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The Clean Energy Certificate Market in the Electricity Sector of the Mexican Energy Modeling System

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FIRMA

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Abstract

One of the objectives of the Energy Reform is to promote the use of Clean Energy sources to generate electricity in Mexico, in such a way to decrease the Greenhouse Gases emitted in this sector by following the example of other countries where the Clean or Renewable Generation has seen a substantial boost on its number of power plants installed, due to the enactment of a Green Certificate or Green Credit that allows these power plants to receive an extra income asides the Electricity sales. To replicate the same effect, the Mexican government has created a Clean Energy Certificate and a Clean Energy Certificate Market, which are considered as the main tools to accomplish the Clean Energy Goals proposed in the “Electric Industry Law”.

The purpose of this paper is to know if the implementation of the Clean Energy Certificate system is capable to improve the Clean and Renewable Energy Generation in Mexico. Likewise, other purpose is to evaluate the implications of these instrument over the Wholesale Electricity Market and to model the Clean Energy Certificate Market in the Mexican electric system planning.

An in-depth analysis about the Clean Energy Certificate Market is conducted to detect the characteristics, parameters and equations that defines the behavior of the Clean Energy Certificates Market, such as the Market Price, quantity demanded, quantity supplied, among others, and to develop a model that executes these equations. Subsequently, three 15-year simulations are performed with the assistance of the energy planning model developed by the National Autonomous University of Mexico called Sistema de Modelación Integral del Sector Energético, by linking the Clean Energy Certificate Model to the energy planning model to estimate the growth of the clean energy generation due to this Certificate system. These three scenarios were selected to determine the participation of fossil fuels at the Mexican energy mix.

The results obtained from the three scenarios show that the Clean Energy Generation increases over the next fifteen year due to the implementation of the Clean Energy Certificate Market. However, it is also noted that the participation of technologies fueled by Natural Gas does not decreases and maintains almost the same share of 2017.

Out of the three scenarios, the scenario where Clean Power Plants based on fossil fuels receive a percentage of Clean Energy Certificates per Megawatt-hour generated, is the scenario with the lowest breach of the Clean Energy Goals, while keeping relatively low Certificates prices compared to the other two scenarios.

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Acronyms

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CENACE
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CFE
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CHP
Combined Heat and Power, 59, 60, 61, 62, 65, 66, 67, 68, 70, 73, 78, 81, 82, 83, 86, 87, 88, 89, 90, 91, 92, 94, 95, 96, 97, 99, 100, 101, 102, 104, 105, 106, 107
CRE
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DECC
Department of Energy & Climate Change, 13, 17
GDP
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kWh
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LIE
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LSPEE
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MW
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MWh
Megawatt-hour, 14, 17, 18, 27, 29, 31, 32, 37, 40, 43, 55, 57, 58, 59, 61, 62, 66, 82, 86, 88, 89, 92, 97, 102
NPV
Net Present Value, 45, 46, 47, 51, 70, 73, 77
Ofgem
Office of the Gas and Electricity Markets, 16, 18
PEMEX
Petróleos Mexicanos, 25
PRODESEN
Programa de Desarrollo del Sistema Eléctrico Nacional (Development Program of the National Electric System), 58, 59, 60, 63, 66, 83
RO
Renewables Obligations, 13, 14, 15, 16, 18, 23, 24
ROC
Renewables Obligation Certificate, 14, 17
ROI
Return On Investment, 47, 48
SEN
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SENER
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UNAM
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UNFCCC
United Nations Framework Convention on Climate Change, 12

1. The Renewable Energy Certificates Around the World

To this day there is a huge concern for the sustainability of life on Earth. The environmental footprint left by humans on our planet has led to an unstable behavior of flora and fauna. The concern is that if we do not do something to reduce our footprint, there could be permanent and even irreversible changes in the ecosystems.

Several countries have come to this realization and have taken measures to prevent and mitigate climate change by intervening in areas such as reducing deforestation, indiscriminate fishing and hunting and environmental waste. In the environmental waste area, specifically, the governments apply strong penalties to those who violate policies, with a fee being one of the weakest penalties and a jail sentence the strongest. These policies are mainly oriented towards industrial areas such as the oil & gas industry, electric industry, food industry, pharmaceutical industry and all those that contribute to a country's Gross Domestic Product.

To reduce the electric power industry emissions, and to reinforce the penalties previously mentioned, governments aim to increase renewable energy electricity generation by giving tax benefits or credits/certificates which have liquidity, thereby representing an extra profit to the renewable power plants.

This chapter presents the background of the Renewable Energy Certificates, as one of the possible solutions to reduce a country's emissions. First, it is described the employment of Carbon Credits as a tool to decrease the Green House Emissions, then one of the foremost and successful examples of a Renewable Certificate system, with the United Kingdom's case, is presented since this led to the creation of the Clean Energy Certificates in Mexico.

1.1. Clean Energy Certificates Background

Countless papers and investigations have theoretically and experimentally proven the rise of Earth's temperature due to Greenhouse Gases (GHG). The first of its kind was an attempt at the end of the 19th century from Samuel Pierpoint Langley to determine the moon's temperature by measuring the radiation emitted from it, in which he found odd temperature numbers caused by interference coming from Earth's atmosphere[1]. Eventually, the cause of this interference would be attributed to some atmospheric gases such as Carbon Dioxide, Methane, water vapor, ozone and other gases.

Nowadays, almost every person knows that these gases are the main reason for climate change and despite this, it was until 1992 when several countries decided to join forces to prevent and mitigate climate change at the United Nations Framework Convention on Climate Change (UNFCCC) and establish solutions to this problem. While international actions were taken to fight climate change, it was not until 1997 when some countries fully committed to, at least, maintain their GHG emissions, where each committed country approved and signed those goals in the "Kyoto Protocol".

One of the systems to reduce GHG emissions proposed at Kyoto Protocol was the implementation of a new instrument called "Carbon Credit". It essentially offers economic incentives to those who do not exceed their committed emissions, thereby the committed countries receive one Carbon

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[1] Archer David. *The Long Thaw: How Humans Are Changing the Next 100,000 Years of Earth´s Climate.* Princeton University Press. 2009. P. 19

Credit for each ton of CO_2 equivalent avoided, and once a Carbon Credit is obtained, the owner can trade it as they would with any other commodity in a Credit Market. In this Credit Market, every Carbon Credit can be traded for money that could be invested in new clean projects reducing the GHG emissions every year[2].

However, the Carbon Credits and the Kyoto Protocol presented some problems such as the insufficiency of the committed goals by these countries to mitigate Climate Change[3] and the impediment created by the Carbon Credits on the economic development by forcing all industries to reduce their emissions and thereby making their products more expensive. A way to promote economic growth while at the same time complying with environmental policies has been sought, and thereby the creation of a Renewable Obligation Certificates System was proposed.

1.2. United Kingdom Renewables Obligations

Around the world, several policies have been implemented to reduce GHG emissions and mitigate Climate Change, and one of the most accepted measures to achieve this goal is promoting clean or renewable electricity generation through the creation and implementation of Renewable Energy Certificates. One of the first countries to establish this system was the United Kingdom.

The goals proposed by the United Kingdom at the Kyoto Protocol was to reduce their GHG emissions 12.5% by 2012, taking as a reference the emissions of 1990, and the U.K. government also proposed an internal goal, not included in the Kyoto Protocol, to achieve 80% reduction by 2050[4]. To accomplish these goals, in 2009 the U.K. government also presented specific targets for each economic sector, where two of these targets were addressed directly to the energy sector. The first target established that in 2020 at least 15% of all the primary energy consumption must be produced by renewable sources, while the second target established that at least 30% of all electricity consumed in the U.K. must be produced by renewable sources (Department of Energy & Climate Change, 2010).

To promote the use of renewable energy in the electricity energy mix, the Department of Energy & Climate Change (DECC) introduced the Renewables Obligations (RO) on April 1, 2002 which bind all electricity suppliers to deliver a certain amount of electricity coming from renewable sources every year and in case they do not comply whit this obligation, they must pay a penalty fee. The ROs are established every year and are published for the year to come, i.e. the 2017 ROs were published in 2016, the 2016 RO in 2015, and so on. In 2002 the obligated regions were England, Wales and Scotland, and later in 2005 Ireland was included.

To comply with the ROs, the suppliers must demonstrate their compliance by submitting a paper called Renewables Obligation Certificates (ROCs) a similar to the Carbon Credits. However, the main difference between ROCs and Carbon Credits is that Carbon Credits are issued for each equivalent ton of CO_2 avoided, while ROCs are issued for each MWh of renewable energy generated (Department of Energy & Climate Change, 2010).

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[2] United Nations. Kyoto Protocol to the United Nations Framework Convention on Climate Change. 1998

[3] T.M.L. Wigley. *The Kyoto Protocol: CO_2, CH_4 and Climate Implications.* Geophysical Research Letters, vol. 25. pp. 2285-2288. 1998

[4] *Climate Change Act 2008.* pp. 108. 2008.

1.2.1. Renewables Obligations Characteristics

One of the main features of ROs is the full support for renewable energy power plants, given that the definition of Renewable Energy shown in the National Renewable Energy Plan for the United Kingdom is the same to the definition established by the European Parliament and of the Council in the Directive 2009/28/EC, and which aims to promote the use of energy sources "coming from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases"[5].

Another feature of ROs, according to the 2009 Renewable Obligation Order (Secretary of State, 2009), is that the calculation for every year obligation begins with the estimation of the total amount of electricity likely to be supplied to the United Kingdom's consumers, in megawatt hours, which is then multiplied, according to the corresponding period, by the sum of the numbers found in the second and the third column of Table 1.1. The result of this calculation is Calculation A.

Table 1.1: Renewables Obligation Certificates (ROCs) obligation calculation

Period	ROCs per supplied electricity in Great Britain [ROCs/MWh]	ROCs per supplied electricity in North Ireland [ROCs/MWh]
April 1, 2009 – March 31, 2010	0.097	0.035
April 1, 2010 – March 31, 2011	0.104	0.040
April 1, 2011 – March 31, 2012	0.114	0.050
April 1, 2012 – March 31, 2013	0.124	0.063
April 1, 2013 – March 31, 2014	0.134	0.063
April 1, 2014 – March 31, 2015	0.144	0.063
April 1, 2015 – March 31, 2016	0.154	0.063
Each subsequent period of twelve months ending on March 31, 2037	0.154	0.063

Once the value of Calculation A has been obtained, the Secretary of State estimates, in megawatt hours, the total amount of renewable electricity likely to be supplied to consumers. Given this estimate, the Secretary of State calculates how many renewables obligation certificates are likely to be issued in respect of that renewable electricity during that obligation period. The number of renewables obligation certificates likely to be so issued must be increased by:

- 8%, if the obligation period ends on March 31, 2011.
- 10%, for any other obligation period.

[5] European Parliament and of the Council. *Directive 2009/28/EC.* Article 2, ident a). 2009

This new value for that obligation period is known as Calculation B and is expressed in ROCs.

To determine the total number of ROCs required to be issued by suppliers, the Secretary of State uses the following criteria:

- If the value of Calculation A is equal or greater than Calculation B, the total obligation for said period is the value of Calculation A,
- If the value of Calculation B is greater than Calculation A, the total obligation for said period is the value of Calculation B.

With this criterion, the Secretary of State ensures that the number of ROCs to be issued is the highest possible.

The final step is to obtain the number of ROCs that a specific electric supplier must issue to discharge its renewables obligation in accordance with the next criterion:

- If the total obligation is Calculation A, the suppliers are required to produce the percentage set out on the second column of Table 1.1;
- If the total obligation is Calculation B, the suppliers are required to produce the percentage obtained using the next equation:

$$\frac{figure\ set\ out\ in\ second\ column\ of\ \text{Table 1.1} * Calculation\ B}{Calculation\ A}$$

Following these amendments, every year since 2002, the Secretary of State has published the Renewable Obligation Percentage that a specific supplier must present to comply with the RO. The values are shown in Table 1.2.

Table 1.2: Renewable Obligation Percentage to Meet, 2002 - 2017[6]

Obligation Period	Renewable Obligation (RO) Percentage of Total Supplied Electricity
April 1, 2002 – March 31, 2003	3.0
April 1, 2003 – March 31, 2004	4.3
April 1, 2004 – March 31, 2005	4.9
April 1, 2005 – March 31, 2006	5.5
April 1, 2006 – March 31, 2007	6.7
April 1, 2007 – March 31, 2008	7.9
April 1, 2008 – March 31, 2009	9.1
April 1, 2009 – March 31, 2010	9.7
April 1, 2010 – March 31, 2011	11.1

[6] The Department of Energy and Climate Change post every year a paper called "Renewables Obligation Level Calculations" which has all the calculations made for each period.

April 1, 2011 – March 31, 2012	12.4
April 1, 2012 – March 31, 2013	15.8
April 1, 2013 – March 31, 2014	20.6
April 1, 2014 – March 31, 2015	24.4
April 1, 2015 – March 31, 2016	29.0
April 1, 2016 – March 31, 2017	34.8
April 1, 2017 – March 31, 2018	40.9

1.2.2. Characteristics of the Renewables Obligations Certificates

Once the renewable obligation percentage is published, the Office of the Gas and Electricity Markets (Ofgem) issues and delivers ROCs to all the renewable generation depending of their energy generated on that period and then are allowed to sell their ROCs to suppliers or any person willing to acquire and resell them as seen in Figure 1.1 and subsequently, the suppliers must submit to Ofgem the ROCs they acquired. If a supplier does not submit enough ROCs to comply with his Renewable Obligation, he is forced to pay a penalty fee known as “buy-out-price”, where all the money collected from penalty fees goes to a fund called “buy-out fund”, which is redistributed to the suppliers that submitted ROCs[7].

According to the value of the “buy-out-price”, three different situations can occur:

1. If ROs are greater than the renewable generation, the ROC price is lower than the buy-out price.
2. If ROs are lower than the renewable generation, the ROC price is greater than the buy-out price.
3. If ROs are equal than the renewable generation, the ROC price is equal than the buy-out-price.

ROCs were established not only as an instrument so that the United Kingdom authorities could check the ROs compliance of the suppliers, but also as an instrument to promote renewable energy by creating an artificial need for ROCs, and allowing for ROCs to be considered as a commodity, exactly the same way that Carbon Credits were proposed at the Kyoto Protocol.

The ROC price is set when an electricity supplier and a ROC owner come to a purchase agreement, which gives an economic incentive to the renewable generation and thereby increasing its profits made with the electricity generated by renewables. In this manner, it can be noted that the price of electricity each person living in the United Kingdom must pay has three components attached to every megawatt hour consumed: a price for all the consumed electricity, taxes and a ROC price.

[7] https://www.gov.uk/government/publications/2010-to-2015-government-policy-low-carbon-technologies/2010-to-2015-government-policy-low-carbon-technologies#appendix-5-the-renewables-obligation-ro

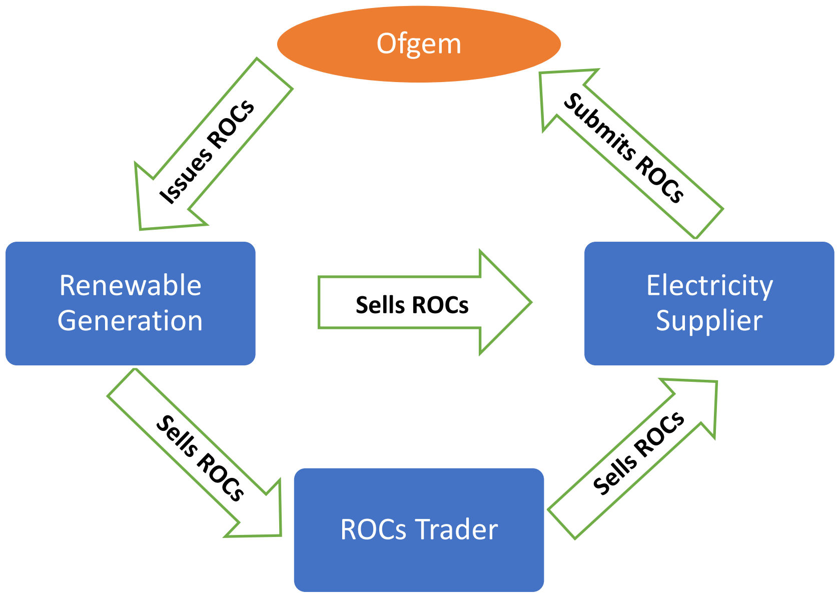


Figure 1.1: ROCs System Diagram

According to the DECC, the ROCs emitted for every megawatt-hour generated by renewables does not always equal one ROC (Table 1.3) and it is up to the DECC's decision to establish the number of ROCs that each technology must receive. With this policy, the DECC ensures to support the renewable technologies which are in the process of technological maturation.

Table 1.3: ROCs Delivered by Technology from 2013 to 2016

Technology	2013-2014 [ROC/MWh]	2014-2015 [ROC/MWh]	2015-2016 [ROC/MWh]	2016-2017 [ROC/MWh]
Advanced gasification / Pyrolysis	2	2	1.9	1.8
Anaerobic Digestion	2	2	1.9	1.8
Dedicated Biomass	2	2	1.9	1.8
Closed Landfill Gas	0.2	0.2	0.2	0.2
Sewage Gas	0.5	0.5	0.5	0.5
Regular Biofuels	0.3	0.3	0.5	0.5
Geothermal	2	2	1.9	1.8
Hydro	0.7	0.7	0.7	0.7
Onshore Wind	0.9	0.9	0.9	0.9
Offshore Wind	2	2	1.9	
Ground Mounted Solar Photovoltaic	1.6	1.4	1.3	1.2
Waves	5	5	5	5
Tidal	5	5	5	5

Source: "Renewables Obligation Banding Levels: 2013-2017" published by the Department of Energy & Climate Change

What the Secretary of State seeks to do by issuing ROCs is that all the RO be complied merely with ROCs. However, as seen in Table 1.4, this did not happen at the beginning of the implementation of the RO, but over the last five periods, more than 90% of the ROs were met with ROCs. Although every single period of the RO was not wholly fulfilled with ROCs, that did not affect the ROC system, in fact the opposite happened, since the penalty fees paid thanks to the RO breach ended up as an income to the renewable power plants, thereby boosting more alike projects and gradually increasing the number of ROCs emitted and then issued, which explains the growth of the percentage of RO fulfilled with ROCs from 2002 to 2015.

Table 1.4: Renewables Obligation met with Renewables Obligation Certificates, 2002-2016

Period	Total Obligation [MWh]	ROCs issued to Ofgem	RO fulfilled with ROCs [%]
2002/03	9,261,568	5,562,669.00	60.06
2003/04	13,627,412	7,610,144.00	55.84
2004/05	15,761,067	10,855,848.00	68.88
2005/06	18,032,904	13,699,317.00	75.97
2006/07	21,629,676	14,612,654.00	67.56
2007/08	25,561,357	16,466,751.00	64.42
2008/09	28,975,578	18,948,878.00	65.40
2009/10	30,101,092	21,337,205.00	70.89
2010/11	34,749,418	24,969,364.00	71.86
2011/12	37,676,829	34,404,733.00	91.32
2012/13	48,915,432	44,773,499.00	91.53
2013/14	61,858,174	60,757,250.00	98.22
2014/15	71,922,000	71,276,525.00	99.10
2015/16	84,439,465	84,384,727.00	99.94

Source: "Renewables Obligation: Other Annual Reports" from 2002 to 2006 and "Renewables Obligation (RO) Annual Report" for the remaining periods.

1.2.3. Impacts of Renewable Obligations Certificates

One of the most remarkable changes that has arisen thanks to the implementation of the RO and Renewable Obligations Certificates (ROCs) is that, according to Department for Business, Energy & Industrial Strategy data[8], electricity generation using coal as fuel has decreased and the United Kingdom energy mix has been diversified (See Figure 1.2). Additionally, energy generation by renewables went from 11.67 [TWh] in 2002 to 83.23 [TWh] in 2016 (

[8] Department for Business, Energy & Industrial Strategy, *Energy Trends section 5: electricity,* last update: August 31, 2017. Digest of UK Energy Statistics (DUKES)

Table 1.5), and the share of renewable energy went from 3.01% in 2002 to 24.52% by 2016 (Figure 1.3).

The most outstanding renewable technologies in this energy transition experienced by United Kingdom are Bioenergy, Wind and Solar, which solely contributed with 1.45% for the former and 0.33% for wind and solar of the 387.25 [TWh] of electricity generated in 2002 (See Figure 1.4), while in 2016 the proportion was 14.08% for wind and solar, and 8.85% for bioenergy (See Figure 1.5).

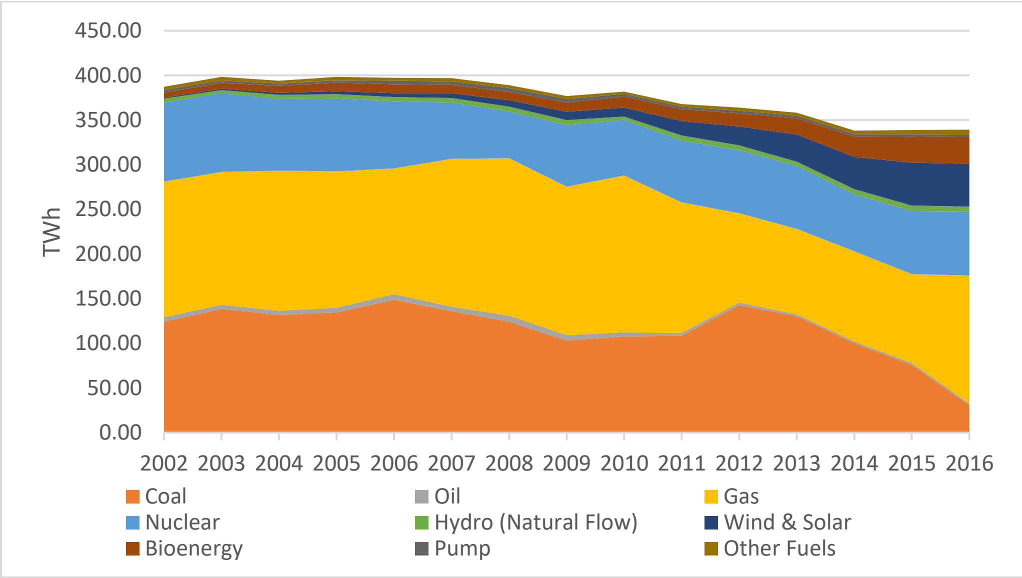


Figure 1.2: United Kingdom's Electricity Generation, 2002-2016

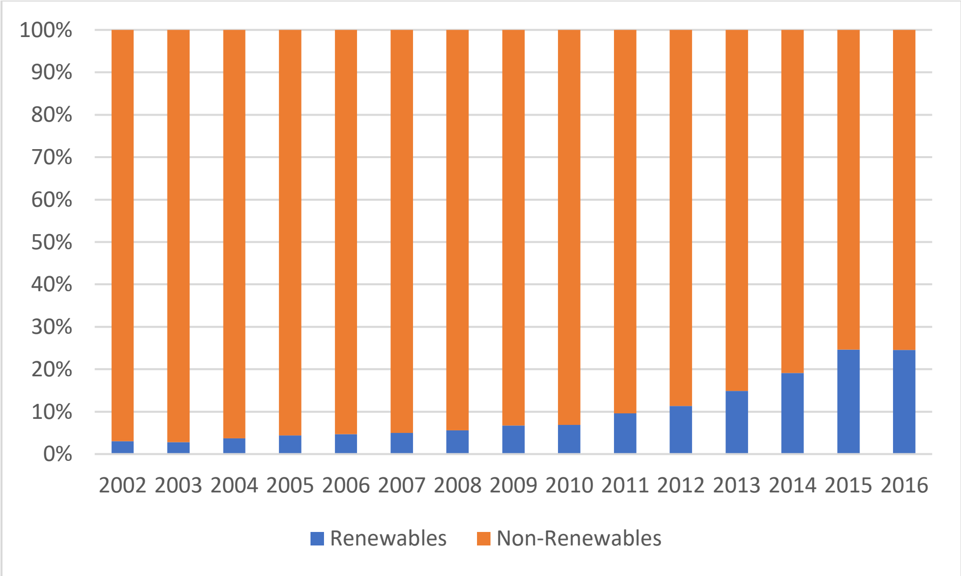


Figure 1.3: United Kingdom's Share of Renewables on Electricity Generation, 2002-2016

