropriate cost level for the user, which implies:

$$\begin{aligned} &Min\ \sigma_P = \sqrt{Var(C_P)} = \sqrt{\underset{\sim}{\mathbf{w}}^{\mathbf{T}} Var(\underset{\sim}{\mathbf{C}}) \underset{\sim}{\mathbf{w}}} \\ &\text{Subject to:} \\ &E(C_P) = \underset{\sim}{\mathbf{w}}^{\mathbf{T}} E(\underset{\sim}{\mathbf{C}}) = c \\ &\qquad \underset{\sim}{w}^T \underset{\sim}{1} = 1 \end{aligned} \quad (8)$$

Case Study

Based on real information, a hypothetical scenario was created with fictitious companies in which a manufacturing company faces the decision-making concerning the supply of electric energy. This was done using the current context in Mexico since the Energy Reform.

The company *Manufacturas de Occidente* is headquartered in the United States of America. Its operation in Mexico includes several loading points located in several states of the Mexican Republic.

In 2016, the operation at these loading points had an electric power supply with a contracted demand of 3,500 kW in HM rate with the Federal Electricity Commission. It had an annual consumption of 12,400 MW-h, with a simple rate of MXN$1.34 per kW-h.

In the search for new electricity supply offers that could give a better price for 2017 and the following years, *Manufacturas de Occidente* received different proposals. Now, the decision must be made on which of the following options would be most convenient:

a) Continue the contract with CFE at 100% capacity. Regardless if this were not the decision, the requirement would be to continue with the CFE, at least with a minimum consumption, due to the need to have the backing of electricity supply. According to the contracts with the CFE in HM rate, the minimum monthly payment results from applying the charge per kilowatt of billable demand to 10% of the contracted demand. It is worth mentioning that the common practice is to share the energy supply with CFE and another supplier. Given that the billing of the electricity service is composed mainly of energy and demand (other services are minor) one possibility is that the other provider meets the full consumption of energy and only part of the billable demand, leaving the rest of the billable demand to the CFE, meeting the requirement of 10% of contracted demand.
b) Establish a contract with Universal Energy, which offers a rate referenced to the HM rate minus a 16% discount, with a rate of MXN$1.25 per kWh indexed to the National Consumer Price Index (INPC for its acronym in Spanish). The contract would operate on a take-or-pay basis, so the energy not consumed would also be paid for. Given that Universal Energy has clean generation capacity, through a legacy contract, it has the opportunity to bank energy, that is, generate it at a given time, deliver it to the grid and use it at a future time, when required.
c) *Nueva Era*, which gets its power from a generator with a legacy interconnection contract from wind generation; offers a rate of $70 USD per MWh; indexed with the USCPI. This is a pay as you use scheme.
d) *Generador Potosino* offers a pay as you use contract with a rate referenced to the HM rate, with a weighted discount of 6%. The specific discount per period is 2% in base period, 3.5% in intermediate period, and 15% in peak period. In addition, an 8% discount on the billable demand rate. The generation supply source is composed of combined cycles, cogenerations and wind generation.
e) Establish a contract with *Comercializadora Buendía*, which offers an efficient cogeneration supply that contemplates variable discounts with a maximum of 12% with respect to the HM rate, in take or pay mode, at a simple rate per generation cost of 3 USD cents/kWh, considering operation and maintenance costs with an increase indexed to the US CPI, plus a portage cost of 0.04 MXN/kWh, in addition to the cost of natural gas from the price of

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gas in Mexico with an efficiency of 7,200 Btu/kWh. Given that the generation of *Comercializadora Buendía* is efficient cogeneration (clean generation), it has the opportunity for banqueting, which simplifies the fact of ensuring that 100% of the energy is delivered.