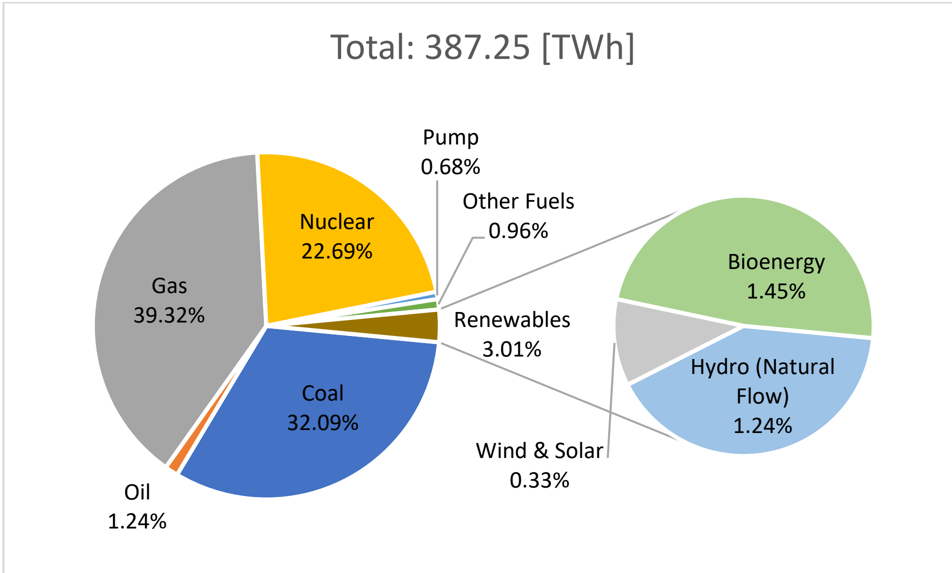


Figure 1.4: United Kingdom's Electricity Generation Share by Technology in 2002

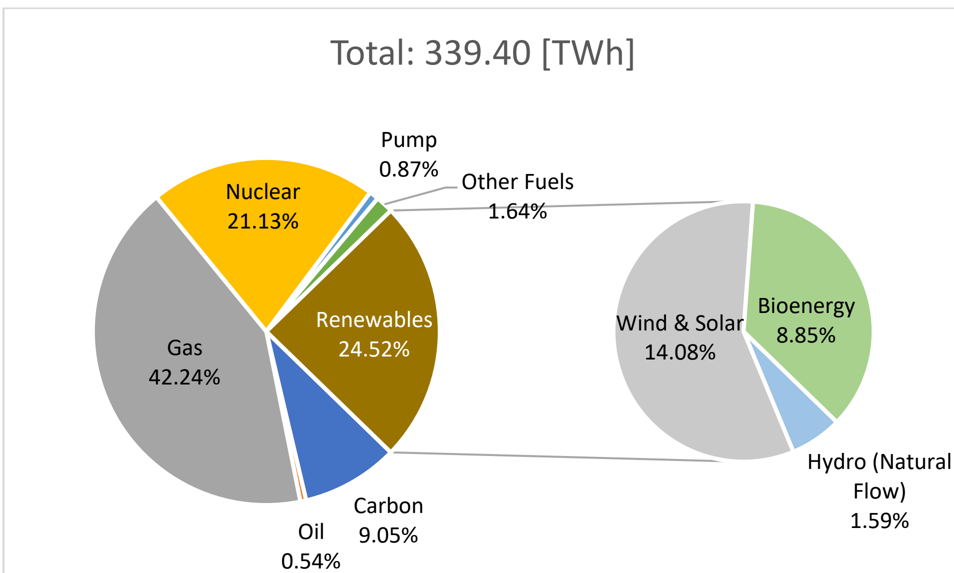


Figure 1.5: United Kingdom's Electricity Generation Share by Technology in 2016

Table 1.5: United Kingdom's Electricity Generation by Technology, 2002-2016

Units: TWh

	Year														
Technology	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Coal	124.28	138.46	131.79	134.64	148.85	135.94	124.38	103.04	107.59	108.44	142.79	130.26	100.24	75.88	30.71
Oil	4.80	4.59	4.64	5.34	6.17	5.05	6.71	5.99	4.81	3.12	2.89	2.07	1.92	2.04	1.84
Gas	152.28	148.88	157.06	152.64	140.83	165.79	176.22	166.50	175.65	146.50	100.17	95.84	100.89	99.88	143.36
Nuclear	87.85	88.69	80.00	81.62	75.45	63.03	52.49	69.10	62.14	68.98	70.41	70.61	63.75	70.34	71.73
Hydro Re-Pump	2.65	2.73	2.65	2.93	3.85	3.86	4.09	3.69	3.15	2.91	2.97	2.90	2.88	2.74	2.96
Other Fuels	3.72	3.80	3.06	3.68	3.37	3.47	3.19	3.20	2.54	2.82	3.40	3.39	3.89	4.64	5.57
Hydro (Natural Flow)	4.79	3.23	4.84	4.92	4.59	5.08	5.14	5.23	3.59	5.69	5.31	4.70	5.89	6.30	5.39
Wind & Solar	1.26	1.29	1.94	2.91	4.24	5.29	7.14	9.30	10.33	16.21	21.21	30.41	36.02	47.86	47.79
Bioenergy	5.63	6.69	7.94	9.69	9.93	9.32	9.57	10.71	12.26	13.31	14.73	18.10	22.62	29.24	30.04
Renewables Total	11.67	11.21	14.72	17.52	18.76	19.69	21.85	25.24	26.18	35.21	41.25	53.21	64.52	83.40	83.23
Non-Renewables Total	375.57	387.16	379.21	380.84	378.53	377.14	367.07	351.51	355.89	332.77	322.62	305.07	273.57	255.51	256.17
Total Generation	387.25	398.36	393.93	398.36	397.28	396.83	388.92	376.75	382.07	367.98	363.87	358.28	338.10	338.92	339.40

According to the International Energy Agency (International Energy Agency, 2016) the GHG emissions in the UK went from 519.9 to 407.8 million tons of CO_2 from 2002 to 2014 (a 21.55% reduction) which led the UK to move from 7th to the 15th place among the countries with the most emissions (Figure 1.6).

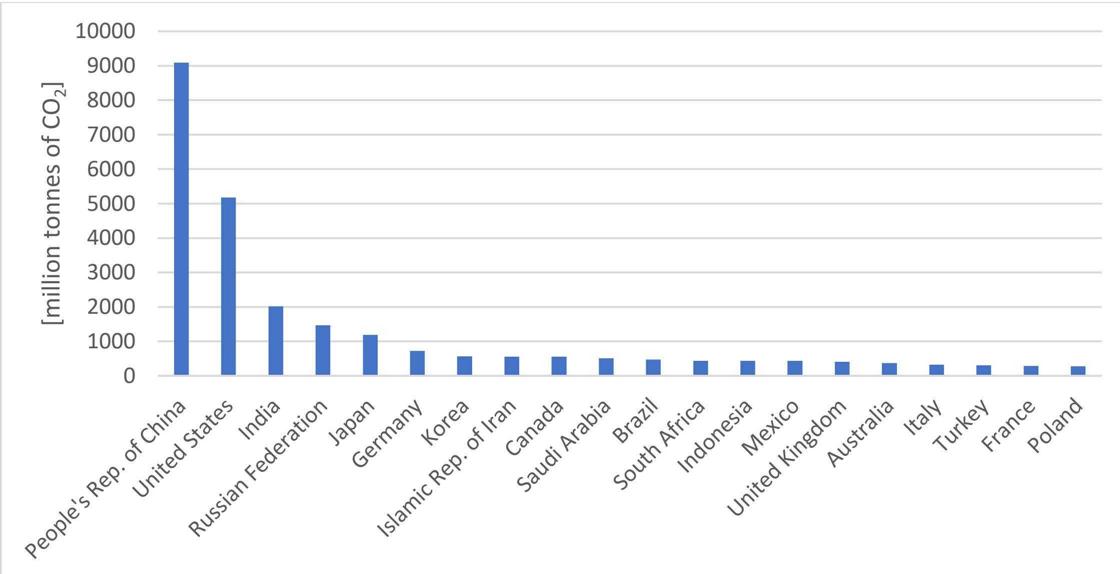


Figure 1.6: CO_2 Emissions by Country

However, in 2014, 36% of emissions came from the electricity industry, followed by the transport sector with 28% and 20% from other sectors (Figure 1.7). These three sectors together contribute to 84% of United Kingdom CO_2 emissions.

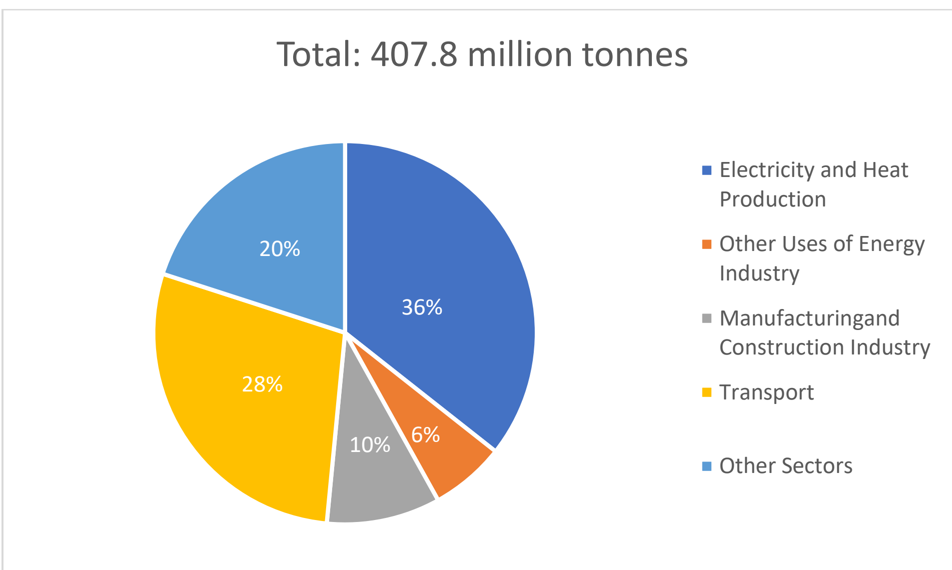


Figure 1.7: United Kingdom CO_2 Emissions Share by Sector in 2014

Although it seems like all the policies adopted by the UK could heavily affect electricity prices, the truth is that the price per kWh paid by domestic users in 2016 was 0.183 [EUR/kWh], while domestic users in Denmark paid almost twice that price, paying 0.308 [EUR/kWh]. The price per kWh paid by domestic users in the United Kingdom in 2016 was below the price paid by countries such as Germany, Denmark, Italy, Spain, Portugal and Switzerland, however United Kingdom's price was higher than countries such as Norway, France, Croatia and the Netherlands (Figure 1.8).

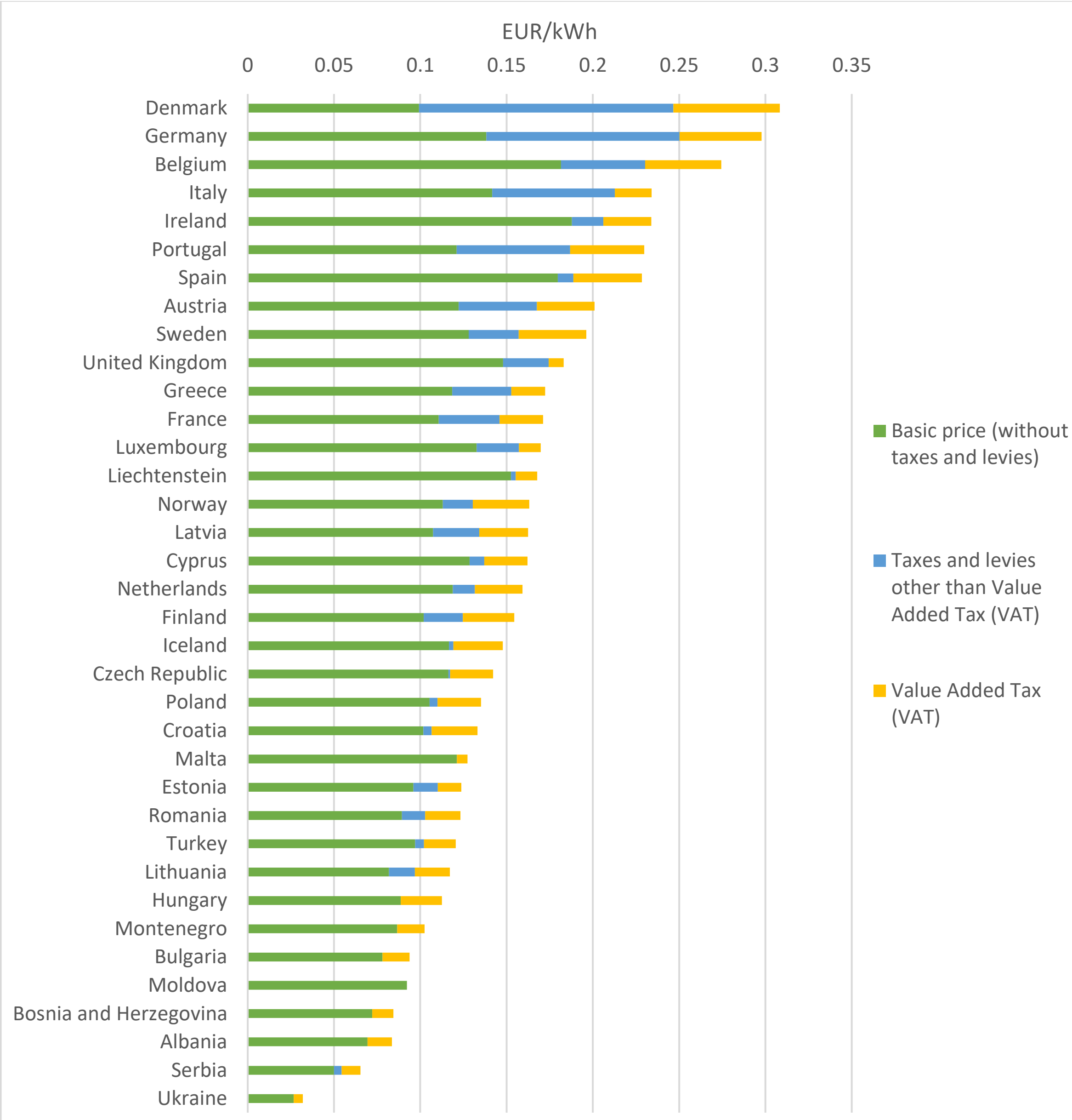
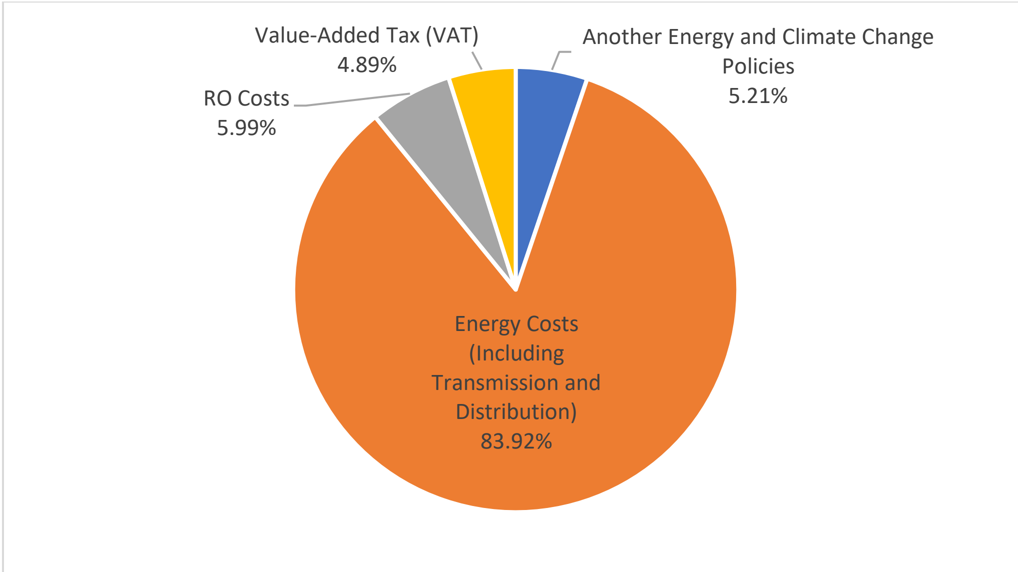


Figure 1.8: European Union Electricity Price in 2016

Of all the price of electricity paid in the UK, almost 6% goes to the RO and the ROCs compliance and this percentage, added to the other energy and climate change policies, accounts for 10% of the domestic user's electricity price due to energy policies (Figure 1.9).



Source: Estimated impacts of energy and climate change policies on energy prices and bills, published by Department of Energy & Climate Change

Figure 1.9: Distribution of United Kingdom's Electricity Prices in 2014

In summary, this chapter exposed the UK's plans to decrease CO_2 emissions by increasing the share of renewable energy in the energy mix have been successful thanks to all the energy policies adopted. The growth presented by renewable energies is mostly due to the creation and implementation of the ROs and the ROCs. The GHG reduction goals were not only met thanks to the implementation of the ROs, but also to other energy policies explicitly designed for electricity generation and to the rest of the economic sectors. The energy transition that the UK has, and is still developing, was reached not only by the determination of the people living in this region, but also by the economic and governmental support with the purpose to reduce their environmental footprint, and nowadays this is producing excellent results and proving to other countries that these energy policies are the best way a country has, so far, to help mitigate and reduce climate change.

2. The Clean Energy Certificates in Mexico

As mentioned earlier, different regions around the world have decided to adopt measures to decrease their greenhouse gases emissions, and one of the most common policies is to encourage the renewable or clean electricity generation through the creation of either Renewable or Clean Energy Certificates.

For this certificate system to properly work, the government first establish a minimum percentage of clean or renewable generation and then they proceed to issue certificates to the power plants that meet the clean or renewable generation requirements. Subsequently, the government establishes another obligation percentage, but this time, a percentage of the electricity sold by electricity retailers that they must comply with Certificates, forcing retailers to buy these certificates to a clean power plant and then submit them to the government.

This Certificate system has proven to be successful in countries like the United Kingdom, where the electricity generation by renewables has increased since the first ROC enact, which, in 2014, would draw the attention of the Mexican Government, since, as in the case of UK, Mexico was already committed at the Kyoto Protocol to reduce its GHG emissions by increasing its clean energy generation. In that same year, a radical change in the scheme of the Mexican electric system was already occurring with the enact of the Energy Reform and the subsequent creation of a Clean Energy Certificates Market, to replicate similar results of the ROC system in Mexico.

This chapter describes in detail the legal bases derived from the Energy Reform, such as the Electric Industry Law, the Clean Energy Certification Criteria, the Electricity Market Bases and all the statutes that regulate the creation and the subsequent operation of the Clean Energy Certificate system as a tool to boost the installation of new Clean Power Plants in Mexico.

2.1. Legal Bases for Clean Energy Certificates

As part of the Energy Reform, enacted in August 11, 2014 by the Mexican President Enrique Peña Nieto, a relevant change in the structure of the Oil and Electricity sectors has been implemented, which enables, not only private investment on new projects, but also, enables other companies besides *Petróleos Mexicanos* (PEMEX) and *Comisión Federal de Electricidad* (CFE) to participate in any process of the energy chain of said sectors. Along the Energy Reform, 11 reforms or laws were approved to carry out this change, being the *Ley de Hidrocarburos* and the *Ley de la Industria Eléctrica* (LIE) the most remarkable reforms.

With the creation of the LIE, the vertically integrated power model established in the 20th century was transformed into a Wholesale Electricity Market, and besides this, one of the primary targets of the LIE is to promote the use of clean sources in Mexico´s power generation to reduce the GHG emissions coming from the electricity sector. To achieve this, the *Secretaría de Energía* (SENER) has set several goals that establish participation of clean energy sources in any electricity generation process for different years (Secretaría de Energía, August 11, 2014).

- 25% at 2018
- 30% at 2021
- 35% at 2024

- 45% at 2035
- 50% at 2050

Unlike the United Kingdom's support for renewable energies, the LIE supports not only the renewable energy but also to other energy sources considered CO_2 clean technologies. The LIE considers "Clean Sources" the following technologies:

a) Wind;
b) Solar, in every form;
c) Ocean energy in its different forms: tidal, Ocean Thermal Energy Conversion, wave, sea currents and salt gradient concentration;
d) Geothermal power;
e) Bioenergy determined by the *Ley de Promoción y Desarrollo de los Bioenergéticos* (Law on the Promotion and Development of Bioenergy);
f) Energy obtained with methane and other associated gases at waste disposal sites, cattle farms and sewage treatment plants, among others;
g) Energy obtained from hydrogen combustion or hydrogen fuel cells, provided that the minimum efficiency is within the range established by *Comisión Reguladora de Energía* (CRE) and the emissions standards established by the Ministry of Environment and Natural Resources in its life cycle;
h) Hydroelectric energy;
i) Nuclear energy;
j) Energy obtained from agricultural or urban solid waste, provided that its process does not generate dioxins and furans or other emissions with potential health or environment threat and fulfils the Mexican Official Standards issued by the Ministry of Environment and Natural Resources;
k) Efficient Combined Heat and Power according to the efficiency criteria established by Energy Regulatory Commission and emissions criteria established by the Ministry of Environment and Natural Resources;
l) Energy generated from sugar mills according to the criteria established by CRE and the emissions criteria established by the Ministry of Environment and Natural Resources;
m) Energy generated from power plants with Carbon Capture and Storage or Carbon Biosequestration process where their efficiency, measured in generated kWh per ton of emitted carbon dioxide equivalent, must be equal or greater than the minimum efficiency established by CRE and the emissions criteria established by the Ministry of Environment and Natural Resources;
n) Low carbon emissions technologies according to international standards and;
o) Other technologies determined by the Secretariat of Energy and the Ministry of Environment and Natural Resources, based on energy and hydric efficiency parameters and standards, atmospheric emissions and waste generation, directly, indirectly or in its life cycle.

To reach the clean energy goals and stimulate the power generation coming from clean sources, the LIE established the creation of a new instrument called *Certificados de Energía Limpia* (CELs) or Clean Energy Certificates which are defined as the "Paper issued by CRE that accredits the production of a determined amount of electric energy generated with clean energy and it serves to meet the requirements associated to the consumption of Load Centers".

According to the document *Lineamientos que establecen los criterios para el otorgamiento de Certificados de Energías Limpias y los requisitos para su adquisición* (Clean Energy Certification Criteria), Section II, paragraphs 4, 5 and 7 (Secretaría de Energía, October 31, 2014):

> Shall be entitled to receive CELs for a twenty-year period those representing:
>
> I. Clean Power Plants that started operation after August 11, 2014.
>
> II. The Centrales Eléctricas Legadas (Bequeathed Power Stations) that generates electric energy from Clean Sources and came into operation before August 11, 2014, as long they have done a project to increase their Clean Energy Production. In this case, the twenty years period begins when the project to increase the Clean Energy Production comes into operation, and the number of CELs issued is the Clean Energy generation excess of the greater of the following values:
>   a) The average generation during the years 2012, 2013 and 2014, including in the calculation only the period in which the Power Plant has been operated, and;
>   b) The average generation during the 10 years prior to the project, including in the calculation only the period in which the Power Plant has been operated.
>
> III. Clean Power Plants that have a capacity and have been excluded of a *Contrato de Interconexión Legado* (Bequeathed Interconnection Agreement) to include themselves in a new Interconnection Contract under the terms of the Law, during the period which the contract holder has the right to include such capacity in the Bequeathed Interconnection Agreement. In this case, the number of CELs corresponds to the Clean Energy generated with that capacity.
>
> Clean Generators have the right to receive, at the Clean Power Plants they represent, one CEL per Megawatt-hour generated free of fossil fuels.
>
> The Clean Distributed Generation will have the right to receive one CEL per Megawatt-hour generated free of fossil fuels multiplied by the fuel free energy percentage and divided by the Supplied Energy Percentage.

When fossil fuels are used, the Clean Generators have the right to receive, at the Clean Power Plants they represent, one CEL per Megawatt-hour generated multiplied by the fuel free energy percentage. To accomplish this guideline, the CRE has issued the Efficiency Criteria and the Calculation Methodology of the Fuel Free Energy Percentage Decree (Comisión Reguladora de Energía, December 22, 2016).

With the enactment of the Clean Energy Certification Criteria and the LIE's 123° article, the basic production and consumption of CELs have been established. Figure 2.1 shows the basic dynamic of Clean Energy Certificates for Clean Energy Generation Plants, Electricity Retailers, Market Participant Qualified Users and End Users with Isolated Supply.

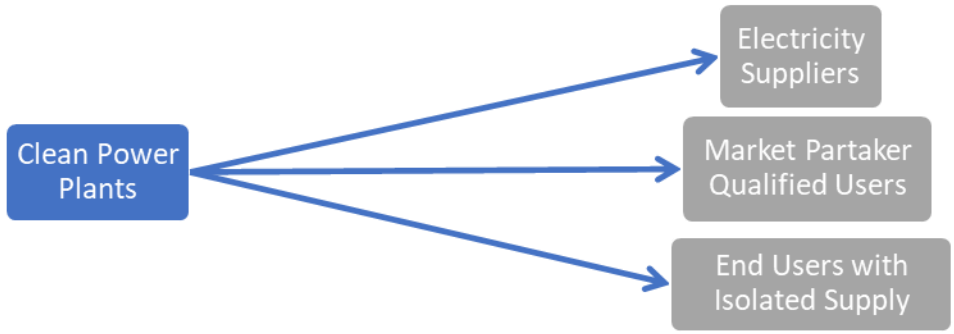


Figure 2.1: Basic Dynamic of Clean Energy Certificates

According to the LIE's subsection I, article 126 "The Secretariat (SENER) will establish the requirements for Clean Energy Certificates acquisition, that the Electricity Retailers, Market Participant Qualified Users and End Users with isolated supply, as well as the holders of Bequeathed Interconnection Agreements associated to the Load Centers consumption that the holder represents or includes". Thus, SENER has already established the previously mentioned requirements to be fulfilled from 2018:

- 5% in 2018 (Secretaría de Energía, March 31, 2015)
- 5.8% in 2019 (Secretaría de Energía, March 31, 2016)
- 7.4% in 2020
- 10.9% in 2021
- 13.9% in 2022 (Secretaría de Energía, March 31, 2017)

Also, according to the Clean Energy Certification Criteria guideline 22, the requirements are calculated as follows:

$$R = \frac{O}{C}$$

Where:

R is the CEL requirement for the Obligation Period, as a consumption percentage.

C is the electricity consumption during an Obligation Period at the Load Centers and Load Points that receive the Obligated Participants. This value is measured in Megawatt-hour.

O is the number of CELs that an Obligated Participant must credit to meet the CEL requirements corresponding to their electricity consumption.

Thus, the requirement is an electricity consumption percentage that needs to be meet with CELs, for example, in 2018 the Obligated Participants must submit to the CRE 5% of their electricity consumption as CEL, however, the Clean Energy Certification Criteria also establishes that an Obligated Participant can choose to differ up to 25% of his CELs obligations per each obligation period, up for two years. Each deferral must be increased by 5% every year until it is settled. However, according to the *Ley de Transición Energética* (Secretaría de Gobernación, 2015), the government established a Flexibility Mechanism applied only at the first four obligation period, where the Obligated Participants can differ up to 50% of their CELs Obligations under the following conditions:

- During the first two obligation periods, when the number of registered CELs is not enough to supply at least 70% of the obligations amount, or
- When the implied CEL price, calculated by the CRE, obtained from basic electricity supply auctions in 2018, 2019, 2020 and 2021, is greater than 60 Investment Units (UDIs)

Those Obligated Participants who do not comply with their CELs Obligation and do not notify their deferral intention to the CRE, must pay a penalty fee between 6 and 42 Mexican wage per CEL (or MWh) that has not been acquired according to Table 2.1. This penalty fee does not exempt the Obligated Participant to comply their CELs obligation, meaning that the participant must pay the penalty fee and buy the missing CELs.

Table 2.1: Penalty Fee (days of minimum wage) per non-complied CEL

	Obligations Compliance was not deferred				Obligations Compliance was deferred			
Non-compliance Percentage	Between 0% and 25%	Between 25% and 50%	Between 50% and 75%	Between 75% and 100%	Between 0% and 25%	Between 25% and 50%	Between 50% and 75%	Between 75% and 100%
First Time	6	8	10	12	8	10	12	14
Second Time	12	16	20	24	16	20	24	28
Third Time or contumacy	18	24	30	36	24	30	36	42

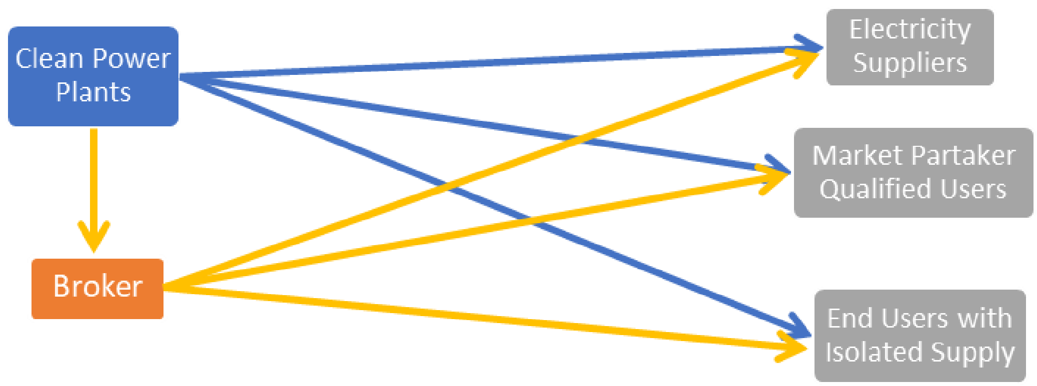
2.2. Clean Energy Certificates Market

The *Bases del Mercado Eléctrico* (Secretaría de Energía, September 08, 2015) mentions that Generators, Vendors and Market Participants Qualified Users are allowed trade:

I. Electric power;
II. Associated Services;
III. Electric power or any other product ensuring the resources adequacy to satisfy the demanded electricity;
IV. The above products, imported or exported;
V. Financial Transmission Rights;
VI. Clean Energy Certificates;
VII. Another products, receivables and penalties required to the efficient operation of the National Electricity System

Therefore, CELs could be acquired through bilateral transactions called Electric Coverage Agreements, where these contracts can be traded independently (e.g. one Electricity Contract and one CEL Contract independent each other) or Electric Coverage Agreements including CELs held through Long-Term Auctions, or through a Short-Term Clean Energy Certificates Market where the *Centro Nacional de Control de Energía* (CENACE) operates a CEL Spot Market at least once a year, beginning in 2018. It's important to mention that the CEL Spot Market is open to anyone according to the Clean Energy Certification Criteria and thus a third CEL market participant, called Broker, can be added to the fundamental dynamics of CELs as shown in Source: Own Creation

Figure 2.2. Until the end of 2017, CELs can only be acquired through auctions.



Source: Own Creation

Figure 2.2: Clean Energy Certificates Market Structure

An electricity auction is roughly like any other English auction; however, according to the *Bases del Mercado Eléctrico* (Electric Market Bases), an electricity auction starts with a Buyer requiring an amount of one or more products at a specific period (usually one year), and for each product the buyer sets a maximum price. Subsequently, the buyer receives offers from bidders and, according to the bidder's price, the amount required by the buyer is dispatched from the lowest to the highest price, until the required amount by the Buyer is completely covered. Finally, the product price has the value of the last dispatched price and each winning bidder receives as payment said price for the product offered. In case that the required amount is not covered, the Buyer has the option to raise the maximum price he is willing to pay to meet the required amount, leave the auction without a product or get some of his requirements for the price he established before. If the product requirement is covered, the electricity auction allows the buyer to do more auctions or iterations and, on each auction, decrease the maximum price until the requirement is met at the lowest price that could be possible.

In Mexico, the Long-Term Auctions are held annually, and they allow a buyer, called Load Responsible Entity, to acquire either the Electric Power, Clean Energy and/or Clean Energy Certificates from the winning Bidders. The contracts celebrated at the Long-Term between the Buyer and the Bidders have a 15- or 20-year term.

2.2.1. Long-Term Auctions

As mentioned before, Long-Term Auctions allows the Basic Service Retailers to enter into contracts to meet their needs of Electric Power, Electric Energy and CELs. In Mexico, the Electric Power and Electric Energy Contracts have a 15-year term, while CEL Contracts have a 20-year term. The main goal of these auctions is to let sellers or bidders have a stable source of payments, supporting the financial investments required to develop new power plants or repower the existing ones.

Until 2017, three Long-Term Auctions have been held, where the buyer has been *Comisión Federal de Electricidad* (CFE) and the bidders have been numerous market participants or electricity generation companies. These three auctions have been important to the CEL Market because the CEL Price obtained at these auctions is considered as the starting point for the CEL Market Price.

To calculate the CEL price offered by a bidder in their Selling Offer, the *Manual de Subastas de Largo Plazo* (Long-Term Auctions Handbook) establishes in sections 4.5 and 4.6 the methodology to calculate the price for each product and to adjust the prices due to inflation and exchange rate (Secretaría de Energía, November 19, 2015). The first one shows how to obtain the price for each product, while the second one shows how to obtain an equivalent price for each Selling Offer depending on the contract dollar or pesos indexing.

The first auction has left satisfactory results, according to (Jiménez, 2016) 5 million 380 thousand 911 CELs per year were covered, representing 84.39% of CFE first request; also 5 million 402 thousand 880 MWh per year of energy were covered, representing 84.93% of the demanded energy. The average reference price per CEL obtained in this auction was 318.11 [MXN/CEL] (18.15 [USD/CEL]).

The second Long-Term Auction once again had CFE as a buyer requiring 10.62 TWh of Clean Energy, 10.62 million of CELs and 1,483 MW of power (capacity). In this auction, the initial prices, as seen in Figure 2.3, stood at 39 [USD/MWh], 19 [USD/CEL] and 87 [USD/kW], while at the final iteration, the prices stood at 12 [USD/MWh], 7 [USD/CEL] and 9 [USD/kW] (PÖYRY Management Consulting). The average price per CEL obtained in this auction was 254.64 [MXN/CEL] (13.30 [USD/CEL). Compared to the first auction, the average CEL Price decreased around 6 USD.

The Second Long-Term Auction results were:

- The participants' offers were more than twice of the required amount by CFE.
- Around one-third of the participants acquired contracts.
- 8.9 TWh of the 10.62 TWh required clean energy was covered and was distributed as follows:
    - Solar Energy: 4.83 TWh (54.3%)
    - Wind Energy: 3.87 TWh (43.5%)
    - Geothermal Energy: 0.19 TWh (2.2%)
- Maximum Prices per product:
    - CELs: $375.25 MXN per CEL (20.7 USD/CEL)
    - Average Energy and CELs: $33.47 USD/MWh (Centro Nacional de Control de Energía, 2016)

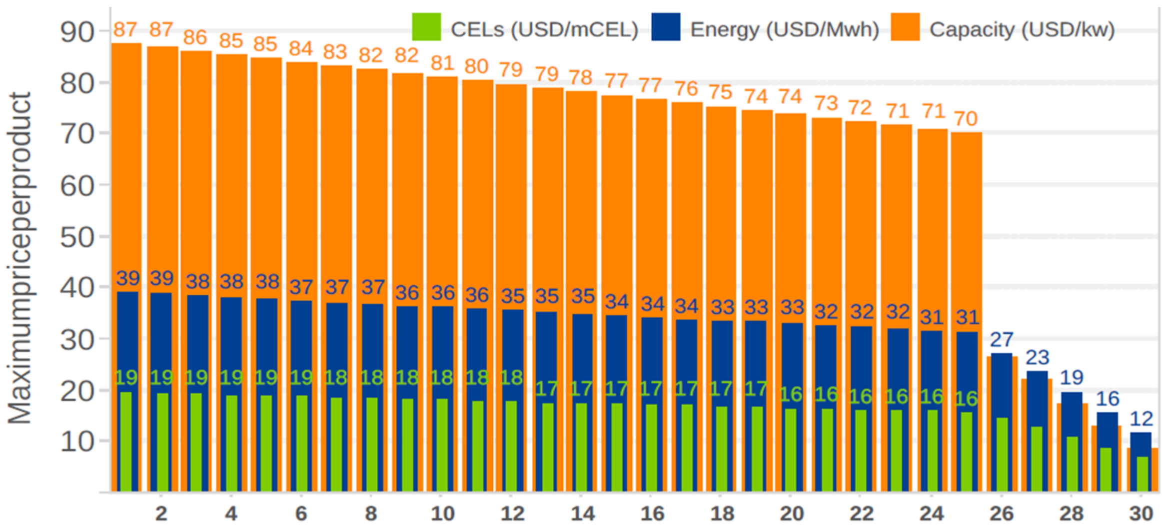


Figure 2.3: Maximum Prices Offered at the 2nd Long-Term Auction by CFE per product

Source: PÖYRY Management Consulting

Finally, the third Long-Term Auction held in 2017 was the first of its kind due to the participation of two buyers besides CFE: Iberdrola Clientes and Menkent (CEMEX). 90.2% of the required Energy, 97.8% of the required CELs and 41.9% of the required Power were met in this auction, with the following figures:

- 5.49 million MWh of Energy
- 5.95 million CELs
- 593 MW-year of Power

The CELs and energy offers were met with merely solar and wind energy, contributing 55.35% of Energy and 58.31% of CEL with solar energy and 44.65% of Energy and 41.69% of CEL covered with wind energy (Centro Nacional de Control de Energía, November 22, 2017).

The preliminary results of this auction shown a decrease in prices compared to the second long-term auction. The average prices obtained were:

- Clean Energy (Energy+CEL): 20.57 [USD/MWh+CEL] (38.54% lower than previous auction)
- Power: 36,253 [USD/MW-year]
- Clean Energy Certificates: 7.28 [USD/CEL]

The average CEL price obtained at the third auction is considered as the reference for the opening CEL Market in 2018, and from there on, the price must be determined through supply and demand dynamics.

It’s worth to mention that a CEL doesn’t expire until it is presented to the CRE as a CEL compliance, meaning that once a CEL is emitted it can be traded over and over.

2.3. Clean Energy Certificates Issues

As mentioned before, CELs main goal is to boost clean energy generation in Mexico and consequently the decrease of Mexico’s GHG emissions, but as a new implementation, CELs have presented some problems due to uncertainty in prices. In 2016 the *Cámara Nacional de la Industria de la Transformación* (CANACINTRA) was dissatisfied for CEL obligations that the companies they stand for must comply and it considered that with this, the electricity prices will rise and, also, showed their doubt about CELs supply and demand[9]. One year later, the president of CANACINTRA stated that few companies will be using clean energy, since they will be forced to either generate their own clean energy as a first option or acquire it from other companies as second option[10], and any of these options will need a big investment by the industry.

Another issue is that the Qualified Retailers not belonging to a clean energy company could harm their competitiveness because they will be forced to acquire CELs in the CELs Market, while Qualified Retailers belonging to a clean energy company could acquire CELs directly of their clean energy company at a lower price compared to the market price[11].

It is important to mention that, almost 10,000 MW of clean capacity are still in the former regime, that is the *Ley del Servicio Público de Energía Eléctrica* (LSPEE), and in 2017 only 1,028 MW have migrated to the new regime (the Electric Industry Law) and are allowed to enter to the Wholesale Electricity Market. Because of this, it is believed that the 2018 CEL requirement will not be met, since the capacity, and therefore, the energy credited to receive CELs will not be enough to satisfy the CEL Demand.

The main issue with the creation of a CEL System is that the Market Participants still do not know several punctual details about Wholesale Electricity Market, which complicates the estimation of future CELs prices and therefore, the prices offered in the auctions could be far from reality, forcing them to breach their contracts.

Ultimately, with all the regulations surrounding the CELs, it's clear that their implementation must need funding to take place and, in the end, the CELs price will be visible on the electricity bill of every single Mexican consumer, leaving the necessity to know in advance the most likely CEL scenarios and to take action at a serious CEL price increase, taking into account the CEL production and CEL demand which are described in this chapter, and this dynamic can be introduced at the Mexican planning system as a new variable.

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[9] http://www.milenio.com/negocios/Preparan-amparos-Ley-Transicion-Energetica_0_665933419.html
[10] http://www.milenio.com/negocios/empresas-energias-limpias-combustibles-industrias-milenio-edomex-noticias_0_1002499888.html
[11] https://www.energiaadebate.com/blog/1818/

3. Mexican Clean Energy Certificate Market Modeling

In this chapter, the model to determine the impact of the CEL Market on the Mexican Electric System is established following the legal bases and the dynamics of the CEL Market mentioned in Chapter 2. To model this impact, it is necessary to do an analysis of the CELs dynamic and later give a mathematical interpretation of the CELs dynamic taking into consideration all the variables that could affect it. The analysis process shapes the basic algorithm of the Mexican Energy Certificate Market model and the mathematical interpretation process provides its properties to the CEL Market algorithm.

The analysis starts with the breakdown of each process involved at the CELs dynamic since its issuance and subsequent trade until its liquidation. Once the CELs dynamic is established the next step of the analysis is the representation of the CELs Supply and Demand behavior through several equations, and its output is used at the third step to obtain the CEL price. This third step follows the Supply and Demand model used at the microeconomic theory and it is represented with a linear equation which can be considered as an approximation of the real behavior. Due to the lack of information regarding on this topic, it is not possible to obtain a polynomial equation, however once the CEL Market is well established this equation could be refined.

The last step of the analysis consists in calculate the potential impacts of a Mexican CEL Market on the investment of new clean energy projects, the main assumption of this step is that thanks to the CELs price, the investment or the investor trust on this kind of projects should increase and, since the impact is measured over a project investment, the tool used to obtain this value is the economical evaluation of each clean energy project.

After the CELs dynamic is represented through equations, the last thing to do is to obtain the model of this dynamic by arranging all the processes and introducing all the needed equations into a single integrated system.

3.1. Analysis of Clean Energy Certificates Cycle

The Clean Energy Certificates cycle starts one year prior a CEL obligations period with SENER creating a CEL demand by establishing the next-period CEL requirements according to LIE's article 126, subsection I. Then, during the CEL obligations period, the CRE issues and delivers CELs to the Clean Power Plants according to the electricity they generated each calendar month according to the Clean Energy Certification Criteria, being January the first and December the last month of the CEL obligations period. Here is where the Obligated Participants are free to choose to liquidate their CELs obligations either monthly or annually at the end of the period and each liquidated CEL are removed from the CELs market and the cycle repeats itself at the next obligation period as shown in Figure 3.1. It is worth to mention that the sub-process named "Clean Power Plants trade CELs" is the CELs dynamic presented in Figure 2.1: Basic Dynamic of Clean Energy Certificates and Source: Own Creation

Figure 2.2: Clean Energy Certificates Market Structure.

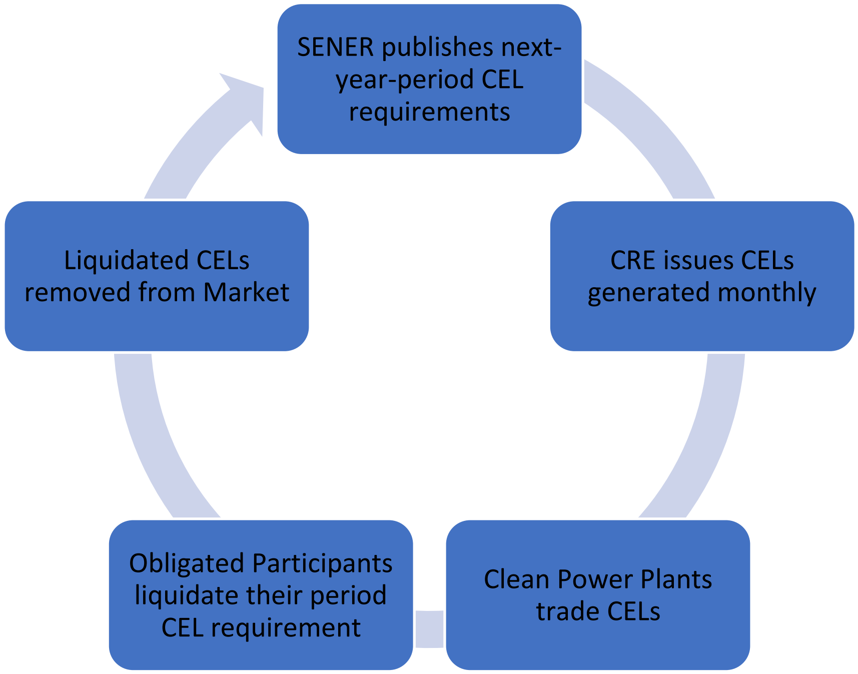

Figure 3.1: Clean Energy Certificates Cycle

The first box of the CELs cycle named "SENER publishes next-year-period CEL requirements" takes place when SENER establishes a CEL requirement as a consumption percentage of Electricity Retailers, Market Participant Qualified Users and End Users with isolated supply, as well as the holders of Bequeathed Interconnection Agreements associated to the Load Centers consumption that the holder represents or includes. To represent this order into an equation, every single electricity user in Mexico is considered an Obligated Participant, since basically most of the Obligated Participants, that is Electricity Retailers, Market Participant Qualified Users and End Users with isolated supply, are the biggest consumers of End Use electricity in Mexico. This means that every electricity end user in Mexico is obligated to comply the CEL requirements, however this does not mean that every electricity user is forced to buy CELs, but this really means that these users comply their CEL requirements through entities named retailers or market participant qualified users or End Users with isolated supply. Owing to the legal situation of the "holders of Bequeathed Interconnection Agreements associated to the Load Centers consumption that the holder represents or includes" and to facilitate calculation, this Obligated Participant is not considered as an Obligated Participant.

After this process and once the CEL requirements period begins, the CRE issues CELs to all the Clean Power Plants at the end of each calendar month according to the Clean Energy Certification Criteria, this process is shown at Figure 3.1 and named "CRE issues CELs generated monthly". The Clean Energy Certification Criteria Guideline 3, paragraph 4 describes the characteristics of the Power Plants credited to receive CELs which basically consists of three standards, however in this paper, Clean Power Plants that are credited to receive CELs are those who comply only with indent I, meaning that only Clean Power Plants that began operations after August 11, 2014 are credited to receive CELs. Indents II and III are not considered due to the highly detailed information needed to incorporate them to the analysis, since it requires the schedule data of repowering for "old" Clean

Power Plants and the Interconnection Status of every single Clean Power Plant which on February 2018 is still not available to the public. The Criteria used in this paper to consider a Power Plant as a credited clean power plant to receive CELs consists of two standards as seen in Figure 3.2.

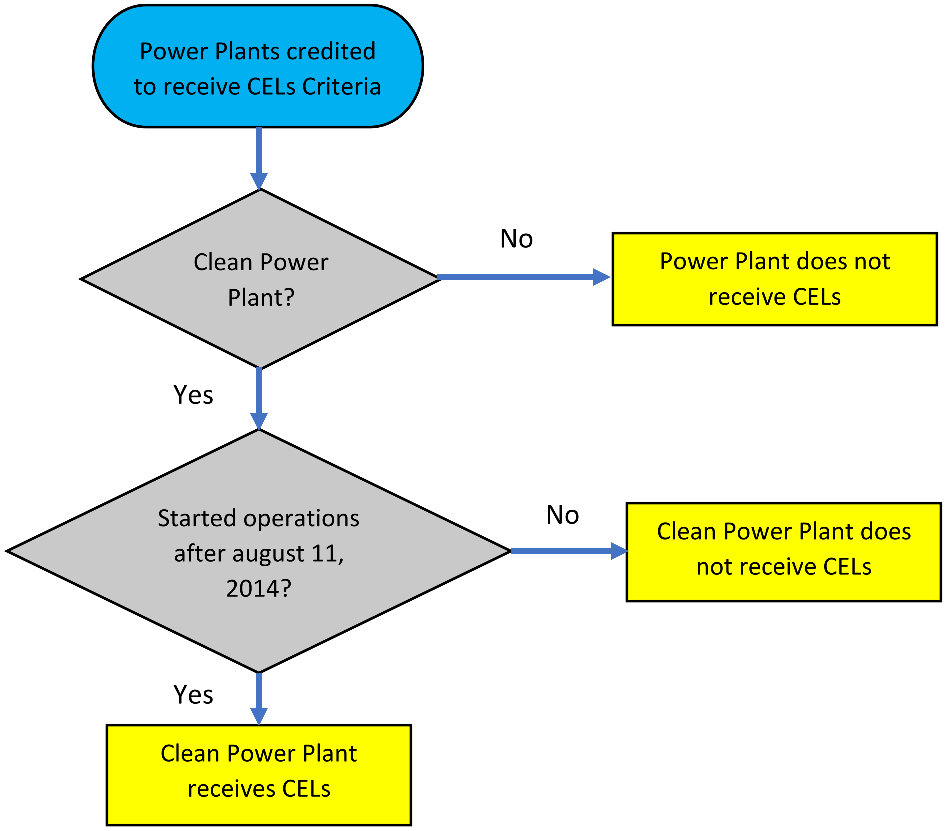

Figure 3.2: Power Plants Credited to Receive CELs Criteria

The next process of the cycle named "Clean Power Plants Trade CELs" takes place after a Clean Power Plant receives CELs equal to the energy generated at the power plant in the period and is when CELs acquire their market price by trading them to the Obligated Participants, either through the CEL Market or a Long-Term Auction. The importance of this process lies at the potential value of the price of each traded CEL, which defines if the investment on new clean power plants increases. This process is explained in detail in Section 3.3.

The fourth process named "Obligated Participants liquidate their period CEL requirement" occurs when Obligated Participants demonstrate that they comply with the period CEL requirement and is when Obligated Participants choose to defer or not their compliance obligations. This decision is ultimately made by the same Obligated Participants according to their interests, that is, depending on their economic and financial situation or the number of CELs available in a period; meaning that CELs demand is greater than CELs supply. This last situation, where a CELs compliance deferral happens, is the only situation taken into consideration for the analysis and subsequent simulation of CELs, since the introduction of the economic and financial situation of every Obligated Participant into the analysis and simulation requires a great amount of data and even with that, being domestic users of electricity the most part of the Obligated Participants, the decision to defer CELs compliance falls only on the dynamics of supply and demand of CELs.

The last process named "Liquidated CELs removed from Market" happens when the CRE removes the liquidated CELs mentioned in the fourth process from their system, leaving a CELs inventory for the next obligation period.

3.2. Clean Energy Certificates Supply and Demand

According to the analysis and assumptions made in Section 3.1 the initial value of CELs Demand are calculated by Equations (1) and (2):

$$CEL_{demand_n} = CEL\ Obligation\ \%_n * EUEC_n \quad (1)$$

$$EUEC_n = GC_n - PPOU_n - TDL_n \quad (2)$$

Where:

$\boldsymbol{CEL_{demand_n}}$	is Mexico's CEL consumption at the "n" year.
$\boldsymbol{CEL\ Obligation\ \%_n}$	is the CELs Obligation Percentage published by SENER.
$\boldsymbol{EUEC_n}$	is Mexico's End Use electricity consumption, measured in MWh.
$\boldsymbol{GC_n}$	is Mexico's Gross Electricity Consumption, measured in MWh.
$\boldsymbol{PPOU_n}$	is the own use of electricity in every Power Plant in Mexico, measured in MWh.
$\boldsymbol{TDL_n}$	are Mexico's electricity losses in Transmission and Distribution, measured in MWh.
$\boldsymbol{n}$	the year in study.

According to the definition of Clean Energy Certificates found at the Electric Industry Law, *"*one CEL will be equal to one Megawatt-hour of Clean Energy generated". This definition is represented by the Equation (3):

$$CEL_{supply_n} = CEC_n \quad (3)$$

Where:

$\boldsymbol{CEL_{supply_n}}$	is the Mexico's CEL supply, measured in CELs.
$\boldsymbol{CEC_n}$	is the Clean Energy Generated by every Clean Power Plant credited to receive CELs, measured in MWh.

Since Clean Energy Certificates do not expire, the first approximation of the CEL supply depends only on the Clean Energy generated, however this does not show the impact of the CEL Inventory, therefore, to represent the CEL Inventory, a new variable is added as shown in Equation (4):

$$CEL_{supply_n} = CE_n + CEL\ Inventory_{n-1} \quad (4)$$

Where:

$\boldsymbol{CEL\ Inventory_{n-1}}$ is the Mexico's CELs Inventory of the previous period.