First, the average expected costs for each of the options were estimated. In order to estimate means, variances, and covariances, monthly data were considered from January 2011 to October 2016. For the analysis, an independent calculation was made for each loading point and then the estimated rates per loading point were weighted to obtain a final rate for Western Manufactures. For the construction of the cost matrix, the following methodology was followed for each of the supply options:

a) The CFE has a rate composed of four factors, three energy rates at peak, intermediate and base periods, and billable demand (power). As a first effort, and with the purpose of simplifying the analysis, it was considered that every month they had the same consumption profile, which would imply that the operation of the company was stable throughout the year. Given the historical HM of the CFE rates and current demand, a matrix of historical costs per kW-h was constructed with the CFE. Finally, historical costs were deflated using the INPC.
b) *Universal Energy* has a 16% discount HM referenced rate and a $1.25 per kWh rate. Since no historical data was available, the historical costs of CFE were estimated directly, deflated, adjusted 16% below, and compared with the flat rate of $1.25 per kWh. One hundred percent of the energy supplied by Universal Energy was considered, as well as the billable demand supplied. The excess billable demand is calculated and covered by the CFE.
c) *Nueva Era* has a dollar rate converted to pesos, using the historical peso-dollar parity and deflated on the basis of the INPC. One hundred percent of the energy supplied by *Nueva Era* was considered, as well as the billable demand supplied. The excess billable demand is calculated and covered by the CFE.
d) *Generador Potosino* has a rate per period and per billable demand. The mix of consumption per load point was estimated according to historical data in order to define a rate per period. The excess billable demand is calculated and covered by the CFE.
e) *Comercializadora Buendía* has an energy rate based on the cost of generation. The period rate was constructed using the historical costs of natural gas. It was compared with an energy rate weighted with a 10% discount to the HM rate. Finally, the rate for *Comercializadora Buendía* was estimated. The excess billable demand is calculated and covered by the CFE.
f) Once a table of estimated rates for each option and for each load point was constructed, from January 2011 to October 2016, the rate was weighted based on the energy consumed at each load point in order to condense it into a table of weighted rates (comparable costs), which is shown in Table 1 of Appendix 1.

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From a graph of the costs of the different alternatives throughout time, it can be observed that the *Nueva Era* dollar proposal behaves differently from the other options that are referenced to the HM rate of the CFE. It can be observed that this rate, in dollars, tends to increase in recent months, as can be observed in Figure 2.

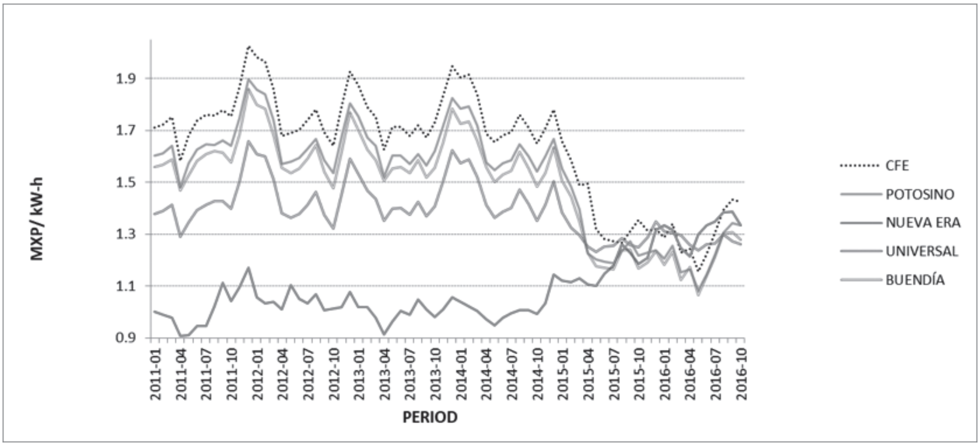

Figure 2. Supply Options Cost Chart.

Source: Own elaboration with data from the CFE, Bank of Mexico and United States Federal Reserve.

The means and standard deviations calculated from the cost matrix are included in Table 2.

Table 2

Means and Standard Deviations of Electricity Costs

	CFE	POTOSINO	NUEVA ERA	UNIVERSAL	BUENDÍA
	CFE Rate	CFE - 6%	70 USD / MW-h	CFE - 16% C/ MIN	GENERATION COST
AVERAGE	$ 1.63342	$ 1.52597	$ 1.08618	$ 1.39108	$ 1.48821
STD. DEV.	$ 0.22084	$ 0.20922	$ 0.12611	$ 0.10541	$ 0.19781

Source: own elaboration with data from the CFE, Bank of Mexico and United States Federal Reserve.