The amount of CELs Inventory at the beginning of each period depends on the previous-period CELs supply and CELs demand, where two events can take place depending on if a CEL shortage happens, as it is shown in Equation (5) or, a CELs surplus exists, as it is shown in Equation (6):

$if\ CEL_{supply_n} < CEL_{demand_n}$:

$$CEL\ Inventory_n = 0\ ;\ D_n = \frac{CEL_{demand_n} - CEL_{supply_n}}{CEL_{demand_n}}\ ;\ i_n = 1 \quad (5)$$

$if\ CEL_{demand_n} \leq CEL_{supply_n}$:

$$CEL\ Inventory_n = CEL_{supply_n} - CEL_{demand_n}\ ;\ D_n = 0;\ i_n = \frac{CEL\ Inventory_n}{CEL_{supply_n}} \quad (6)$$

Where:

$\boldsymbol{D_n}$ is the Mexico's CELs compliance deferral as a fraction.

$\boldsymbol{i_n}$ is the CELs fraction that remains as inventory.

As mentioned in Section 3.1, a CEL compliance deferral takes place when the CELs demand is greater than the CELs supply but only up to a 25% of Obligated Participants CEL compliance, meaning that up to 25% of CELs demand per period can be deferred. However, only at the first two obligation periods (2018 and 2019), and thanks to the Flexibility Mechanism, the deferral percentage can go up to 50%, when at least 70% of the obligations are not met with CELs. These criteria are represented by Equations (7) and (8):

$$if\ \left(\frac{CEL_{supply_n}}{CEL_{demand_n}} \geq 0.7\ \ \&\&\ n \leq 2019\ \ \&\&\ D_n > 0.5\right)\ \therefore\ D_n = 0.5 \quad (7)$$

$$if\ (D_n > 0.25\ \ \&\&\ n > 2019)\ \therefore\ D_n = 0.25 \quad (8)$$

The amount of unfulfilled CELs creates a breach of the CEL obligation, which is penalized according to the fees shown in Table 2.1. The value of the deferral and the breach percentage can be obtained with Equations (9) and (10):

$$Deferral_n = D_n * CEL_{demand_n} \quad (9)$$

$$Breach_n = \frac{\left[(1 - D_n) * CEL_{demand_n}\right] - CEL_{supply_n}}{(1 - D_n) * CEL_{demand_n}} \quad (10)$$

To contemplate the previous period CEL deferral on the CELs demand, the variable "Deferral" with a 5% of interest per year is added to Equation (1), leading to the actual value of CELs demand as shown in Equation (11):

$$CEL_{demand_n} = [CEL\ Obligation\ \%_n * EUEC_n] + 1.05Deferral_{n-1} \quad (11)$$

However, Equations (1) and (11) are valid only when the $CELs\ Obligation\ \%_n$ is known. In other words, these equations are valid only when $n < 2023$ since the CELs Obligations percentage for 2018, 2019, 2020, 2021 and 2022 were already published by the SENER. To represent the situation when $n \geq 2023$ it is considered that the Clean Energy Generation and the CEL demand have a linear dependency as seen in Figure 3.3.

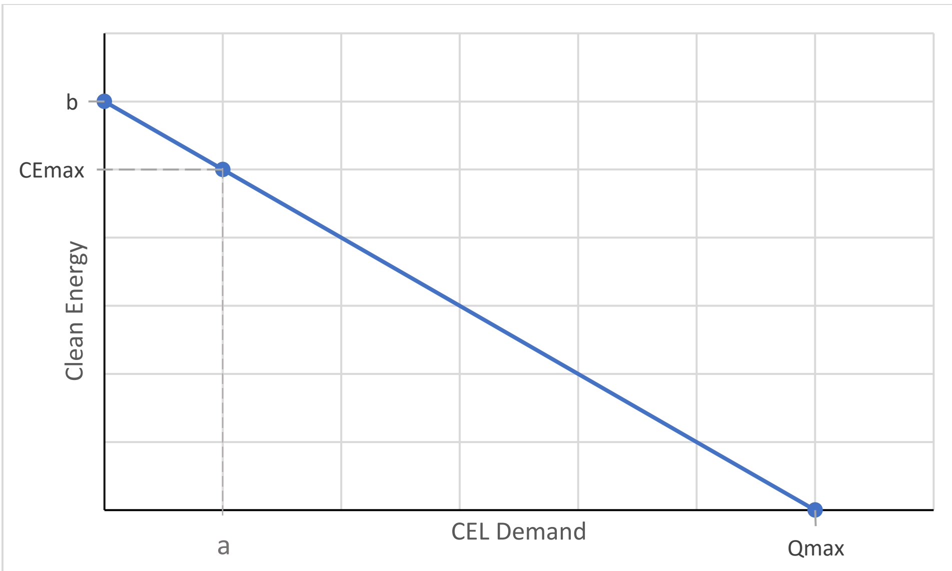

Figure 3.3: CEL Demand Behavior

This curve is built under the assumption that when there is no Clean Energy Generation ($y_n = 0$) the CELs demand reaches its maximum value $\left(CEL_{demand_n} = Q_{max_n}\right)$ and that there is no CELs demand ($CEL_{demand_n} = 0$) when the clean energy generation reaches the “b” value ($y_n = b_n$). Since the value of "b_n" is unknown, it is necessary to make another two assumptions:

1) It is considered that the obligation percentage of the "$n + 1$" period is not lower than the "n" obligation percentage, which means that the CEL Demand is not lower than the end use of electricity multiplied by the previous period obligation percentage as seen in Equation (12).

$$a_n = CELs\ Obligation\ \%_{n-1} * EUEC_n \quad (12)$$

2) The CEL Demand has the value of "a_n" only when the Clean Energy Generation is enough to cover both the clean energy goals and the "$n - 1$" period deferral as seen in Equation (13).

$$CE_{max_n} = CEG_n + \frac{1.05Deferral_{n-1}}{1 - PPOU\%_n - [TDL\%_n * (1 - PPOU\%_n)]} \quad (13)$$

Where:

$\boldsymbol{a_n}$ is the lowest CEL demand of the "n" period.

$\boldsymbol{CEG}_n$ is the Clean Energy Goal of the "n" period, measured in MWh.

$\boldsymbol{PPOU\%_n}$ are the Own Uses of the Mexican Electric System, measured as a percentage of the gross consumption.

$\boldsymbol{TDL\%_n}$ are the Transmission & Distribution Losses of the Mexican Electric System, measured as a percentage of the gross consumption.

With these assumptions, the curve can be represented with the following equations:

$$CE_{max_n} = m_n(a_n) + b_n \tag{14}$$

$$0 = m_n\left(Q_{max_n}\right) + b_n \tag{15}$$

According to Equations (14) and (15), the value of m_n and b_n can be calculated as showed in Equation (16) and Equation (17):

$$m_n = \left(\frac{CE_{max_n}}{a_n - Q_{max_n}}\right) \tag{16}$$

$$b_n = -Q_{max_n} * \left(\frac{CE_{max_n}}{a_n - Q_{max_n}}\right) \tag{17}$$

The value of the CEL Demand is obtained as depicted in Equation (18):

$$CEL\ Demand_n = \frac{CE_n - b_n}{m_n} \tag{18}$$

The value of the CELs obligations percentage can be obtained by clearing the $CELs\ Obligation\ \%_n$ from Equation (1) and then replacing the CEL_{demand_n} variable with Equation (18)(16):

$$CELs\ Obligation\ \%_n = \frac{CE_n - b_n}{EUEC_n * m_n} \tag{19}$$

3.3. Clean Energy Certificates Price

With the creation of a Clean Energy Certificates Market, the dynamic between CEL supply and CEL demand is going to define the value of the CEL price following the economic model of supply and demand. According to (Dominick, 2009) the *Demand* is "The amount of a satisfactory that a person wishes to obtain at a given period is a function of the price of this satisfactory" and the *Supply* is "The amount of a satisfactory that an individual producer is willing to sell at a given period is a function of the satisfactory price or depends from this and the production costs of the producer", the graphic definitions of *Supply and Demand* can be seen in Figure 3.4.

It can be noted that in most cases the demand curve has a negative slope, this means that if the price of this product decreases the demanded quantity increases, while conversely, the supply curve has a positive slope, meaning that if the price increases the supplied quantity decrease. Also (Dominick, 2009) describes that "when the amount of a satisfactory being demanded on the market per unit of time is equal to the amount being supplied to the market at the same period of time" the market is in *Equilibrium.* Geometrically, this equilibrium happens at the intersection between the supply curve and the demand curve. The price and quantity where equilibrium exists are called the *equilibrium price* and the *equilibrium quantity.*

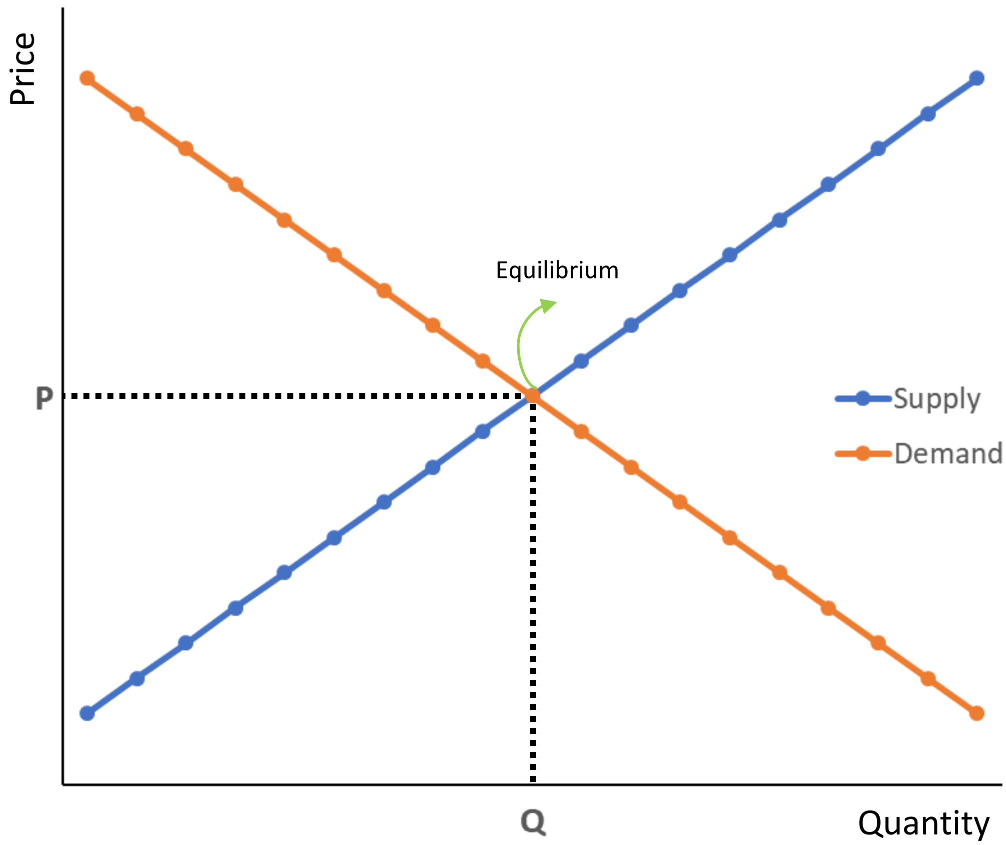

Figure 3.4: Supply and Demand Basics

One of the parameters needed to analyze the behavior of supply and demand curves is the *elasticity* presented by each one of them, where the *Price Elasticity of Demand* "measure the percentage change of the demanded quantity of a satisfactory per time unit, which results of a percentage change at the satisfactory price" (Dominick, 2009). The *price elasticity of demand* can be obtained with Equation (20).

$$e_D = -\frac{\Delta Q}{\Delta P} * \frac{P}{Q} \tag{20}$$

Depending on the value of the *price elasticity of demand*, the demand curve can be named *elastic* if $e > 1$, *inelastic* if $e < 1$ and *unitary* if $e = 1$.

Likewise, the *Price Elasticity of Supply* "measures the percentage change at the supplied quantity of a satisfactory per time unit due to a percentage change at the satisfactory price" (Dominick, 2009) and can be obtained as shown in Equation (21):

$$e_S = \frac{\Delta Q}{\Delta P} * \frac{P}{Q} \tag{21}$$

Depending on the value of this elasticity, the supply curve can be named *inelastic* if $e < 1$, *elastic* if $e > 1$ or *unitary* if $e = 1$. Graphically, when the supply curve intercepts the quantity axis the curve it can be called *inelastic supply*, when the curve intercepts the price axis the curve can be called *elastic curve* and when the supply curve intercepts the origin, the curve can be called *unitary curve*.

By extrapolating this microeconomic model to the CELs Market as a first approximation, it is considered that the price of the CELs demand presents a linear behavior with a negative slope, like an elastic curve, since the uncertainty involving the CEL price and the CEL Market complicates the estimation of a "real" demand equation.

Thereby, the price of the CELs demand follows the same pattern seen in Figure 3.5 and is represented in Equation (22) as a linear equation:

$$P_{Demand_n} = \left(-\frac{P_{max_n}}{Q_{max_n} + 1.05Deferral_{n-1}} * Q_n\right) + P_{max_n} \tag{22}$$

Where:

$\boldsymbol{P_{Demand_n}}$ is the potential price per CEL in Mexico.

$\boldsymbol{P_{max_n}}$ is the potential maximum price per CEL in Mexico.

$\boldsymbol{Q_{max_n}}$ is the maximum amount of CELs demand in Mexico.

$\boldsymbol{Q_n}$ is the amount of CELs demand in Mexico.

Figure 3.5: Clean Energy Certificates Price Graphic Representation

The potential maximum price per CEL (P_{max_n}) is equal to the maximum penalty fee shown in Table 3.1, which means that the value of P_{max_n} depends on the value of the breach and the contumacy times in which the Obligated Participants have not met their obligations. This price is considered as the maximum price per CEL that Obligated Participants are willing to pay.

Table 3.1: Maximum CEL prices[12] [USD/MWh]

Breach Percentage	Between 0% and 25%	Between 25% and 50%	Between 50% and 75%	Between 75% and 100%
First Time	35.95	44.94	53.92	62.91
Second Time	71.90	89.87	107.85	125.82
Third Time or contumacy	107.85	134.81	161.77	188.74

The maximum amount of CELs demanded (Q_{max_n}) is the maximum value possible of Clean Energy generation, as if every clean power plant were credited to receive CELs. This means that CELs demand should never exceed the maximum Clean Energy generation at the "n" period, since this could lead to a serious CEL outage. Equation (23) depicts this situation:

$$Q_{max_n} = \left(\sum_{t=1}^{T} CF_{1,t} * Cap_{n,t} * 8760 \right) \quad (23)$$

Where:

$\boldsymbol{t}$ is the generation technology.

$\boldsymbol{CF_{1,t}}$ is the capacity factor of the "t" generation technology at the first obligation period.

$\boldsymbol{Cap_{n,t}}$ is the installed capacity of the "t" generation technology at the "n" obligation period.

As seen in Equation (24), the elasticity of the CELs demand price is always greater than one, meaning that the CELs demand behaves as an elastic curve:

$$e_D = -\frac{Q_{max}}{P_{max} - P_{min}} * \frac{P}{Q} > 1 \quad (24)$$

Even though the CELs demand has an elastic behavior, the same cannot be told about CELs supply, which behaves as an inelastic curve, since the main purpose of a Power Plant is not the CELs generation but the electricity generation, meaning that Clean Power Plants are not going to adjust their electricity generation depending on the CELs Price. According to this fact, Clean Power Plants generates the maximum amount of electricity possible while indirectly generate the maximum amount of CELs regardless the value of the CELs price, which implies that the CELs supply quantity

[12] It is considered that the 2018 minimum wage in Mexico is 88.36 [MX$/Day] and the exchange rate until December 31, 2017 was 19.6629 [MX$/USD]

is constant and the CELs supply price does not depend of the amount of CELs supply. Equation (25) represents this demeanor:

$$0 \leq P_{supply_n} < \infty \quad (25)$$

Where:

$\boldsymbol{P_{supply_n}}$ is the potential price per CEL that suppliers could accept.

However, as seen in Figure 3.6, by combining both curves in the same graphic, the maximum value possible of P_{supply_n} has the value of the maximum price per CEL demanded (P_{max_n}):

$$0 \leq P_{supply_n} \leq P_{max_n} \quad (26)$$

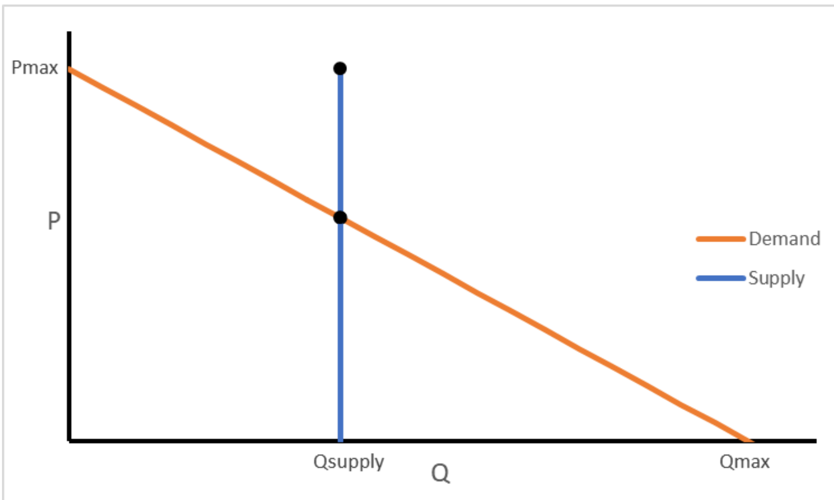

Figure 3.6: Clean Energy Certificates Supply and Demand Curves

According to Equation (27), the supply quantity (Q_{supply_n}) is never going to be greater or equal than the maximum amount of CELs demanded (Q_{max_n}). This means that the maximum possible amount of CELs supply happens when absolutely all the electricity in Mexico is generated by Clean Power Plants.

$$0 \leq Q_{supply_n} \leq Q_{max_n} \quad (27)$$

As mentioned in Section 3.2, the CEL Deferral allows to the Obligated Participants to postpone up to 50% of their CEL Obligation in the first two Obligation Period and up to 25% for the other additional periods. Because of this situation, the y-intercept of the CEL Demand Curve shown in Figure 3.6 changes according to the value of the deferral percentage. Equation (28) represents the effect of the CEL Deferral on the Equilibrium Price.

$$P_{eq_n} = [P_{max_n} * (1 - D_n)] - \frac{P_{max_n} * CEL_{supply_n}}{Q_{max_n} + 1.05Deferral_{n-1}} \quad (28)$$

As seen in in Figure 3.7, the CEL Demand curve moves parallel depending on the Deferral Value and therefore, the CEL Deferral can also be considered as a form to ease the Equilibrium Price per CEL that the Obligated Participants are going to pay.

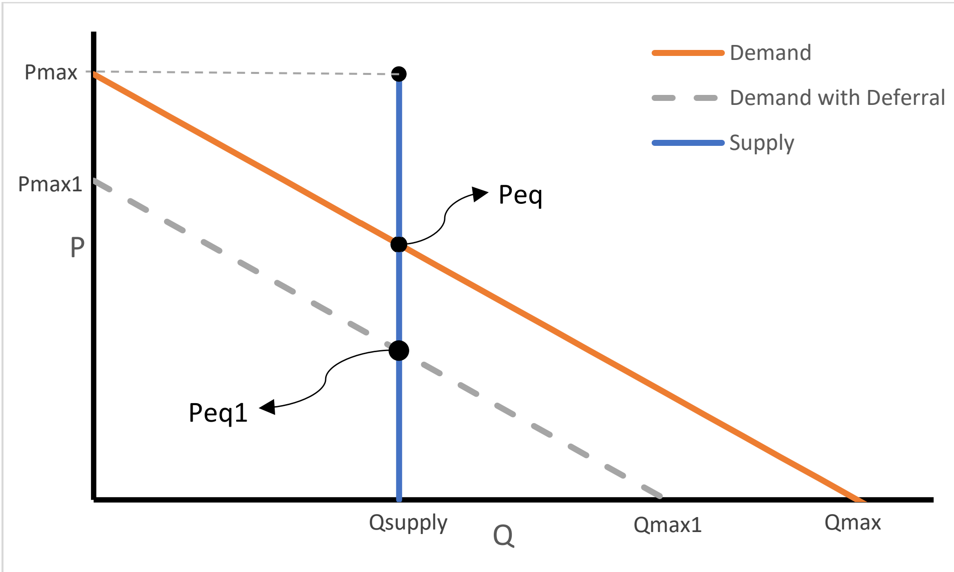

Figure 3.7: CEL Deferral Effect

3.4. Clean Energy Certificates Impact

One of the main objectives derived from Mexico's Energy Reform is to reach the clean energy generation goals established in the *Electric Industry Law* and the main instrument proposed to achieve these goals is the emission of Clean Energy Certificates, which, through sale transactions of CELs such as Long-Term Auctions or the CEL Market, increases the income of those who generate electricity with clean sources. According to this, the first postulation to estimate the impact of the CEL system on new clean energy projects is that the income of these new projects to be executed in Mexico increases depending on the CELs price obtained in Section 3.3.

A widely used way to evaluate the effect of a new law on a specific energy project, is to estimate the changes that could happen after such enactment, by calculating the Cash Flow that the project will have in the future. In general, this Cash Flow includes the status of the Income, Costs, Depreciation, Taxes and Investments that will be made by the project.

In every power generation project it is considered as "income" to the profit coming from the electricity sales, however, by including the concept of "CELs Income" to the Cash Flow, two different Cash Flows can be obtained: one where the power plant do not receive CELs and the second one where the power plant do receive CELs (See Figure 3.8).

Nevertheless, to consider the Cash Flow as a decision-making tool, it is necessary to add two more assess methods that consider the value of money through time: The Net Present Value (NPV) and the Internal Rate of Return (IRR).

The NPV is the value of an investment project measured in current money, in other words, is the equivalent in current money (USD, MXN, €, GBP, etc.) of all the present and future income and expenses that constitute the project. The value of the NPV shows if an investment can generate value to the owner and if this disbursement is worth. The NPV is calculated according to Equation (29).

$$NPV = -I_0 + \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} \tag{29}$$

Where:

$\boldsymbol{I_0}$ is the initial investment.

$\boldsymbol{CF_t}$ is the Cash Flow at the end of the "t" period.

$\boldsymbol{r}$ is the discount rate of the project.

$\boldsymbol{n}$ number of periods.

Electric Power Income (+)	Electric Power Income (+)
	CELs Income (+)
Total Income = EPI (+)	Total Income = EPI + CELI (+)
Fixed Operation & Maintenance Costs (-)	Fixed Operation & Maintenance Costs (-)
Variable Operation & Maintenance Costs (-)	Variable Operation & Maintenance Costs (-)
Fuel Costs (-)	Fuel Costs (-)
Transmission Costs (-)	Transmission Costs (-)
Total Costs = FOMC + VOMC + FC + TrC (-)	Total Costs = FOMC + VOMC + FC + TrC (-)
Operating Income = TI – TC	Operating Income = TI – TC
Depreciation	Depreciation
Machinery and Equipment (+)	Machinery and Equipment (+)
Buildings (+)	Buildings (+)
Total Depreciation = ME + B (+)	Total Depreciation = ME + B (+)
Profit Before Taxes = OI – TD (+)	Profit Before Taxes = OI – TD (+)
Taxes (+)	Taxes (+)
Profit After Taxes = PBT - T	Profit After Taxes = PBT - T
Investments (+)	Investments (+)
Working Capital Changes (+/-)	Working Capital Changes (+/-)
Cash Flow = PAT + TD – I + WCC	Cash Flow = PAT + TD – I + WCC

Figure 3.8: Energy Project Cash Flow with and without Clean Energy Certificates Income

The NPV has three possible interpretations:

- If $NPV > 0$, it means that the project generates profits;

- If $NPV < 0$, it represents the cost of committing ourselves in the project;
- If $NPV = 0$, it means that the project does not generate profits and neither losses.

The Internal Rate of Return (IRR) is the discount rate that, once applied to the expected Cash Flows of the project, generates a value equal to the current value of the investment to be made to obtain such Cash Flows. The main purpose of the IRR is to find a return rate that summarizes the merits of a project. It is not possible to obtain an equation to calculate the IRR, since the resulting equation is an Nth order polynomial and the number of possible solutions increase according to the value of "n", however the IRR can be obtained either through trial-and-error or using specialized software.

Unlike the NPV, the IRR needs to be compared with the discount rate of the project, meaning that:

- If $IRR > r$, it is recommended to invest on the energy project since it delivers greater profits than any other alternative project;
- If $IRR < r$, it is better to invest on other options;
- If $IRR = r$, this do not define a posture, since the investment on the energy project delivers the same profit as an alternative project.

The next step is to evaluate the CEL impact through the calculation of the NPV of all the 20-year CEL Income as shown in Equation (30), this NPV represents the amount of money to which applied the formula of the IRR delivers the same CEL income at the 20-year period. The 20-year period represents the period that a Clean Power Plant will receive CELs.

$$NPV_{CEL\ Income} = \sum_{t=1}^{20} \frac{CEL\ Income_t}{(1 + IRR)^t} \tag{30}$$

Where:

$\boldsymbol{NPV_{CEL\ Income}}$	is the NPV of the project in the 20-year CELs Income.
$\boldsymbol{CEL\ Income_t}$	is the CELs revenue of the "t" year.
$\boldsymbol{IRR}$	is the IRR of the project.