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The variance and covariance matrix is shown in Table 3.

Table 3

Variance and covariance of Electricity Costs

	CFE	POTOSINO	NUEVA ERA	UNIVERSAL	BUENDÍA
	CFE Rate	CFE - 6%	70 USD / MW-h	CFE - 16% C/ MIN	GENERATION COST
CFE Rate	0.048769	0.045256	-0.019229	0.020691	0.042700
CFE - 6%	0.045256	0.043773	-0.017865	0.019773	0.040688
70 USD / MW-h	-0.019229	-0.017865	0.015903	-0.005882	-0.016776
CFE - 16% C/ MIN	0.020691	0.019773	-0.005882	0.011111	0.018781
GENERATION COST	0.042700	0.040688	-0.016776	0.018781	0.039127

Source: own elaboration with data from the CFE, Bank of Mexico and United States Federal Reserve.

Figure 3 shows the Expected Cost graph, $E(C_P)$, according Cost Volatility, $\sigma(C_P)$, which was built by simulating different weights to the different supply options that make up the portfolio.

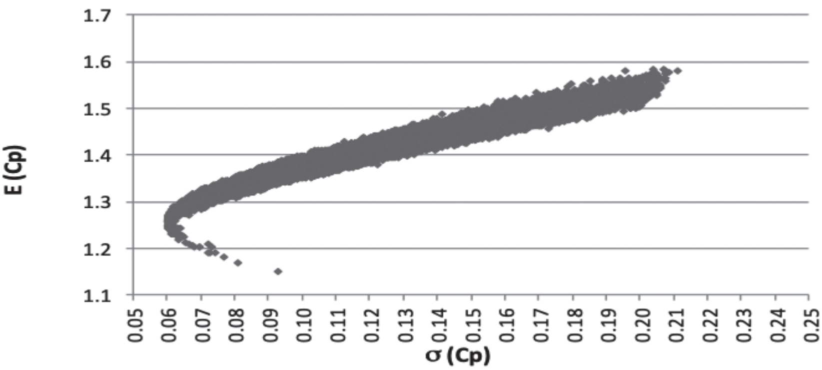

Figure 3: Possible power supply portfolio

Source: Own elaboration with data from the CFE, Bank of Mexico and United States Federal Reserve.

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In addition to a low price per kW-h of electricity, *Manufacturas de Occidente* also seeks to reduce the risk. It wants to ensure a reasonably stable price that allows it to make medium- and long-term plans reliably, but it is willing to assume a moderate risk that allows obtaining a better price than the minimal variance portfolio. Therefore, a low risk level is the first quartile. The methodology used would not change if the company wanted to assume more or less risk.

Figure 3 shows that the standard deviation of the costs of possible portfolios varies from 0.05 to 0.21 pesos. The standard deviation of the first quartile is 0.0900 (a variance of 0.0081).

The mathematical approach to the problem is:

$$MinE[w_1C_1 + w_2C_2 + w_3C_3 + w_4C_4 + w_5C_5] \equiv Min\ \underset{\sim}{w}^T E(\underset{\sim}{C}) \tag{9}$$

Subject to $\underset{\sim}{\mathbf{w}}^{\mathbf{T}}\underset{\sim}{1} = 1$, $\sqrt{Var(C_P)} = \sqrt{\underset{\sim}{\mathbf{w}}^{\mathbf{T}} Var(\underset{\sim}{\mathbf{C}})\underset{\sim}{\mathbf{w}}} \le 0.09$ (10)

$$\underset{\sim}{\mathbf{w}}^{\mathbf{T}} Var(\underset{\sim}{\mathbf{C}})\underset{\sim}{\mathbf{w}} = \underset{\sim}{\mathbf{w}}^{\mathbf{T}} \begin{bmatrix} 0.048769 & 0.045256 & -0.019229 & 0.020691 & 0.042700 \\ 0.045256 & 0.043773 & -0.017865 & 0.019773 & 0.040688 \\ -0.019229 & -0.017865 & 0.015903 & -0.005882 & -0.016776 \\ 0.020691 & 0.019773 & -0.005882 & 0.011111 & 0.018781 \\ 0.042700 & 0.040688 & -0.016776 & 0.018781 & 0.039127 \end{bmatrix} \underset{\sim}{\mathbf{w}} \tag{11}$$

$$\underset{\sim}{\mathbf{w}} = \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \\ w_5 \end{bmatrix} \tag{12}$$

$$\underset{\sim}{C} = \begin{bmatrix} 1.63342 \\ 1.52597 \\ 1.08618 \\ 1.39108 \\ 1.48821 \end{bmatrix} \tag{13}$$

$$\underset{\sim}{1} = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} \tag{14}$$

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Results

After solving this problem of Quadratic Programming, the mix of the portfolio is as shown in Table 4.

Table 4.
Resulting Portfolio

	CFE	POTOSINO	NUEVA ERA	UNIVERSAL	BUENDÍA
	CFE Rate	CFE - 6%	70 USD / MW-h	CFE - 16% C/ MIN	GENERATION COST
Mix	0%	0%	85%	0%	15%

Source: own elaboration with data from the CFE, Bank of Mexico and United States Federal Reserve.

The selection would be 85% of consumption to the option of *Nueva Era*, with a rate in USD, and 15% of the option of *Comercializadora Buendía*.

The cost of this portfolio is MXN$1.1464 per kilowatt-hour, in a simple rate. The variance of the portfolio is 0.0081 (standard deviation of 0.0900).

It is important to recognize that the methodology considers the options to be infinitely divisible, as Kumar, Mohanta, and Reddy (2015) comment, which is not necessarily applicable to reality. However, the information obtained can be a valuable guide in decisions taken concerning the energy supply portfolio. While a wattmeter only helps differentiate consumption between two suppliers (CFE and one other), limiting the use of only one additional supplier to the CFE for each site, the company analyzed here has several sites. This means that the appropriate sites could be selected for one supplier (Nueva Era and the CFE, for example) and the rest of the sites for a second (*Comercializadora Buendía* and the CFE). In this way, an adaptation could be achieved between the solution obtained from this methodology and the reality of operation.

Conclusions

In this work, a hypothetical scenario was built based on current and real information, with a user and diverse suppliers in the wholesale electric market of Mexico and in the context of the Energy Reform. In the constructed case, the user faces a diversity of supply options, from which they can select to establish electricity supply contracts.

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The objective was to use the Markowitz Model (normally used to build investment portfolios) to validate its usefulness as a support tool in the decision-making of a company that, under the scenario of opening the energy market, has the possibility to look for different options of electricity supply.

The constructed scenario includes a variety of suppliers that have a pricing structure associated with the generation technology and its financing source. In this way, a supplier whose technology uses natural gas will have a price structure tied to the price of gas, with the volatility of the gas price. On the other hand, a supplier whose technology is based on photovoltaic solar panels, for example, will have a mostly fixed price structure, tied to the cost of the financing that the initial installation requires.

For the case study of this work, historical prices were constructed based on real information.

The Markowitz Model seeks to maximize the return on an investment portfolio by accepting a certain level of risk. With a different approach, this work seeks to minimize the cost of a portfolio of options for electricity supply to the user, accepting a certain level of risk.

The resulting supply portfolio is 85% *Nueva Era* and 15% *Buendía*. The former, with a wind generation model that offers a stable price over time based on financing in dollars, and the latter with a generation model based on natural gas with a low price but high historical volatility. This is a solution that combines the stability, or low risk, of the cost associated with wind technology, and a low cost of natural gas, with a higher risk, due to the volatility of its price.

The result of the case study presented was consistent with the concepts developed by Markowitz with regard to diversification reducing risk. It is important to highlight that the resulting solutions, based on the use of the Markowitz Model, constitute another decision-making tool that could undoubtedly strengthen analyses and help improve the process of configuring an optimal electricity supply portfolio.

At this time, when the electricity market in Mexico is emerging, the options for an electricity user are limited, both by the lack of supply of electricity and by the lack of maturity in the market. It should be considered that, as the electricity market in Mexico matures, supply options could change, including bilateral contracts under the new Law and the option of Qualified Users Participating in the Market, for which the proposed model would remain valid.

A future line of research could include hedging financial instruments in the model. Hedging instruments can decrease the risk of those supply options that rely on hydrocarbons and provide a portfolio with less risk.