According to Friedlob (T. Friedlob & J. Plewa Jr., 1996), the Return on Investment (ROI) is a "tool used by creditors and owners to assess the company's ability to earn an adequate rate of return. ROI relates profit (the reward) to the size of the investment used to generate it", in other words, the ROI compares the profits obtained by a project and the investment made on that project. The ROI can be calculated as seen in Equation (31):

$$ROI = \frac{Profits}{Investment} - 1 \tag{31}$$

Where:

$\boldsymbol{ROI}$	is the Return on Investment.
$\boldsymbol{Profits}$	is the value of the profits made by the project.

$\boldsymbol{Investment}$ is the value of the investment put on the project.

Using the definition of the ROI, the impact of the CEL price on the investment of a Clean Energy project can be represented as shown in Equation (32). The value of this division illustrates the change on the investment costs of a clean energy project thanks to the CELs revenue, e.g., if the revenue from CELs increases, the value of the solution of Equation (32) increases as well.

$$ROI_{CEL\ Income} = \left(\frac{NPV_{CEL\ Income}}{Investment\ Costs} - 1\right) \tag{32}$$

Where:

$\boldsymbol{ROI_{CEL\ Income}}$ is the Return on Investment thanks to the CEL Income.

$\boldsymbol{Investment\ Costs}$ are the total investment cost of a Clean Energy project, as monetary measure.

However, to calculate the new Investment Cost of the project due to the CELs income, the ROI must illustrate the exact opposite of what Equation (32) depicts, to do this, the ROI value must be multiplied by -1 as shown in Equation (33). This adjustment is done under the assumption that the investment cost of a clean energy project decreases as the value of the CELs Impact decreases, as depicted by Equation (34). This not necessarily means that the real investment costs of each clean energy project are going to decrease, however, this does mean that some or even all the Investment Costs are covered by the CEL Income at the end of the 20-year period.

$$CELs\ Impact = -ROI_{CEL\ Income} \tag{33}$$

$$New\ Investment\ Costs = Investment\ Costs * CELs\ Impact \tag{34}$$

Where:

$\boldsymbol{CELs\ Impact}$: is the impact of the CELs price on the total investment of a Clean Energy project.

$\boldsymbol{New\ Investment\ Costs}$ is the investment cost of a Clean Energy project given the introduction of a CEL price as the project income.

3.5. Clean Energy Certificates Model

Now that the CEL dynamic between Supply & Demand is represented through equations, the CEL model can be obtained by arranging each CEL process into blocks as shown in Figure 3.9. It must be noted that this model only calculates the CEL impact in one year, and to obtain the CELs impact on several periods this model needs to be applied year by year.

The first block of the CEL model, named "Clean Power Plants Discretization", is the complete process showed in Figure 3.2 and is applied to every single power plant installed at the "n" period.

Once the discretization is done, the next process, named "CELs Supply and Demand", calculates the CEL Supply & Demand according to Section 3.2 and it follows the flowchart shown in Figure 3.10. It can be seen that if $n = 2018$, the value of the variables "$CEL\ Inventory_{2017}$" and "$Deferral_{2017}$"

is equal to zero, since 2018 is the first CEL Compliance period and there is not be CEL Inventory nor CEL Deferral.

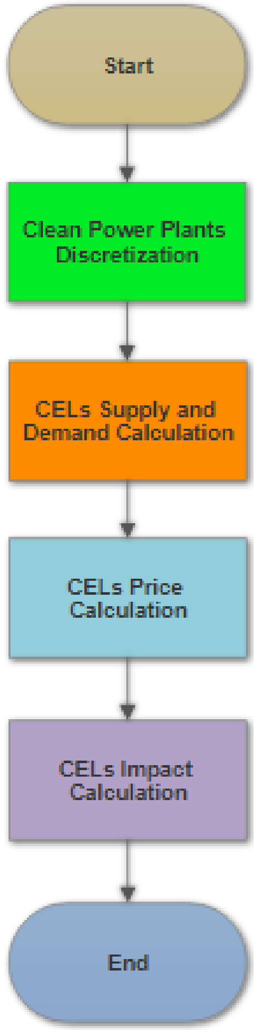

Figure 3.9: Clean Energy Certificates Model Flowchart

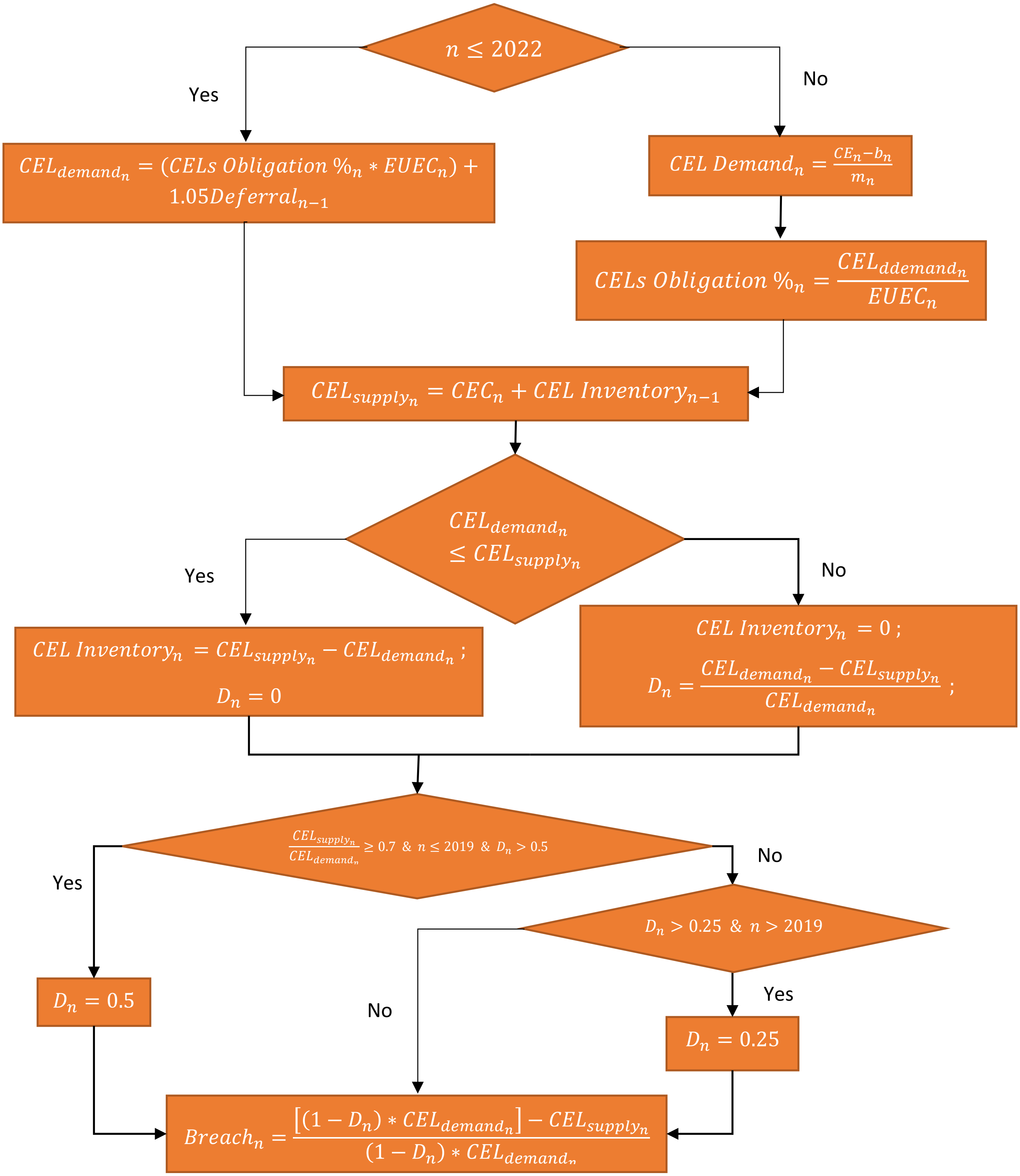

Figure 3.10: Clean Energy Certificates Supply and Demand Calculation Flowchart

The third process of the CEL Model, named "CEL Price Calculation", consists of the selection of the Maximum CEL Price (P_{max_n}) following the criteria shown in Table 3.1 and of the Calculation of the

CEL equilibrium price (See Figure 3.11), which is used as an input data for the fourth process of the Clean Energy Certificates Model.

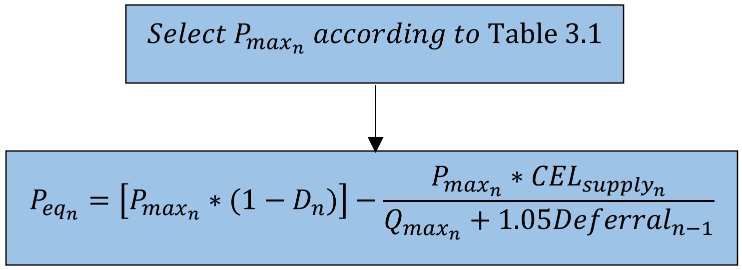

Figure 3.11: Clean Energy Certificates Price Flowchart

The final block named "CELs Impact Calculation" consists of four basic subprocesses, starting with the estimation of the Cash Flow that every energy project delivers. It must be noted that each energy technology has its own Cash Flow, depending on their technical and economic data, and to facilitate calculations, it is considered that every technology is represented by an archetype power plant. Once the Cash Flow of every energy technology is obtained, the IRR, the NPV and the CELs Impact percentage are calculated following the methodology described in Section 3.4.

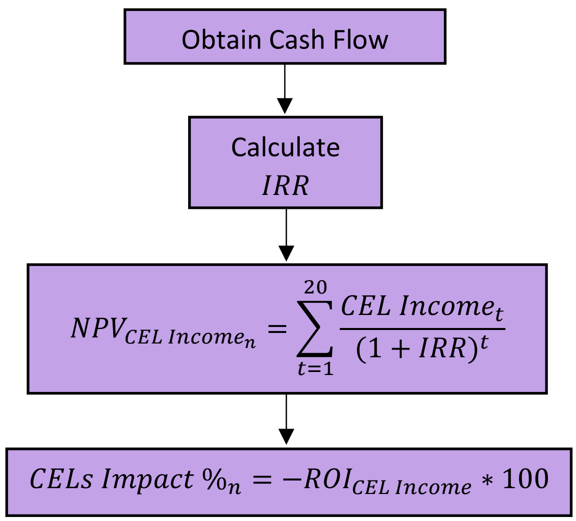

Figure 3.12: Clean Energy Certificates Impact Flowchart

4. Simulation of the Impacts of Clean Energy Certificates

The CEL Model proposed in Section 3 was tested by linking it into the energy modelling system called *Sistema de Modelación Integral del Sector Energético (SIMISE),* created by UNAM. Three different scenarios were selected and developed to determine if the implementation of the CEL System increases the Clean Energy generation over the next fifteen years.

This chapter begins with a basic explanation of the main models that make up SIMISE, a description of how these modules interact with each other to deliver an optimization of the power planning, emphasizing the interaction between SIMISE's Transmission and Power Generation Model and the CEL Model. Thereafter, it is described the input data that the CEL Model requires to perform appropriately all the calculations mentioned in Chapter 3, as well, it is described the characteristics of the three simulation scenarios and the assumptions made on each one of them. It must be noted that these three scenarios have been selected to determine the role of fuel-based technologies to meet the Clean Energy Generation Goals.

Finally, with the input data collected, a 15-year simulation of the Mexican Electric System is performed for each selected scenario to obtain the parameters that depicts the behavior of these scenarios, such as Electricity Generation, Capacity Evolution, CELs Supply & Demand, CEL Prices, etc.

4.1. Sistema de Modelación Integral del Sector Energético (SIMISE)

The *Energy Sector Integral Modeling System*, also known as SIMISE for its acronym in Spanish, was born as a project developed by the *Universidad Nacional Autónoma de México (UNAM)* under the supervision of the SENER whose objective is to create a Mexican energy modelling system. The purpose of SIMISE is to become the tool with which SENER and other institutions in Mexico can rely on to carry out long-term energy outlooks and to anticipate different events that could change the demeanor of the Mexican energy system.

In order to perform an energy planning and evaluate the possible scenarios, the most relevant aspects of SIMISE are:

- Have a long-term vision of the tendencies and behavior of the power system.
- Tend to the specific requirements of the energy sector.
- Optimize the balance of the energy supply and demand.
- Evaluate the impact of the energy policies

The energy planning methodology uses a macroeconomic analysis, outlooks of the energy demand, an analysis of the energy resources, a characterization of the energy conversion technologies and the optimization of the energy supply-demand balance (Figure 4.1).

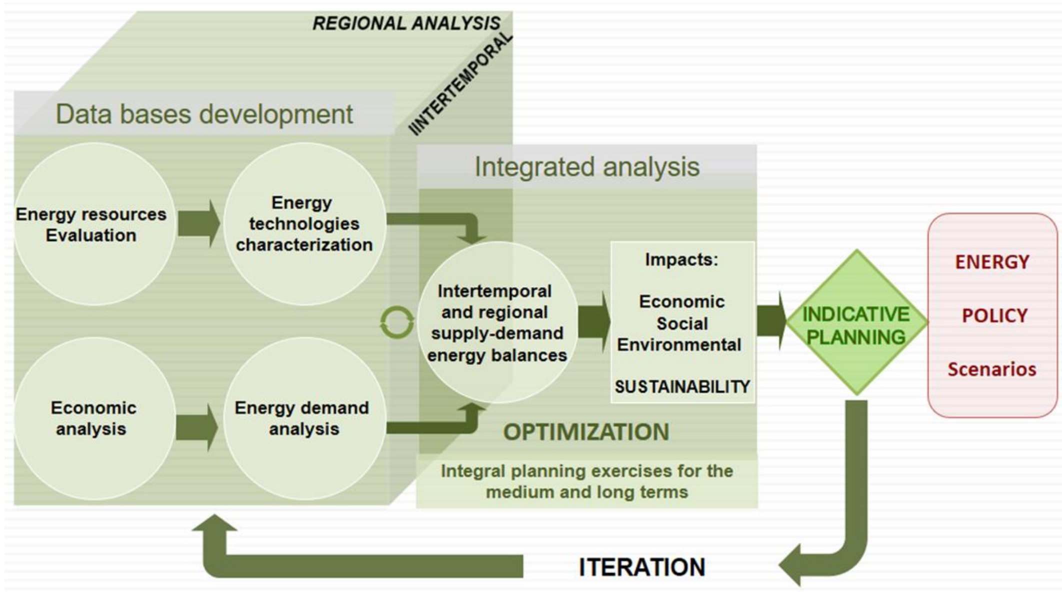

Figure 4.1: Outline of the Energy Planning Analysis made in SIMISE

Source: SIMISE

SIMISE, as any computer system, is integrated by modules that perform different activities of the energy planning, employing models and data bases certified from different institutions in Mexico. SIMISE is formed by an Economic Module, a Demand Module, a Supply Module and three Transformation & Transport Modules as shown in Figure 4.2. The Economic Module is formed by models that runs a macroeconomic analysis of Mexico while the Demand Module estimates the future energy demand of the main economic sectors. The Supply Module evaluates the energy resources of Mexico that may be supplied in the future. The structure of this Supply Module consists of four main blocks: Hydrocarbons (Gas and Oil), Renewables (Hydro, solar, wind, geothermal and bioenergy), Nuclear and Coal.

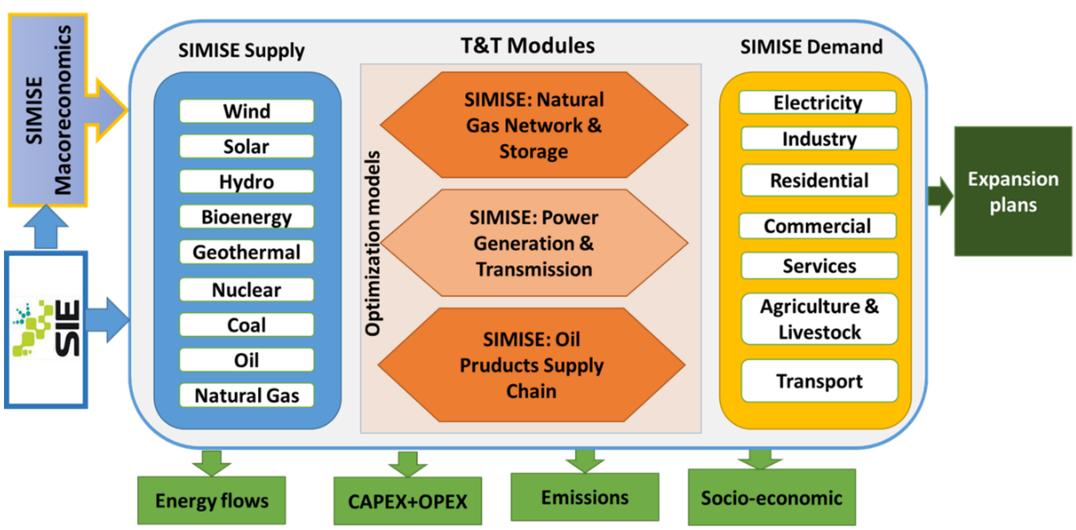

Figure 4.2: Modules Structure Employed in SIMISE

Source: SIMISE

The Transformation & Transport Module consists of three optimization methodologies designed specifically for each main energy sector:

- The Natural Gas Network & Storage module optimizes the infrastructure of the natural gas transport network, beginning with the extraction and/or import process and ending with the final consumption. This module also includes the natural gas storage process.
- The Oil Products Supply Chain module characterizes the costs and parameters of the hydrocarbon's transformation & processing and the distribution infrastructure & operation of oil products, including the storage of hydrocarbon.
- The Power Generation & Transmission module takes into consideration the existing power plants and interconnections between nine regions.

The Power Generation & Transmission module consists of a system of linear equations that solve the objective function (F.O.) finding a minimum cost expansion scenario that accomplishes the restrictions previously established. The objective function is shown in equation (35):

$$F.O. = \sum_{k=1}^{K} \sum_{r=1}^{R} C_{k,r,n} \quad r: region \tag{35}$$

Where:

$\boldsymbol{C_{k,r,n}}$ is the total cost of the "k" energy technology at the "n" period and at the "r" region.

The total cost of the system consists of four main costs as shown in Equation (36).

$$C_{k,r,n} = \sum_{r=1}^{R} \sum_{k=1}^{K} (CD_{k,r,n} + CI_{k,r,n} + CT_{k,r,n} + CO\&M_{k,r,n}) \tag{36}$$

Where:

$\boldsymbol{CD_{k,r,n}}$ is the dispatch cost of the "k" energy technology at the "n" period and at the "r" region, measured in [USD].

$\boldsymbol{CI_{k,r,n}}$ is the infrastructure cost of the "k" energy technology at the "n" period and at the "r" region, measured in [USD].

$\boldsymbol{CT_{k,r,n}}$ is the transmission cost of the "k" energy technology at the "n" period and at the "r" region, measured in [USD].

$\boldsymbol{CO\&M_{k,r,n}}$ is the Operation and Maintenance Cost of the "k" technology at the "n" period and at the "r" region, measured in [USD].

Each cost is calculated according to equations (37), (38), (39) and (40):

$$CD_{k,r,n} = \left[\frac{RT_{k,r,n}}{Pc_{k,r,n}} * PreC_{k,r,n} + CO\$Mv_{k,r,n} \right] * Gen_{k,r,n} \tag{37}$$

$$CI_{k,r,n} = \left[CInv_{k,r,n} + CO\&Mf_{k,r,n}\right] * Cap_{k,r,n} * frc_{k,r,n} \quad (38)$$

$$CT_{k,r,n} = \left[CTrans_{k,r,n}\right] * Gen_{líneas_{k,r,n}} \quad (39)$$

$$CO\&M_{k,r,n} = CO\&Mf_{k,r,n} * Cap_{i_{k,r,n}} \quad (40)$$

Where:

$\boldsymbol{RT_{k,r,n}}$ is the Thermal Regime of the "k" energy technology, measured in [MJ/MWh].

$\boldsymbol{Pc_{k,r,n}}$ is the Heat of Combustion of the "k" energy technology, measured in [MJ/Unit].

$\boldsymbol{PreC_{k,r,n}}$ is the Fuel Price of the "k" energy technology, measured in [USD/Unit].

$\boldsymbol{CO\&Mv_{k,r,n}}$ is the Variable Operation and Maintenance Cost of the "k" energy technology, measured in [USD/MWh].

$\boldsymbol{Gen_{k,r,n}}$ is the dispatched energy of the "k" energy technology in each region, measured in [MWh].

$\boldsymbol{CInv_{k,r,n}}$ is the Investment cost of the "k" energy technology, measured in [USD/MW].

$\boldsymbol{frc_{k,r,n}}$ is the factor to adjust the investment cost of the "k" energy technology at the "r" region.

$\boldsymbol{CO\&Mf_{k,r,n}}$ is the Fixed Operation and Maintenance Cost of the "k" energy technology, measured in [USD/MW].

$\boldsymbol{Cap_{k,r,n}}$ is the optimum capacity to install of the "k" energy technology at the "r" region, measured in [MW].

$\boldsymbol{CTrans_{k,r,n}}$ is the transmission cost of the "k" energy technology at the "r" region, measured in [USD/MWh].

$\boldsymbol{Gen_{líneas_{k,r,n}}}$ is the optimum energy that travels through the transmission lines, measured in [MWh].

$\boldsymbol{Cap_{i_{k,r,n}}}$ is the initial capacity of the "k" energy technology at the "r" region and at the "n" period, measured in [MW].

4.2. Interaction of the Clean Energy Certificates Model with SIMISE

As mentioned in Section 3.4, the Clean Power Plants consider the CEL price as an income that, it can be used either to liquidate a fraction of their operative costs, to invest in projects not related to the energy sector, to decrease their electricity prices, to increase also their profitability. However, as has been mentioned in Section 4.1, SIMISE delivers an indicative energy planning for a specific period, by optimizing the costs of the electric system, as seen in Equation (36). This means that, the optimization is not based on electricity prices and neither on the profitability of energy projects. In this manner, to introduce the CEL Market Model into the SIMISE Model, it is assumed that the risk on the investment of Clean Energy Projects should increase or decrease according to the value of the CEL Price, meaning that the higher the CEL Price is, the lower this risk is, and therefore, the greater the profitability of the energy project is.

For SIMISE to consider these aspects, it is proposed that each value of the $CEL\ Impact_{j,k}$ obtained from the CEL Market Model replaces the variable $frc_{k,r,n}$ found at the SIMISE Model. In this way, SIMISE interprets the value of the CEL Impact fraction as a decrease on the Investment Cost of the clean energy technologies, due to the CEL Income, which, depending on the value of the CEL Price, should boost the construction of Clean Energy projects. Equation (41) depicts this situation:

$$CI_{k,r,n} = \left[CInv_{k,r,n} + CO\&Mf_{k,r,n}\right] * Cap_{k,r,n} * CEL\ Impact_{k,r,n} \tag{41}$$

The interaction between the CEL Market Model and SIMISE begins by taking the output data provided by the optimization process made by the Power Generation & Transmission Optimization Module and the external data such as the CELs Obligation Percentage and the Electricity Final Consumption to solve the equations shown in Chapter 3. Once that the CEL Market Model ends its calculation process, it delivers the CEL Impact Fraction ($CEL\ Impact_{j,k}$) back to SIMISE, which performs the power & transmission optimization of the next simulation year, thereby looping the interaction sequence again (Figure 4.3).

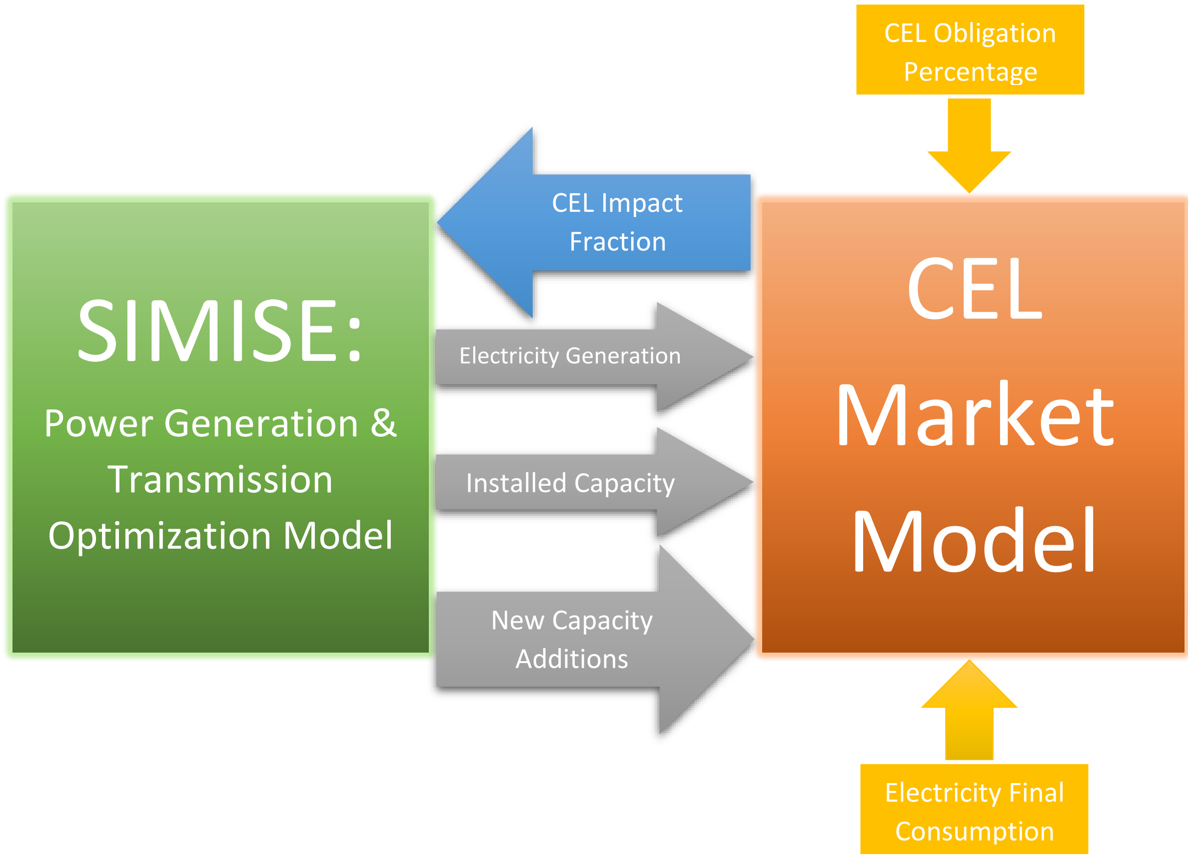

Figure 4.3: Interaction of the Clean Energy Certificates Model with SIMISE

The characteristics of the input data that the CEL Model requires is presented in Table 4.1, where the first three parameters are data collected directly from the SIMISE Model, while the rest of the parameters must be obtained externally.

Table 4.1: Characteristics of the Clean Energy Certificates Market Model Input Data

Parameter	Description	Units
Installed Capacity $(\boldsymbol{Inst\ Cap_{j,k,n}})$	Installed Capacity of the "k" Technology with a "j" CEL price at the "n" period	Megawatt
New Capacity Additions $(\boldsymbol{Cap\ Add_{j,k,n}})$	Capacity Additions of the "k" Technology with a "j" CEL price at the "n" period	Megawatt
Electricity Generation $(\boldsymbol{Elec\ Gen_{j,k,n}})$	Electricity Generation coming from the "k" Technology with a "j" CEL price at the "n" period	Megawatt-hour
Electricity Final Consumption $(\boldsymbol{EFC_n})$	Projected Final Consumption of Electricity in Mexico at the "n" period	Megawatt-hour
CEL Obligation Percentage $(\boldsymbol{CEL\ Obligation\ \%_n})$	CELs Obligation at the "n" period	Percentage or CEL/MWh
Investment Costs $(\boldsymbol{CInv_{k,r,n}})$	Investment Costs of the "k" Technology Power Plant at the "r" region	2018 USD/MW

Fixed Operative & Maintenance Costs ($\boldsymbol{CO\&Mf_{k,r,n}}$)	Fixed OHMS Costs of the "k" Technology Power Plant at the "r" region	2018 USD/MW
Variable Operative & Maintenance Costs ($\boldsymbol{CO\&Mv_{k,r,n}}$)	Variable O&M Costs of the "k" Technology Power Plant at the "r" region	2018 USD/MWh
Fuel Costs ($\boldsymbol{PreC_{k,r,n}}$)	Fuel Costs of the "k" Technology Power Plant at the "r" region	2018 USD/MWh
Transmission Costs ($\boldsymbol{CTrans_{k,r,n}}$)	Transmission Costs of the "k" Technology Power Plant at the "r" region	2018 USD/MWh
Power Plant Gross Capacity ($\boldsymbol{C_k}$)	Power Plant Gross Capacity of the "k" Technology	Megawatt
Power Plant Capacity Factor ($\boldsymbol{fp_k}$)	Power Plant Capacity Factor of the "k" Technology	Percentage or Fraction
Power Plant Own Uses ($\boldsymbol{UP_k}$)	Power Plant Own Uses of the "k" Technology	Percentage or Fraction
Power Plant Lifetime ($\boldsymbol{VU_k}$)	Power Plant Lifetime of the "k" Technology	Years

Applying the equations shown in Chapter 3 to the input data mentioned above, the CEL Model returns the parameters shown in Table 4.2 as output data.

Table 4.2: Characteristics of the Clean Energy Certificates Market Model Output Data

Parameter	Description	Units
CEL Supply ($\boldsymbol{CEL_{supply_{j,n}}}$)	Clean Energy Certificates Supply due to a "j" CEL price at the "n" period	CEL
CEL Demand ($\boldsymbol{CEL_{demand_n}}$)	Clean Energy Certificates Demand at the "n" period	CEL
CEL Deferral ($\boldsymbol{deferral_{j,n}}$)	CEL deferral with a "j" CEL price at the "n" period	CEL
CEL Inventory ($\boldsymbol{CEL\ Inventory_{j,n}}$)	CEL inventory with a "j" CEL price at the "n" period	CEL
Clean Energy Generation ($\boldsymbol{CEG_{j,n}}$)	Clean energy generation due to a "j" CEL price at the "n" period	Megawatt-hour
Capacity Factor ($\boldsymbol{CF_{j,k,,n}}$)	Capacity Factor of the "k" Technology with a "j" CEL price at the "n" period	Percentage
CELs Obligation Percentage ($\boldsymbol{CELs\ Obligation\ \%_n}$)	CELs Obligation at the "n" period (only when $n < 2022$)	Percentage

To keep the same structure as PRODESEN and since several Clean Energy Technologies are still in development, the CEL Market Model uses data from the following generation technologies:

- Combined Cycle;
- Coal;

- Internal Combustion;
- Fluidized Bed;
- Thermal;
- Turbo Gas;
- Hydro;
- Wind;
- Geothermal;
- Solar;
- Nuclear;
- Bioenergy and;
- Efficient Combined Heat and Power (Efficient CHP).

4.3. Status of the Mexican National Electric System

For SIMISE to perform the optimization of the Mexican power generation, it is necessary to introduce the numerical data that describes the current status of the Mexican National Electric System into the SIMISE Model, such as:

- Current Installed Capacity in Mexico per technology;
- Investment Costs per MW;
- Fixed Operative and Maintenance Costs per MW;
- Variable Operative and Maintenance Costs per MWh;
- Clean Energy Goals and;
- Clean Energy Potential.

4.3.1. Installed Capacity

According to PRODESEN 2018-2032 (Secretaría de Energía, 2018), by 2017 there were 75,685 MW of installed capacity in Mexico, where around 30% of that capacity is considered Clean Energy Capacity and the rest is considered Conventional Energy Capacity. With that installed capacity, almost 330 TWh of electricity was generated, including 69.3 TWh coming from Clean Sources, equivalent to 21.1% of the 2017 electricity generation (See Table 4.3).

Table 4.3: Capacity and Generation Status of the Mexican Electric System in 2017

Technology	2017 Installed Capacity [MW]	2017 Energy Generation [GWh]
Combined Cycle	28,084	165,245
Thermal Power Plant	12,546	42,780
Coal Power Plants	5,378	30,557
Turbo gas	5,136	12,849
Internal Combustion	1,634	4,006
Fluidized Bed	580	4,329
Total Conventional Energy	**53,358**	**259,766**
Hydro	12,642	31,848
Wind	4,199	10,620
Geothermal	926	6,041

Solar	214	344
Bioenergy	1,007	1,884
Distributed Generation	434	760
FIRCO[13]	40	82
Total Renewables	**19,462**	**51,578**
Nuclear	1,608	10,883
Efficient CHP	1,251	6,932
Regenerative Breaks	6.61	4
Clean Energy	**22,327**	**69,397**
Total	**75,685**	**329,162**

Source: PRODESEN 2018-2032.

4.3.1.1. Installed Capacity Credited to Receive CELs

Following the criteria depicted in Figure 3.2, by 2017 only 3,746.69 MW were credited to obtain CELs (See Table 4.4), where 56% belonged to Wind energy followed by Efficient CHP with 16%. These data were obtained by collating the names of the installed clean power plants found at the last four editions of the PRODESEN with the document titled "Tabla de Permisos de Generación e Importación de Energía Eléctrica Administrados al 30 de Abril de 2018" (Comisión Reguladora de Energía, 2018), where the date of start of operations for every power plant is available.

Table 4.4: Cumulated Installed Capacity Credited to Receive CELs (2014-2017) [MW]

Technology	2014	2015	2016	2017
Hydro	8.4	33.4	229.35	235.35
Wind	137.5	833.5	1,610.7	2,126
Geothermal	0	52	35	35
Solar	0	17.315	103.595	154.155
Distributed Generation	0	55.663	130.065	186.628
Nuclear	0	110	208	208
Bioenergy	1.6	3.675	94.032	192.062
Efficient CHP	118	142.398	432.075	609.495
Total	**265.5**	**1,247.951**	**2,842.817**	**3,746.69**

4.3.2. Power Plants Economic and Technical Data

Economic data for every type of existing technology in Mexico in 2017 are shown in Table 4.5, these data consist of Actualized Investment Costs[14], Fixed and Variable O&M Costs and Fuel Costs. The technical data used as reference, such as Gross Capacity, Capacity Factor, Lifespan, etc. are shown in Table 4.6. It should be noted that the economic and technical data were obtained from PRODESEN 2018-2032 excepting for Biogas, CHP and Small Hydro, whose data were obtained from "Projected Costs of Generating Electricity" (International Energy Agency, 2015), since does not exist in Mexico

[13] Trust Fund for Share Risk

[14] These costs include the funding costs during construction.

a standardized power plant with these technologies, due to a diversity of configurations that currently is installed.

Table 4.5: Economic Data of Each Power Plant Technology in Mexico in 2017

Technology	Investment Cost [USD/kW]	Fuel and waste costs [USD/MWh]	Fixed O&M Costs [USD/kW]	Var O&M Costs [USD/MWh]	Discount Rate [%]
Biogas	724.49	0.00	256.45	23.15	10
CHP	1,085.96	30.71	177.026	5.20	10
Small Hydro	1,177.91	0.00	88.97	0.00	10
Wind	1,423.00	0.00	38.10	0.00	10
Geothermal	1,889.57	0.00	105.07	0.05	10
Hydro	1,931.00	0.00	24.40	0.00	10
Nuclear	3,988.53	7.45	101.09	2.42	10
Solar	1,030.00	0.00	10.67	0.00	7[15]
Combined Cycle	1,013.21	30.71[16]	19.00	3.35	10
Thermal Power Plant	2,045.09	103.72	35.80	3.04	10
Coal	1,425.51	28.41	33.80	2.44	10
Turbo Gas	818.24	31.94[17]	5.10	4.78	10
Internal Combustion	2,877.29	85.84	46.40	5.16	10
Fluidized Bed	1,438.00	57.22	35.00	3.00	10

Table 4.6: Technical Parameters of Power Plant Technologies in Mexico in 2017

Technology	Gross Capacity [MW]	Capacity Factor [%]	Lifespan [years]	Own Uses [%]	Thermal Regime [GJ/MWh]
Biogas (Engine)	0.2	80.00	25	3.00	12.00
CHP	4.7	65.00	25	3.00	9.00
Small Hydro	12	45.00	60	1.20	- - -
Wind	100	28.00	25	1.00	- - -
Geothermal	225	80.00	30	5.10	- - -
Hydro	375	41.46	60	1.20	- - -
Nuclear	1400	87.96	60	3.50	10.4
Solar	100	15.00	25	1.90	- - -

[15] Source: Instituto Nacional de Ecología y Cambio Climático. (December 16, 2016). *Estudios de Cadenas de Valor de Tecnologías Seleccionadas para Apoyar la Toma de Decisiones en Materia de Mitigación en el Sectos de Generación Eléctrica y Contribuir al Desarrollo de Tecnologías*. Mexico City.

[16] Prices of December 2017 according to http://www.cre.gob.mx/IPGN/index.html

[17] According to https://www.cenace.gob.mx/Docs/MercadoOperacion/TecnologiaGeneracionReferencia/2018/Tecnolog%C3%ADa%20Generaci%C3%B3n%20Referencia%202017%20v2017%2010%2025%20Preliminar.pdf

Combined Cycle	338	70.00	30	2.60	7.00
Thermal Power Plant	333.3	60.00	30	6.50	14.5
Coal	670	80.00	40	7.30	10.5
Turbo Gas	39	40.00	30	2.10	9.857
Internal Combustion	6	75.00	25	3.00	9.5
Fluidized Bed	290	85.00	40	7.30	12

According to the ”Update of Fares that CFE will Apply to the Public Service of Electricity Transmission during 2018” (Comisión Federal de Electricidad, 2018) and the “Fares of the Transmission Service for Renewable Energies or Efficient Combined Heat and Power” (Comisión Reguladora de Energía, 2018), the electricity transmission costs that a Clean Power Plant must pay are slightly lower than the transmission costs that Conventional Technologies must pay (See Table 4.7), which indicates the preference that the Clean Generation has over Conventional Technologies.

Table 4.7: Electricity Transmission Costs in Mexico, 2018

Technology	Transmission Costs [USD/MWh]
Renewables and Efficient CHP	2.20821954
Conventional Technologies	2.81240305

4.3.3. Clean Energy Potential

The clean energy potential that can be installed in Mexico, according to their economic and technical feasibility, can be seen in Table 4.8. The potential that Efficient CHP has is 300 MW lower than the potential shown by CONUEE (Comisión Nacional para el Uso Eficiente de la Energía, 2009) since the power plant named “CPG Nuevo PEMEX” is already installed and operating, while it is considered by CONUEE as Potential.

Table 4.8: Clean Energy Potential in Mexico

Resource	Potential [MW]	Source
Bioenergy	630.181564	https://dgel.energia.gob.mx/inere/
Efficient CHP	6744.7	(Comisión Nacional para el Uso Eficiente de la Energía, 2009)
Wind	15,375.55	https://dgel.energia.gob.mx/inere/
Geothermal	1903.34	https://dgel.energia.gob.mx/inere/
Hydro (> 30 MW)	1227.3	https://dgel.energia.gob.mx/inere/
Small Hydro	1401.46	https://dgel.energia.gob.mx/inere/
Solar	11648.74	https://dgel.energia.gob.mx/inere/
Total	31243.50	

4.3.4. Clean Energy Generation Goals

Since intermediate Clean Energy Goals are not established by the Mexican government, the value of the clean energy generation goal for each year can be obtained by interpolating the electricity generation goals of 2018, 2021, 2024 and 2035. As seen in Table 4.9, from 2018 until 2024, the clean energy generation goal increases almost 1.67% each year, however, from 2024 until 2032, the clean energy generation goal increases yearly around 0.45%.

Table 4.9: Clean Energy Generation Goals

Year	Goal [%]
2018	25.00
2019	26.67
2020	28.33
2021	30.00
2022	31.67
2023	33.33
2024	35.00
2025	35.45
2026	35.91
2027	36.36
2028	36.82
2029	37.27
2030	37.73
2031	38.34
2032	38.95

4.3.5. Electricity Consumption Outlook

According to the outlook presented in the PRODESEN 2018-2032 (Secretaría de Energía, 2018), the electricity gross consumption over the next 15 years is assumed to increase from nearly 310 GWh by 2017 to 492 GWh by 2032, with an Average Annual Growth Rate (AAGR) of 3.1% (See Table 4.10).

Table 4.10: Electricity Gross Consumption in Mexico, 2017-2032

Year	Gross Electricity Consumption [GWh]
2017	309,727
2018	320,629
2019	331,092
2020	341,712
2021	352,522
2022	363,858
2023	375,009
2024	386,674
2025	398,265
2026	410,100
2027	422,463

2028	435,352
2029	448,658
2030	462,619
2031	477,130
2032	492,165

4.3.6. Capacity Withdrawals

According to the *"Programa Indicativo para la Instalación y Retiro de Centrales Eléctricas"* (PIIRCE) (Secretaría de Energía, 2018), the total capacity withdrawal from 2018 until 2032 is assumed to be equal to 11,821 [MW], where 62.8% of this capacity belongs to thermal power plants withdrawals and 14% to Combined Cycle (See Table 4.11).

Table 4.11: Capacity Withdrawals in Mexico, 2018-2032 (MW)

		Year															
		2018	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**Total**
Technology	**Hydro**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CHP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Turbogas	74.0	0.0	206.0	0.0	182.0	669.0	0.0	0.0	0.0	43.0	0.0	0.0	0.0	0.0	0.0	1174.0
	Combined Cycle	226.0	0.0	211.0	0.0	226.0	239.8	231.8	0.0	0.0	0.0	521.7	0.0	0.0	0.0	0.0	1656.3
	Wind	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
	Solar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Thermal Power Plant	834.0	0.0	3416.0	820.0	320.0	2036.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7426.0
	Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1400.0	0.0	0.0	0.0	1400.0
	Internal Combustion	0.0	0.0	0.0	0.0	73.0	0.0	31.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	104.5
	Bioenergy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Nuclear	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Geothermal	0.0	15.0	30.0	15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	60.0
	Small Hydro	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Fluidized Bed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	New Technologies	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	1134.6	15.0	3863.0	835.0	801.0	2944.8	263.3	0.0	0.0	43.0	521.7	1400.0	0.0	0.0	0.0	11821

4.4. Scenarios Simulation

Three different scenarios were chosen to test the CEL Market Model besides a base scenario, where, in two of the three scenarios, it is considered one fuel-based technology (Efficient CHP) as Clean Energy technology, while the last scenario considers as Clean Energy solely the Energy coming from Renewables. The base scenario is used as a reference of comparison. Each scenario is described as follows.

Base Scenario: The base scenario presented at PRODESEN 2018-2032.

Scenario A: Scenario created with the data provided by PRODESEN 2018-2032. This scenario includes the CEL market model as part of the SIMISE model, it is also considered that Efficient CHP plants will receive the amount of CELs shown at **Calculation of the Fuel Free Energy in Efficient Combined Heat & Power Processes** per MWh they generate.

Scenario B: Scenario created with the data provided by PRODESEN 2018-2032. This scenario includes the CEL market model as part of the SIMISE model, it is also considered that every Clean Energy Power Plant will receive One CEL per MWh they generate.

Scenario C: Scenario created with the data provided by PRODESEN 2018-2032. This scenario includes the CEL market model as part of the SIMISE model, it is also considered that only Clean Energy Technologies free of fossil fuels will receive CELs, in other words, Efficient CHP plants do not receive CELs.

In each scenario, it is considered that the Transmission & Distribution losses decreases each year with a rate of 1% to reach, by 2022, a maximum 8% of losses (See Table 4.12).

Table 4.12: Electricity Losses Percentage

Year	Electricity Losses [%]
2017	13.069%
2018	12.069%
2019	11.069%
2020	10.069%
2021	9.069%
2022	8.069%
2023	8.069%
2024	8.069%
2025	8.069%
2026	8.069%
2027	8.069%
2028	8.069%
2029	8.069%
2030	8.069%
2031	8.069%
2032	8.069%

4.4.1. Scenario A's Results

As seen in Table II.1 and Figure 4.4, the installed capacity of Solar energy presented in Scenario A has the highest Compound Annual Growth Rate (CAGR) over the next fifteen years of all the energy technologies with 28.5%, followed by Efficient CHP with 12.3%. However, Turbo Gas is the technology with the highest capacity addition with almost 30 GW, followed by Wind energy with 14.5 GW of installed capacity.

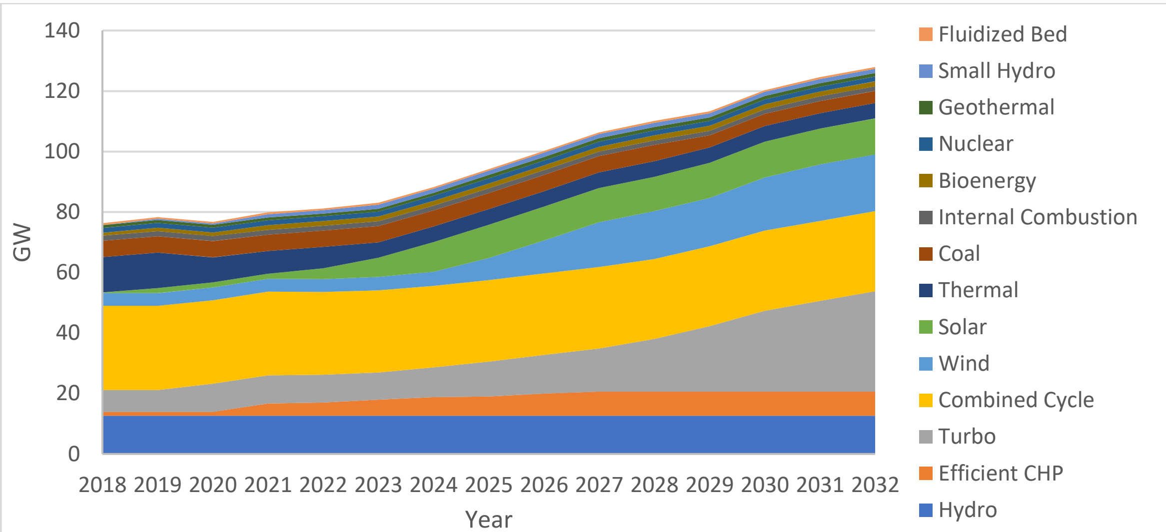

Figure 4.4: Scenario A's Capacity Evolution, 2018-2032

According to Table II.2, the electricity generation by Small Hydro power plants presents the highest CAGR with 40% growth, followed by Solar energy with 26.8%. Also, it can be noted that Thermal, Internal combustion and Fluidized Bed power plants decrease their electricity generation with -16.5%, -13.5% and -8.4% CAGR.

Although clean energy generation has a substantial increase, fuel-based technologies such as Turbo Gas and Combined Cycle prevail as main electricity generation in Mexico´s energy mix (See Figure 4.5), and these two technologies use Natural Gas as fuel.

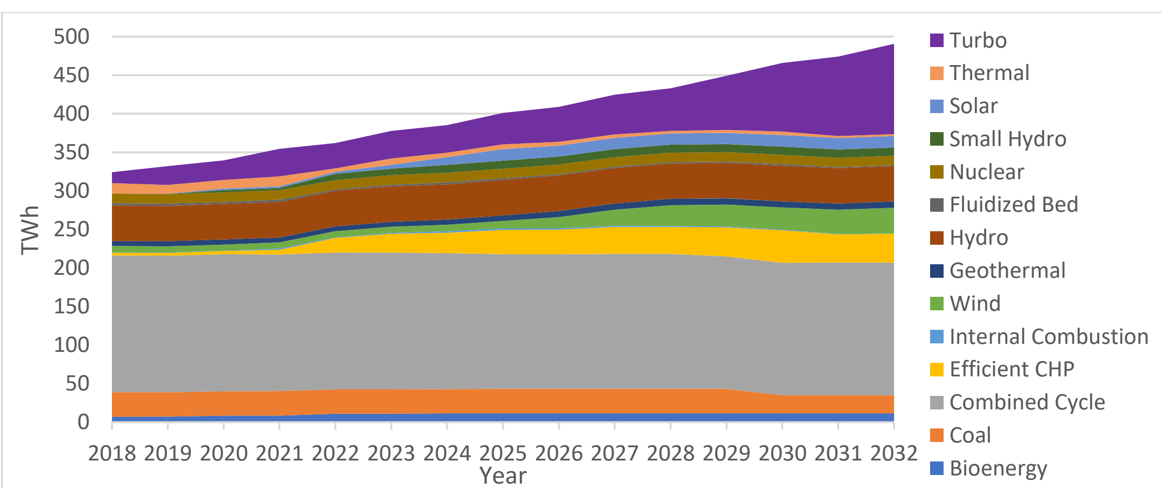

Figure 4.5: Scenario A's Electricity Generation, 2018-2032

The growth of clean energy generation propitiates the increase of the CEL Supply. As seen in Table II.3, in 2018 are 9.386 Million CELs issued, and in 2032 there are 86.950 Million CELs issued. In this scenario, Efficient CHP, Wind and Solar energy are the three main CEL suppliers over the next fifteen years (See Figure 4.6).

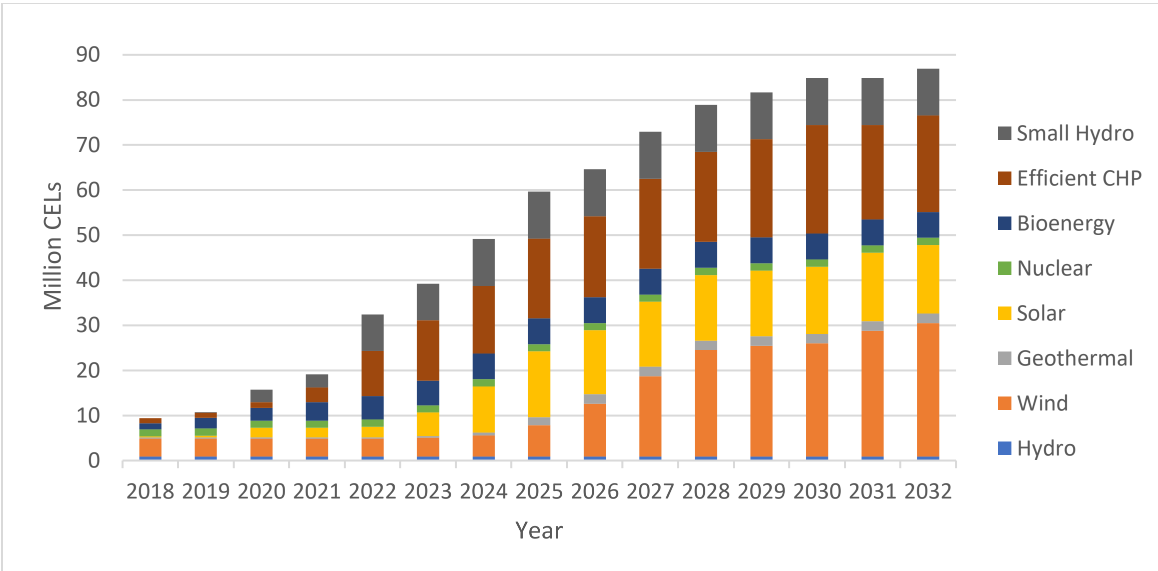

Figure 4.6: Scenario A's CELs Supply

In this scenario, according to the CELs market model proposed in this document, the 2023 Obligation Percentage had an increase of 3.4% compared to the 2022 Obligation Percentage published by SENER, and at the end of 2032 this percentage had a value of 37.4% (See Table II.4). The total CELs Demand and the CELs Obligation Percentage growth over the next fifteen years can be seen on the graph of Figure 4.7.