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Annex

Table A1

Supply Option Cost Matrix.

Supplier	CFE	POTOSINO	NUEVA ERA	UNIVERSAL	BUENDÍA
Rate	CFE Rate	CFE - 6%	70 USD / MW-h	CFE - 16% C/ MIN	GENERATION COST
2011-01	$ 1.7124	$ 1.6036	$ 1.0017	$ 1.3768	$ 1.5582
2011-02	$ 1.7222	$ 1.6118	$ 0.9887	$ 1.3895	$ 1.5664
2011-03	$ 1.7531	$ 1.6409	$ 0.9766	$ 1.4142	$ 1.5871
2011-04	$ 1.5820	$ 1.4790	$ 0.9076	$ 1.2900	$ 1.4692
2011-05	$ 1.6820	$ 1.5724	$ 0.9107	$ 1.3452	$ 1.5274
2011-06	$ 1.7381	$ 1.6256	$ 0.9455	$ 1.3918	$ 1.5824
2011-07	$ 1.7603	$ 1.6469	$ 0.9444	$ 1.4122	$ 1.6086
2011-08	$ 1.7585	$ 1.6451	$ 1.0210	$ 1.4268	$ 1.6209
2011-09	$ 1.7776	$ 1.6625	$ 1.1112	$ 1.4264	$ 1.6135
2011-10	$ 1.7540	$ 1.6406	$ 1.0420	$ 1.3972	$ 1.5774
2011-11	$ 1.8664	$ 1.7466	$ 1.0936	$ 1.4999	$ 1.6821
2011-12	$ 2.0273	$ 1.8989	$ 1.1716	$ 1.6587	$ 1.8601
2012-01	$ 1.9837	$ 1.8573	$ 1.0550	$ 1.6096	$ 1.7992
2012-02	$ 1.9653	$ 1.8391	$ 1.0332	$ 1.5992	$ 1.7827
2012-03	$ 1.8599	$ 1.7408	$ 1.0384	$ 1.5120	$ 1.6829
2012-04	$ 1.6795	$ 1.5701	$ 1.0101	$ 1.3797	$ 1.5573
2012-05	$ 1.6898	$ 1.5797	$ 1.1022	$ 1.3638	$ 1.5352
2012-06	$ 1.7036	$ 1.5934	$ 1.0507	$ 1.3787	$ 1.5529
2012-07	$ 1.7402	$ 1.6281	$ 1.0341	$ 1.4115	$ 1.5921
2012-08	$ 1.7824	$ 1.6674	$ 1.0684	$ 1.4629	$ 1.6435
2012-09	$ 1.6944	$ 1.5847	$ 1.0073	$ 1.3749	$ 1.5406
2012-10	$ 1.6414	$ 1.5353	$ 1.0120	$ 1.3209	$ 1.4781
2012-11	$ 1.7923	$ 1.6773	$ 1.0192	$ 1.4547	$ 1.6162
2012-12	$ 1.9269	$ 1.8049	$ 1.0779	$ 1.5917	$ 1.7697
2013-01	$ 1.8738	$ 1.7545	$ 1.0174	$ 1.5331	$ 1.7012
2013-02	$ 1.7885	$ 1.6738	$ 1.0171	$ 1.4681	$ 1.6253
2013-03	$ 1.7523	$ 1.6401	$ 0.9783	$ 1.4374	$ 1.5861
2013-04	$ 1.6268	$ 1.5208	$ 0.9129	$ 1.3507	$ 1.5072
2013-05	$ 1.7135	$ 1.6018	$ 0.9618	$ 1.3988	$ 1.5537
2013-06	$ 1.7129	$ 1.6020	$ 1.0028	$ 1.4002	$ 1.5581
2013-07	$ 1.6794	$ 1.5712	$ 0.9888	$ 1.3742	$ 1.5352
2013-08	$ 1.7204	$ 1.6094	$ 1.0470	$ 1.4242	$ 1.5851
2013-09	$ 1.6717	$ 1.5635	$ 1.0094	$ 1.3677	$ 1.5184
2013-10	$ 1.7322	$ 1.6201	$ 0.9809	$ 1.4067	$ 1.5566