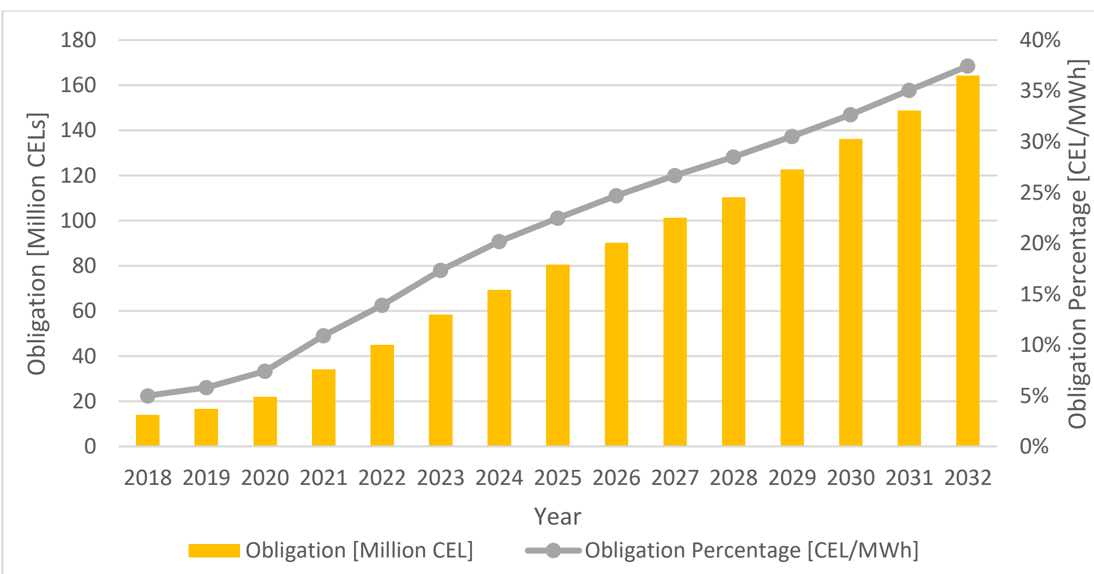

Figure 4.7: Scenario A's CEL Demand and Obligation Percentage, 2018-2032

Following the methodology depicted in **Section 3.3: Clean Energy Certificates Price**, in 2018 a Certificate is sold at an average price of $20.879 USD, while in 2019 this price sees a small decrease and is sold at an average price of $14.556 USD. However, from the year 2020 onwards, this price has a substantial increase and each CEL is sold at $27.885 USD, reaching by 2022 a maximum price of $55.85 USD per CEL (See Table II.5). Also, it can be noted that after the year 2022 the CEL price has a slight decrease, reaching by 2028 a minimum selling price of $36.234 USD (See Figure 4.8).

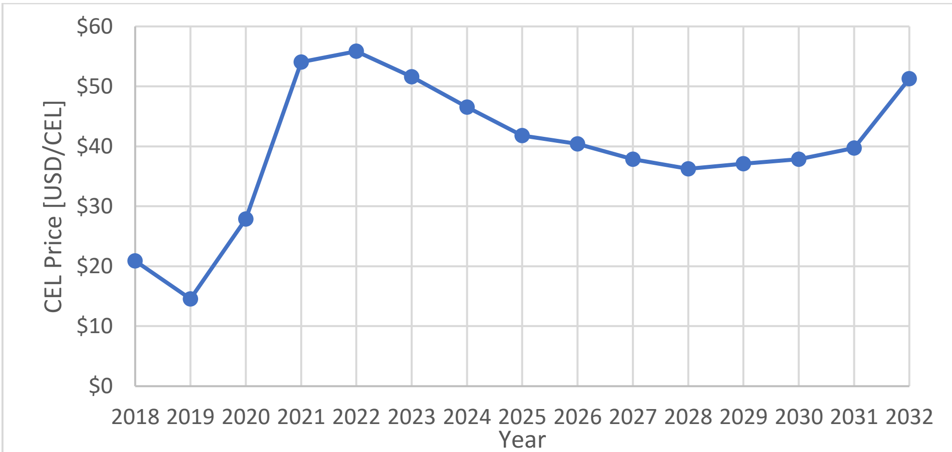

Figure 4.8: Scenario A's CEL Prices

The increase on the CEL Price is associated with the existing difference between the Clean Energy Goals and the Clean Energy Generation. As seen in Figure 4.9, at the end of 2021 and 2032 it can be noted that the highest difference between the generation goal and the actual generation, which coincidentally concurs with the highest CEL Prices previously mentioned. As a result of this, at the 2018-2032 period, the value of the clean energy generation is close to the value of the clean energy goals, and even, it can be noted that in six obligation periods the clean energy generation is slightly higher than the clean energy goals (See Table II.6).

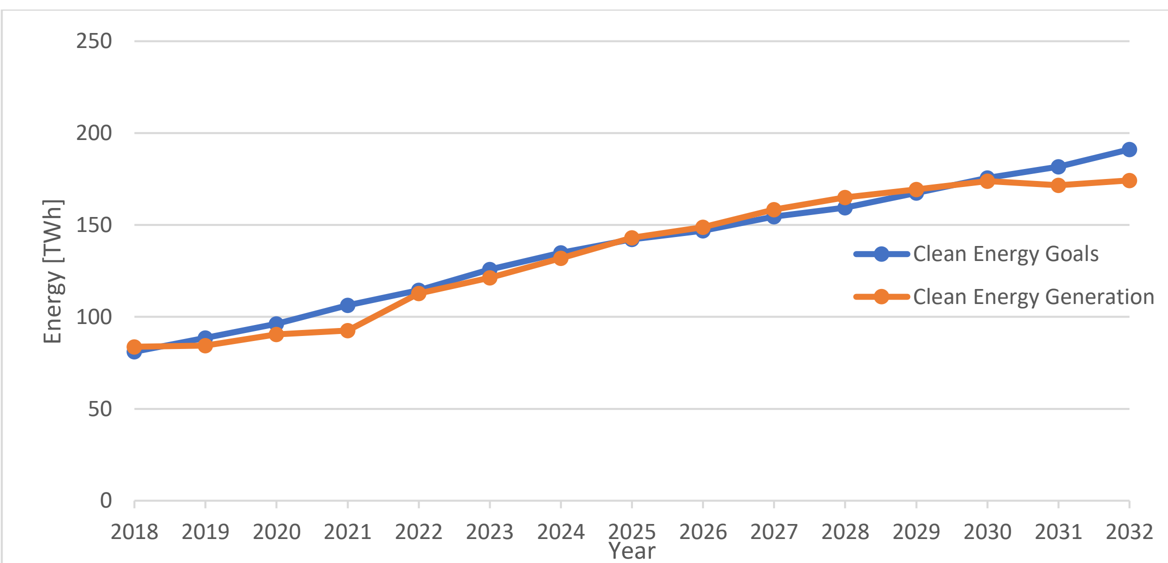

Figure 4.9: Scenario A's Clean Energy Generation vs Clean Energy Goals

The IRR and the NPV for each Clean Energy Technology can be seen in Table II.7 and Table II.8 respectively.

4.4.2. Scenario B's Results

In this scenario, every single Clean Energy Technology, except Nuclear, increase their capacity over the next fifteen years, where Solar, Small Hydro and Efficient CHP are the three clean technologies with the highest CAGR (28.5%, 20.8% and 12.3% respectively). However, in 2024, the installed capacity of Turbo Gas technology has a significant increase, to alleviate this situation there is a boost of the Wind installed capacity in the last four years of the scenario (See Figure 4.10 and See Table III.1).

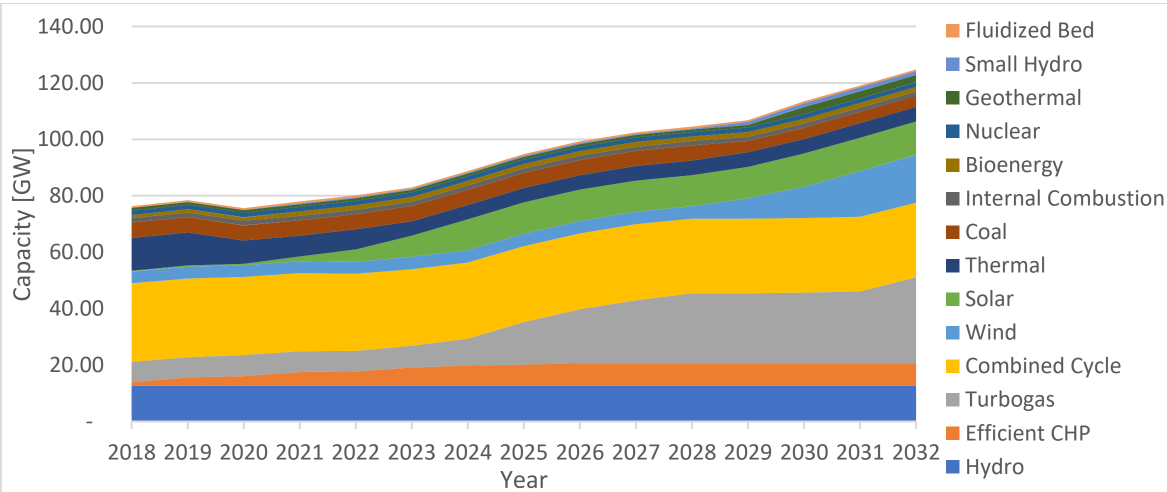

Figure 4.10: Scenario B's Capacity Evolution

As seen in Table III.2, over the next fifteen years, Small Hydro, Solar and Turbogas are the three technologies with the highest increase of energy generation, with 81.1%, 26.8% and 14.1% CAGR respectively, while Thermal and Internal Combustion technologies are the technologies with the lowest CAGR, with -13.5% and -8.1% respectively. Also, as seen in Figure 4.11, in this scenario prevails the use of Combined Cycle and Turbogas power plants as the main energy generation technologies.

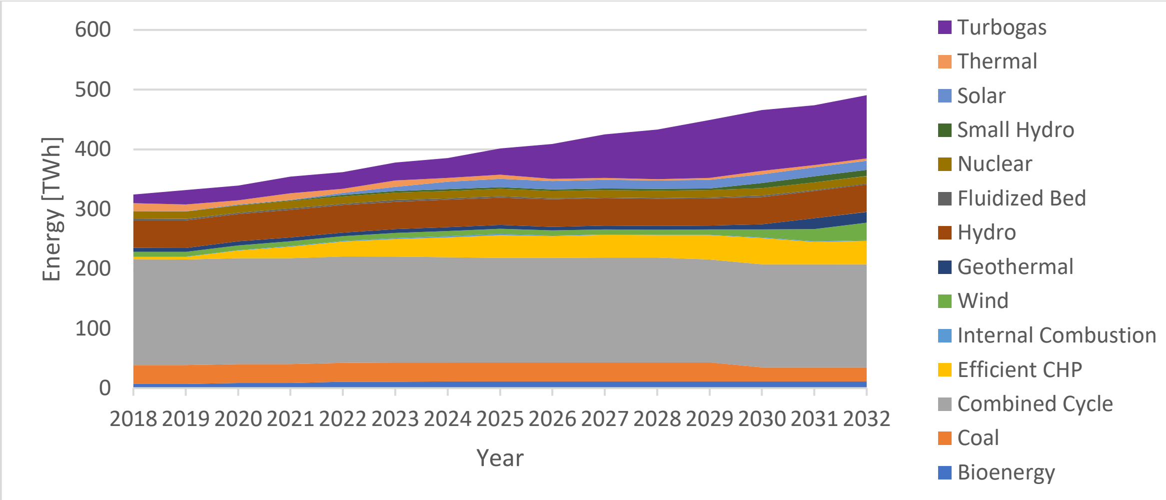

Figure 4.11: Scenario B's Electricity Generation

As seen in Table III.3, the amount of CELs issued in this scenario increases almost ten times the initial value of CELs issued, since in 2018 there are 10.053 Million CELs issued, while in 2032 this amount reaches 107.653 Million CELs issued. As seen in Figure 4.12, between 2025 and 2028, the CELs supply does not increase its value and even in some years of this period the supply depicts a slight decrease. This behavior is explained in detail some paragraphs later.

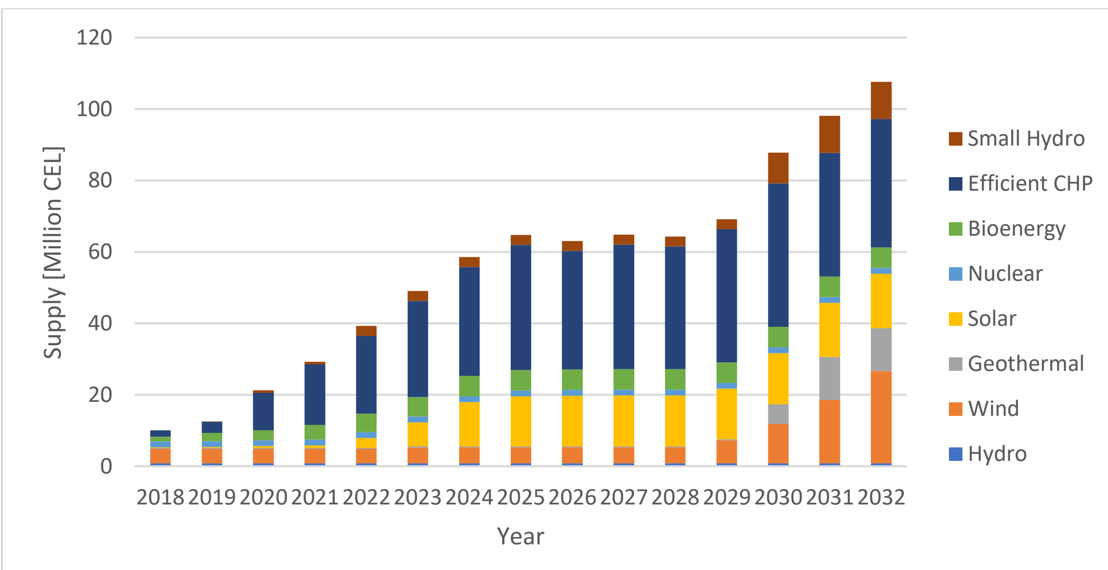

Figure 4.12: Scenario B's CEL Supply, 2018-2032

At the end of 2023, the Obligation Percentage has a value of 17%, thereafter, this percentage increase at an average of 2.57%, meaning that in 2032 the Obligation Percentage is 39.64% of the electricity consumed. In that same year, 173.656 Million CELs are demanded (See Table III.4 and Figure 4.13).

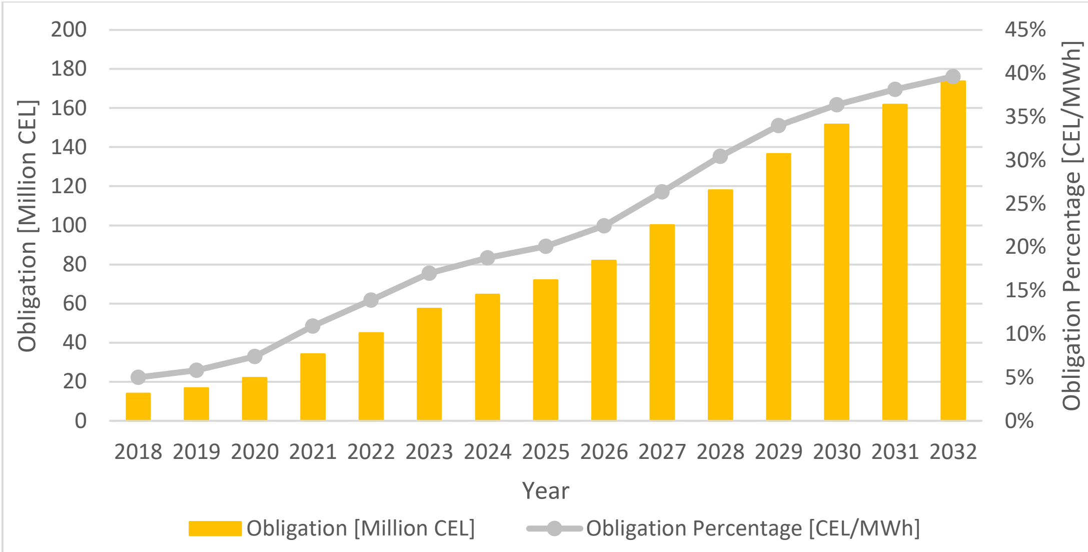

Figure 4.13: Scenario B's CEL Demand and Obligation Percentage, 2018-2032

The dynamic between the CELs Supply and CELs Demand leads to a high volatility of the CEL price. As seen in Figure 4.14, in 2026 the CEL price reached its lowest value with a selling price of $13.375 USD per CEL, while in 2021 the CEL price reached its highest value, selling at a price of $56.321 USD. The initial price per CEL obtained in this scenario has a value of $22.365 USD (See Table III.5).

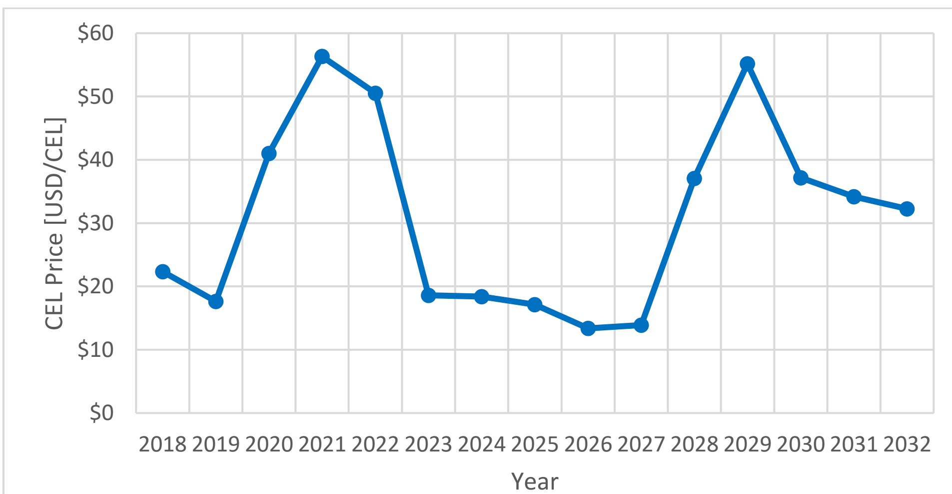

Figure 4.14: Scenario B's CEL Price, 2018-2032

As mentioned before, there is a period where the CELs Supply does not increase since the CEL price obtained in this period is not enough to promote the installation of new Clean Energy Capacity. This situation is reflected on the existing difference between the Clean Energy Goals and the Clean Energy Generation, since, as seen in Figure 4.15, the biggest difference happens exactly at the same period where the CEL Supply stagnates. It is also worth to mention that according to Table III.6, there is not a single year, except 2018, where the Clean Energy Generation is greater than the Clean Energy Goals, however, at the 2019-2025 period, the Clean Energy Generation is 0.65% on average lower than the Clean Energy Goals.

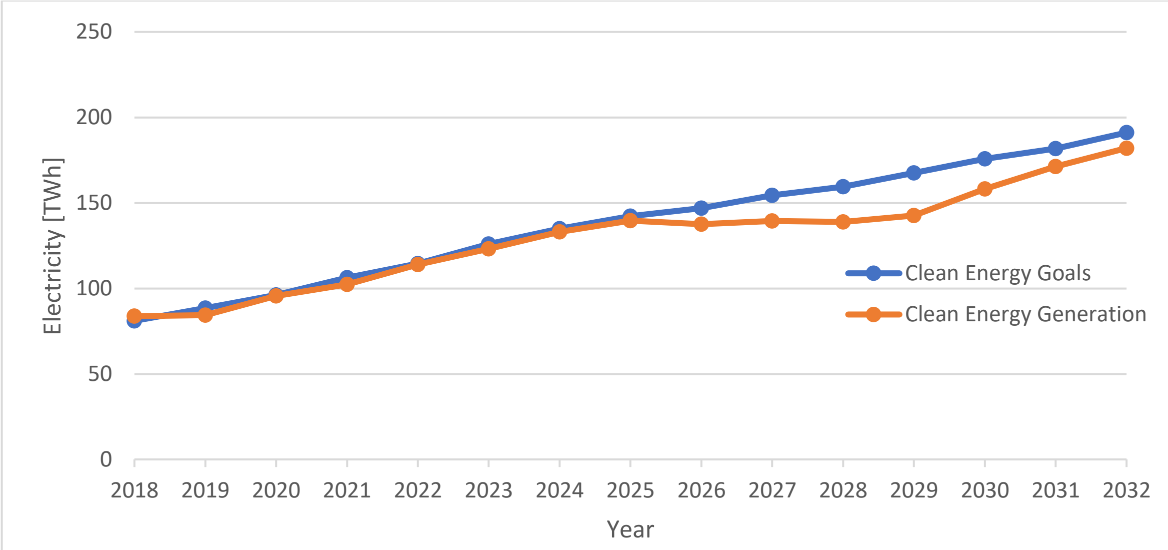

Figure 4.15: Scenario B's Clean Energy Generation vs Clean Energy Goals

The IRR and the NPV obtained for each Clean Energy Technology can be seen in Table III.7 and Table III.8 respectively.

4.4.3. Scenario C's Results

In this scenario, Efficient CHP technology does not increase its capacity over the next fifteen years since it is considered that Efficient CHP does not receive CELs for their energy generation. To compensate its lack of growth, the installation of new Efficient CHP plants are replaced with the installation of Nuclear power plants, which is the clean energy technology with the highest CAGR (8.1%) and even so, its CAGR is not close to the value that Solar energy presents, with a growth rate of 27% (See Table IV.1 and Figure 4.16).

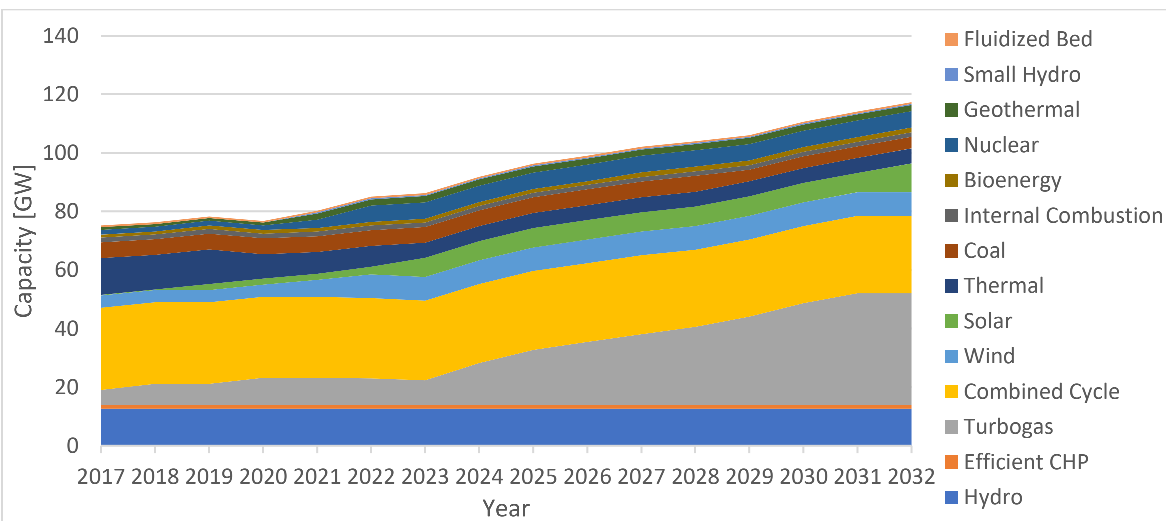

Figure 4.16: Scenario C's Capacity Evolution, 2018-2032

The Electricity generated per technology follows the same trend as the capacity evolution, where Solar and Nuclear energy are two of the three clean energy technologies with the highest annual growth (22.6% and 9.0% respectively). It is noteworthy that the other technology with the highest CAGR is Small Hydro technology with a 16.7% growth over the next fifteen years. In this scenario however, Combined Cycle and Turbo Gas technologies prevail as the main electricity generators (See Table IV.2 and Figure 4.17).