2013-11	$ 1.8340	$ 1.7162	$ 1.0088	$ 1.5021	$ 1.6514
2013-12	$ 1.9481	$ 1.8246	$ 1.0560	$ 1.6246	$ 1.7853
2014-01	$ 1.9041	$ 1.7827	$ 1.0403	$ 1.5751	$ 1.7251
2014-02	$ 1.9164	$ 1.7932	$ 1.0203	$ 1.5885	$ 1.7353
2014-03	$ 1.8391	$ 1.7212	$ 1.0043	$ 1.5211	$ 1.6611
2014-04	$ 1.6874	$ 1.5774	$ 0.9709	$ 1.4119	$ 1.5590
2014-05	$ 1.6542	$ 1.5464	$ 0.9489	$ 1.3624	$ 1.5002
2014-06	$ 1.6817	$ 1.5728	$ 0.9775	$ 1.3880	$ 1.5285
2014-07	$ 1.6943	$ 1.5851	$ 0.9943	$ 1.4011	$ 1.5459
2014-08	$ 1.7605	$ 1.6468	$ 1.0056	$ 1.4724	$ 1.6185
2014-09	$ 1.7122	$ 1.6014	$ 1.0060	$ 1.4157	$ 1.5532
2014-10	$ 1.6488	$ 1.5422	$ 0.9925	$ 1.3530	$ 1.4826
2014-11	$ 1.7082	$ 1.5986	$ 1.0338	$ 1.4137	$ 1.5365
2014-12	$ 1.7798	$ 1.6673	$ 1.1434	$ 1.5027	$ 1.6363
2015-01	$ 1.6591	$ 1.5537	$ 1.1216	$ 1.3844	$ 1.5062
2015-02	$ 1.5848	$ 1.4833	$ 1.1144	$ 1.3250	$ 1.4441
2015-03	$ 1.4902	$ 1.3951	$ 1.1298	$ 1.2963	$ 1.3500
2015-04	$ 1.4961	$ 1.2256	$ 1.1053	$ 1.2511	$ 1.2278
2015-05	$ 1.3193	$ 1.2022	$ 1.0989	$ 1.2305	$ 1.1764
2015-06	$ 1.2820	$ 1.1946	$ 1.1460	$ 1.2518	$ 1.1704
2015-07	$ 1.2734	$ 1.1867	$ 1.1781	$ 1.2547	$ 1.1657
2015-08	$ 1.2667	$ 1.2333	$ 1.2605	$ 1.2856	$ 1.2364
2015-09	$ 1.3107	$ 1.2735	$ 1.2285	$ 1.2594	$ 1.2411
2015-10	$ 1.3534	$ 1.2162	$ 1.1851	$ 1.2502	$ 1.1687
2015-11	$ 1.3127	$ 1.2290	$ 1.2092	$ 1.2862	$ 1.1901
2015-12	$ 1.3206	$ 1.2386	$ 1.3157	$ 1.3493	$ 1.2355
2016-01	$ 1.2871	$ 1.2062	$ 1.3344	$ 1.3106	$ 1.1834
2016-02	$ 1.3405	$ 1.2551	$ 1.3167	$ 1.3055	$ 1.2305
2016-03	$ 1.2296	$ 1.1520	$ 1.2451	$ 1.2953	$ 1.1224
2016-04	$ 1.2440	$ 1.1631	$ 1.2139	$ 1.2592	$ 1.1730
2016-05	$ 1.1563	$ 1.0814	$ 1.2998	$ 1.2387	$ 1.0646
2016-06	$ 1.2227	$ 1.1441	$ 1.3337	$ 1.2609	$ 1.1377
2016-07	$ 1.3050	$ 1.2213	$ 1.3500	$ 1.2648	$ 1.2125
2016-08	$ 1.3932	$ 1.3039	$ 1.3825	$ 1.3004	$ 1.3018
2016-09	$ 1.4342	$ 1.3415	$ 1.3867	$ 1.2714	$ 1.3074
2016-10	$ 1.4248	$ 1.3331	$ 1.3349	$ 1.2622	$ 1.2793

Source: Own elaboration with data from the CFE, Bank of Mexico and the United States Federal Reserve.