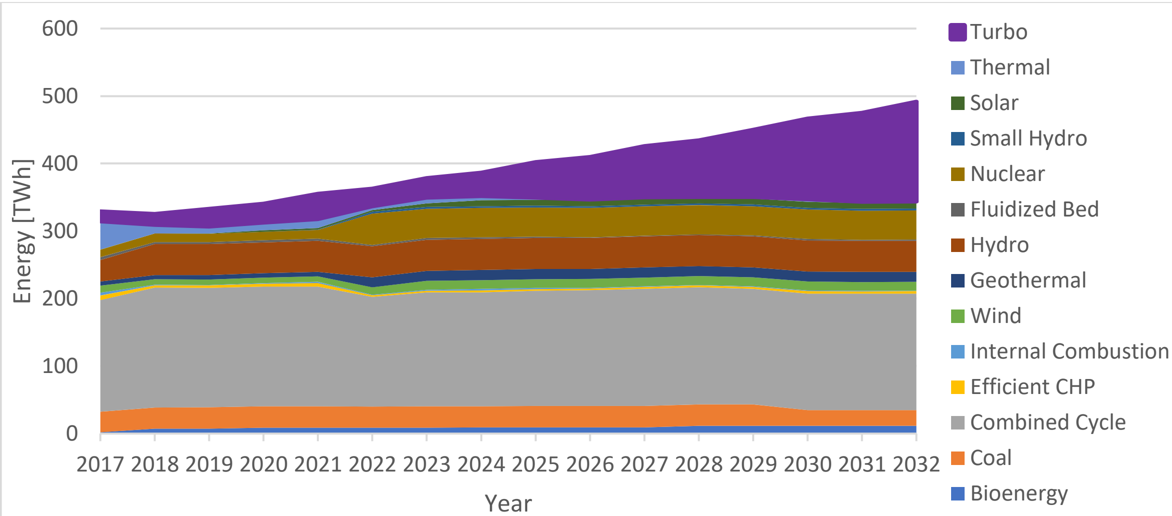

Figure 4.17: Scenario C's Electricity Generation

Over the first five years of this scenario, the CELs supply coming from clean energy power plants has an exponential growth, since in 2018 are 9.386 Million CELs supplied while in 2022 are almost eight times the initial value of CELs available in the market (32.409 Million), and from there on, the growth of the CELs supply is considerably lower than the first five years, since, as seen in Table IV.3, at the end of 2032 there are 86.950 million CEL supplied. The exponential growth of the CELs supply is due to the high CELs supply coming from the new Nuclear power plants, while at the 2022-2023 period, the increase of the CELs supply is due mainly to the growth of Solar and Bioenergy (See Figure 4.18).

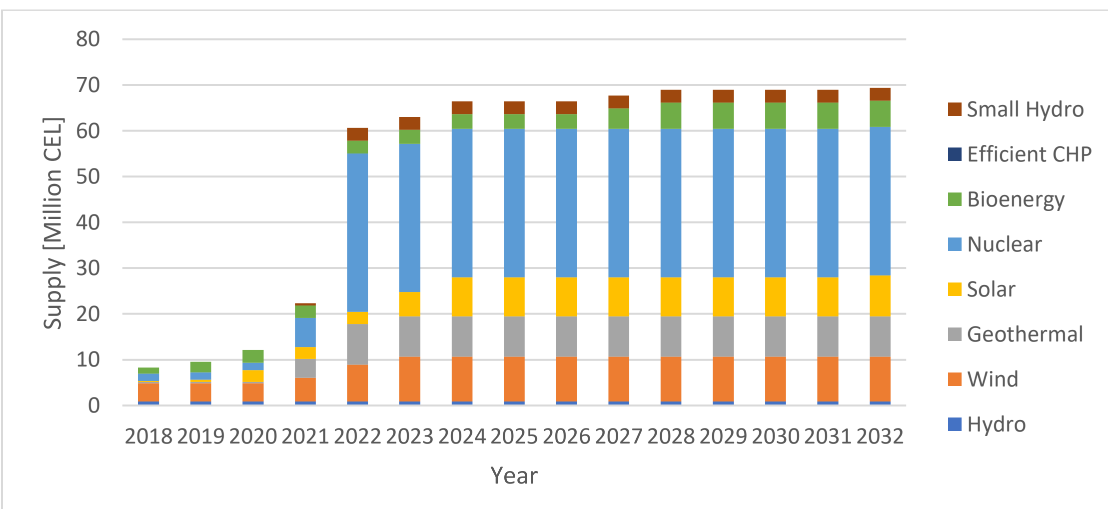

Figure 4.18: Scenario C's CEL Supply

As seen in Figure 4.19, the Obligation Percentage remains the same at the 2022-2024 period due to the high penetration of Nuclear energy, meaning that the CELs Supply is higher than the CELs Demand and creating a CELs Inventory. However, right after this period, the CELs Obligation Percentage increases every year, since in 2032 this percentage is 36.89% (See Table IV.7).

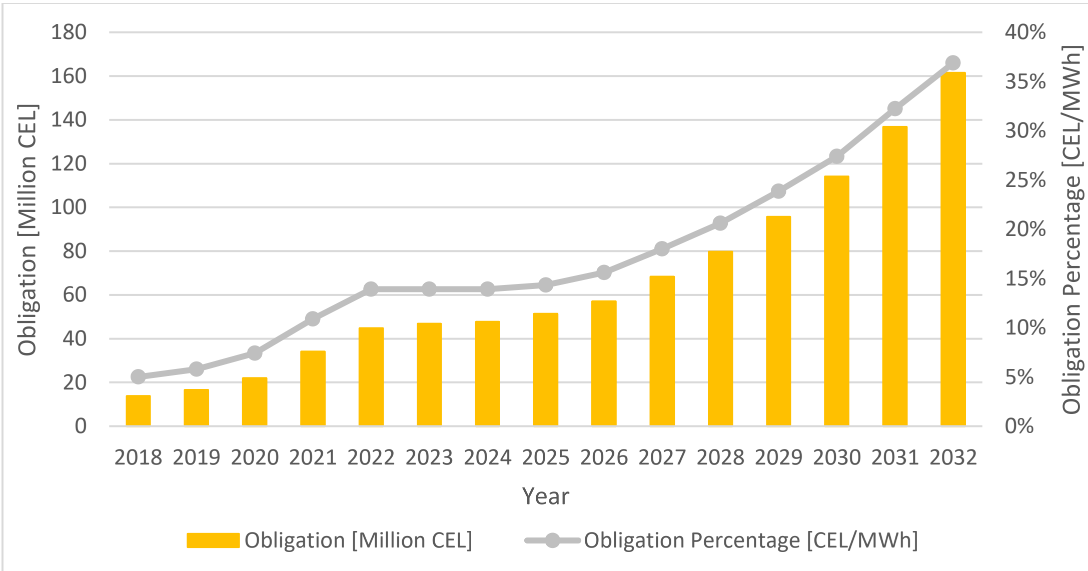

Figure 4.19: Scenario C's CEL Demand and Obligation Percentage

The dynamic between the CELs Supply and CELs demand is reflected over the CEL Price, since in 2018 it has a price of $18.435 USD and in 2021 it reaches a maximum price of $77.864 USD, while at the end of 2027, the CEL price sees its minimum price, settling down at $6.164 USD (See Table IV.5 and Figure 4.20). It can be noted that the period where the Nuclear installed capacity increase coincides with the exponential increase of the CEL price due to the new installed capacity, since at the 2023-2031 period, the CEL Price remains under $20 USD.

By comparing the CELs demand and the CELs supply, it is evident that the last six years of the scenario, the CELs demand is greater than the CELs supply, this means that the CEL Prices present an increase due to the high CELs demand and low CELs supply. However, as seen in Table IV.6, the CEL Prices do not increase since there is enough CELs Inventory and CELs Supply to meet the CELs Demand.

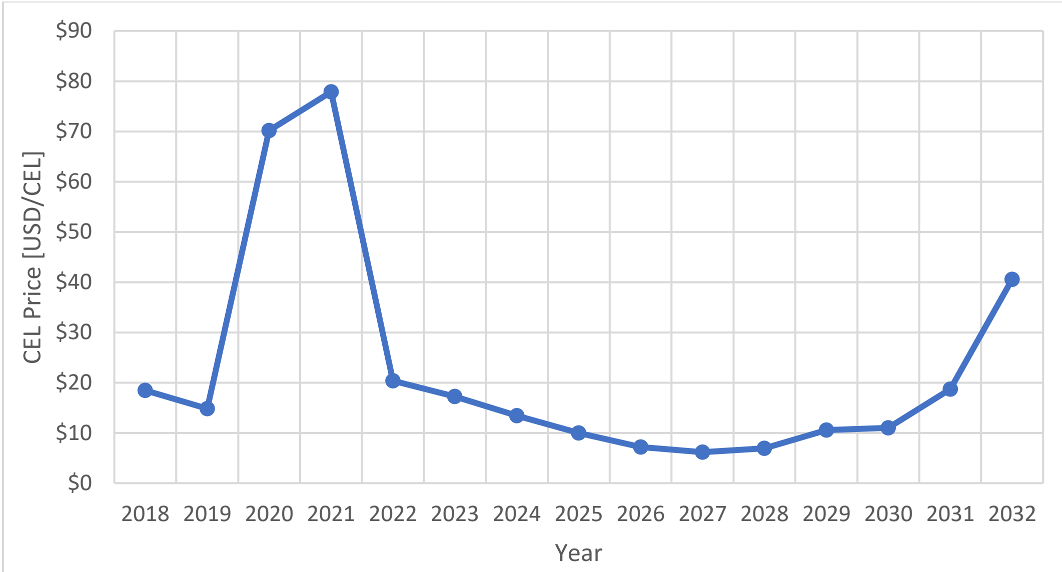

Figure 4.20: Scenario C's CEL Price, 2018-2032

The low CEL prices presented in this scenario are reflected over the Clean Energy Goals, since these are only met in 2018, 2022, 2023 and in 2024, while in the remaining years, the Clean Energy Generation is below the established goals (See Figure 4.21 and Table IV.7). It is noted that in this scenario there is an insignificant increase of the 2022-2032 Clean Energy Generation due to the low CEL Prices, which is not enough to stimulate the installation of new Clean Power Plants.

The behavior shown by the CELs demand can be explained by the existing difference between the Clean Energy Generation and the Clean Energy Goals, where the lower the Clean Energy Generation is compared to the Goals, the higher the CELs demand is, and therefore the higher the CEL Obligation Percentage should be. Even though the opposite can be said, it must be remembered that, according to (Secretaría de Energía, October 31, 2014), the CELs Obligation percentage is never going to be lower value than the previous year.

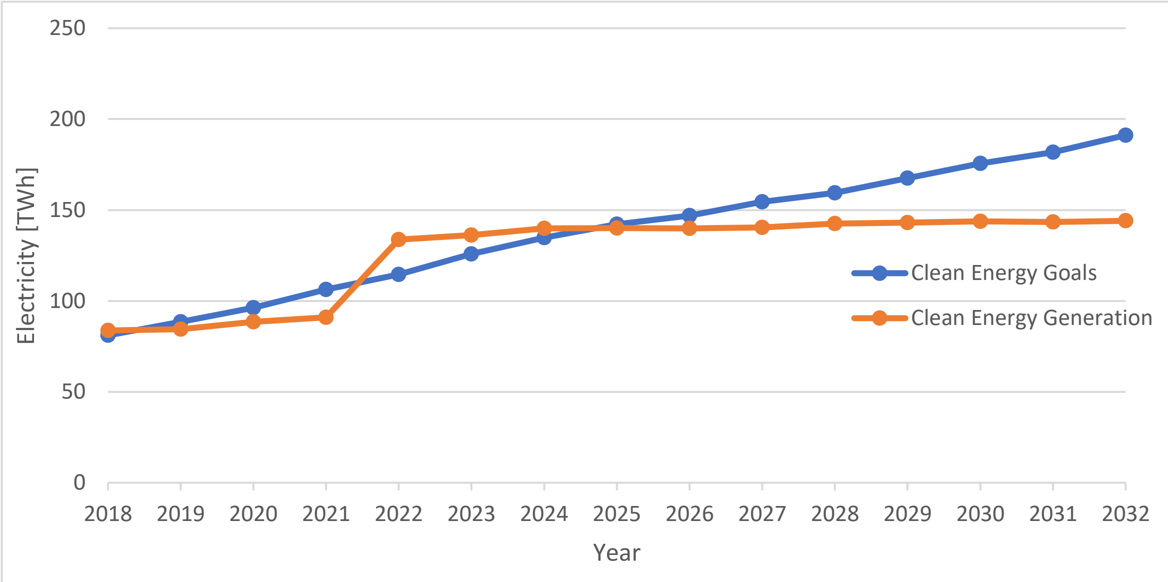

Figure 4.21: Scenario C's Clean Energy Generation vs Clean Energy Goals

The IRR and the NPV for each Clean Energy Technology can be seen in Table IV.8 and Table IV.9 respectively.

5. Conclusions and Recommendations

An analysis of the three scenarios was performed to determine which scenario was the best option, considering the clean energy generation and its installed capacity, the fulfillment or breach of the clean energy goals and the price at which each CEL is sold.

Several changes to the Mexican energy policy are proposed to carry out these scenarios, and, finally, some recommendations are made to help improve the CEL Market Model and future studies regarding the Clean Energy Certificates market.

5.1. Analysis of Results

As seen in Figure 5.1, each Simulation Scenario presented a lower Clean Energy installed capacity than the Base Scenario, however, the Wind Energy participation in the Base Scenario is higher than the participation in the three simulation scenarios. Additionally, in Scenario A and Scenario B, the installed capacity over the next fifteen years of Efficient CHP, Small Hydro and Bioenergy are greater than the Base Scenario and Scenario C due to the influence of the CEL System. The data concerning the installed capacity of the Base Scenario are shown in Table V.1.

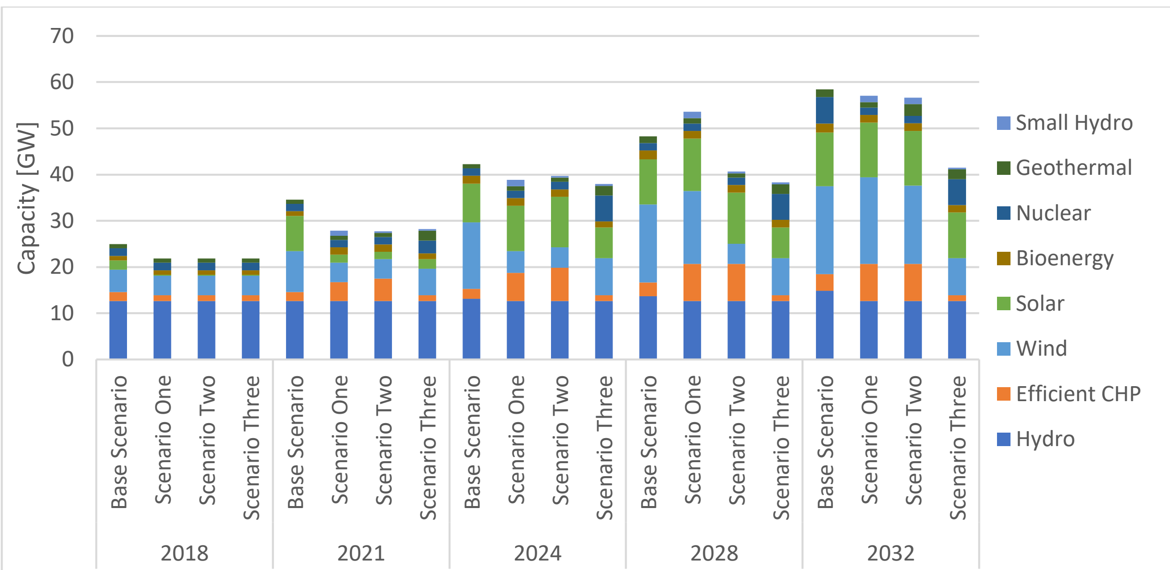

Figure 5.1: Clean Energy Installed Capacity per Scenario

As seen in Figure 5.2, the Base Scenario had the highest Clean Energy Generation of all the four scenarios due to the high contribution of Wind Energy. However, this fact is compensated by Scenario A and Scenario B with the electricity generated by Efficient CHP and Small Hydro technologies. It must be noted that Scenario C had the highest Nuclear Energy Generation and nevertheless, this scenario had the lowest Clean Energy Generation overall. The data of the Base Scenario's Electricity Generation are shown in Table V.2.

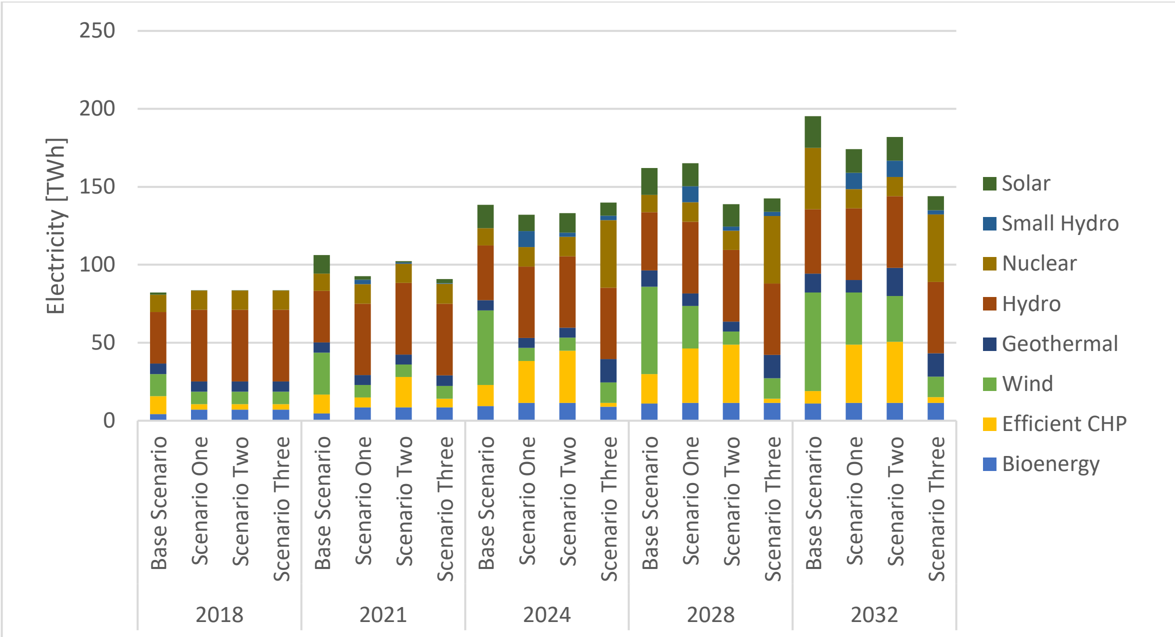

Figure 5.2: Clean Energy Generation per Scenario

Each scenario had an increase of electricity generated from Clean Energy Sources. However, the Clean Energy Generation in Scenario C had the highest difference in relation to the Clean Energy Goals, even though in some years the Clean Energy Generation was greater than the goals, after 2025 the Clean Energy generation is not even close to the Clean Energy Goals, and this scenario could compromise the fulfillment of the 2035 Goal.

As seen in Figure 5.3, the Clean Energy Generation from Scenario A and Scenario B are close to the Clean Energy Goals, however, only Scenario A presents a Clean Energy Generation greater than these Goals. Although several Clean Energy Goals of Scenario A are met and even surpassed, it should be noted that only one of the three Goals established at the Electric Industry Law (Secretaría de Energía, August 11, 2014) is completely fulfilled, since the 2021 and 2024 Clean Energy Generation are lower than the goals, even though in 2032 this Generation is considerably lower than the goals, it is still possible to fulfill the 2035 Goals thanks to the high CEL price of that year.

While it is true that the Clean Energy Generation obtained in Scenario B was lower than the Goals, it is also true that this Clean Generation is closer to that of 2021 and 2024 Clean Energy Goals than the one obtained in Scenario A, where, especially in 2021, it has almost 4% breach on the Goal, while Scenario B has a 1% breach. It is also worth mentioning that in 2032, the Clean Energy Generation presented in Scenario B had the closest value to the Clean Energy Goal, meaning that most likely this scenario could fulfill the 2035 Goal.

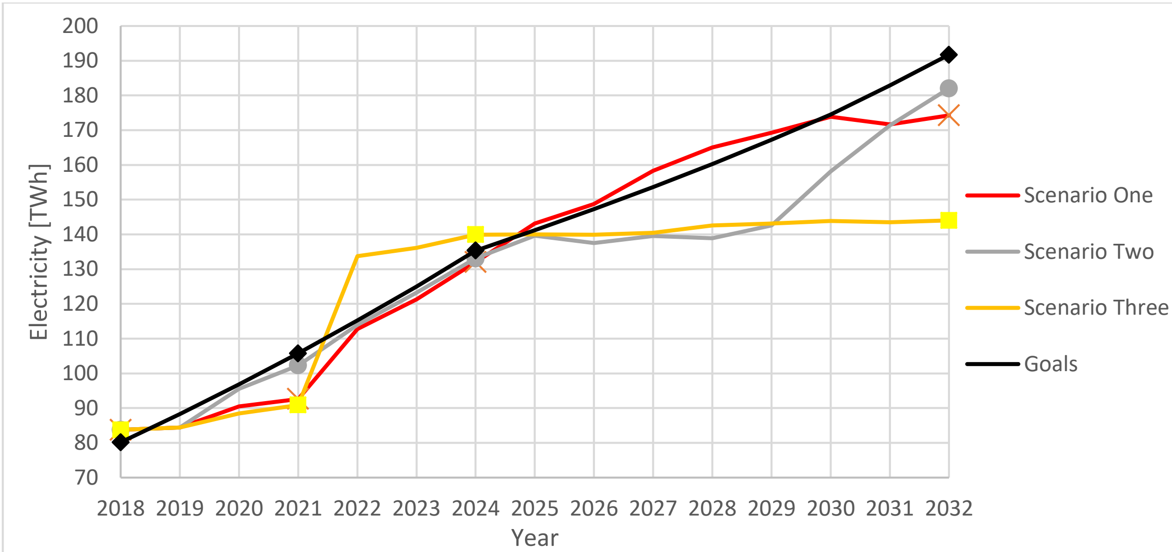

Figure 5.3: Clean Energy Generation of each Scenario vs Clean Energy Goals, 2018-2032

Each scenario presented a highly volatile CEL Price, but, as seen in Figure 5.4, Scenario C had have the highest volatility, with a minimum price of 6.16 [USD/CEL] and a maximum price of 77.86 [USD/CEL]. In fact, these prices were the lowest and the highest prices out of the three scenarios. However, as seen in Table 5.1, 75% of the 15-year period the CEL Prices obtained in Scenario C do not exceed the 19.55 [USD/CEL] price, while 75% of the time, the CEL Price from Scenario A and Two did not surpassed the 39.09 [USD/CEL] and 48.9 [USD/CEL] respectively. Inversely, 75% of the time the CEL Price from Scenario C was higher than 10.27 [USD/CEL], while the CEL Price obtained from scenarios One and Two were higher than 18.03 [USD/CEL] and 36.66 [USD/CEL] respectively.

Even though Scenario A had a higher CEL Price overall, the volatility shown by this scenario is the lowest out of all three, with a mean CEL Price of 39.57 [USD/CEL] and a standard deviation of 11.79 [USD/CEL].

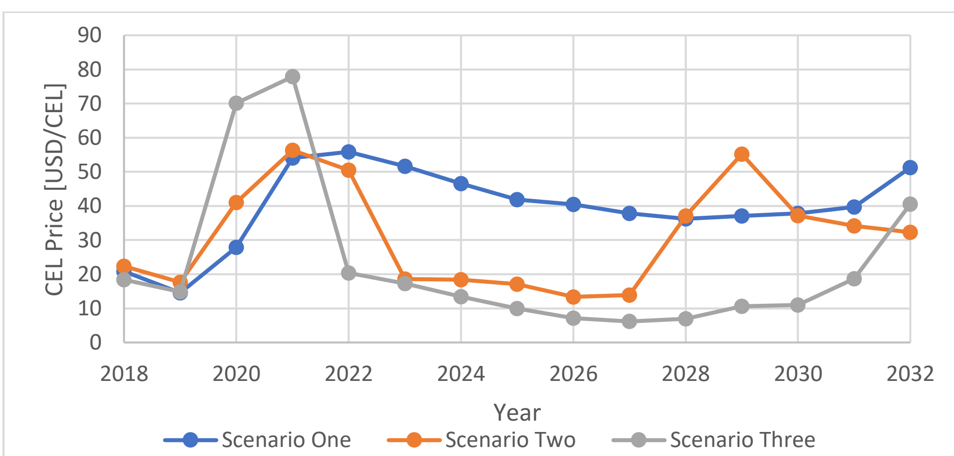

Figure 5.4: CEL Prices Comparison Between Scenarios, 2018-2032

Table 5.1: Summary Statistics of CEL Prices from each Scenario [USD/CEL]

	Scenario A	Scenario B	Scenario C
Minimum	$ 14.56	$ 13.38	$ 6.16
First Quartile	$ 36.66	$ 18.03	$ 10.27
Median	$ 39.71	$ 32.26	$ 14.81
Third Quartile	$ 48.90	$ 39.09	$ 19.55
Maximum	$ 55.85	$ 56.32	$ 77.86
Mean	$ 39.57	$ 31.01	$ 22.89
Standard Dev.	$ 11.79	$ 15.01	$ 22.42

5.2. Conclusions

The adoption of a Clean Energy Certificate system by the Mexican government will boost the installation and electricity generation coming from Clean Energy projects, since the three proposed scenarios presented an increase both in Capacity and in Clean Energy Generation as compared to the base year. With the creation of an Electricity Market, where every Generator competes among themselves to deliver electricity at the lowest price possible, the technology with the lowest levelized cost of generation and the highest technical efficiency has the largest competitive advantage, meaning that Clean Energy projects such as Solar, Wind, Bioenergy, among others, may not be considered as feasible projects. However, the CEL income obtained by the Clean Generators erase the edge between the investment costs of Non-Clean Energy projects and the investment costs of Clean Energy projects.

Although the clean energy generation obtained by each scenario shows an increase over the next fifteen years, Scenario A was the scenario with the lowest difference between the goals and the actual clean energy generation and, as well, it was the only scenario where some of the intermediate goals are met. However, Scenario A did not achieve the 2021 and 2024 clean energy goals established by the Electric Industry Law. In this manner, only the 2024 goal is met by Scenario C, and even so, Scenario B had the closest clean energy generation compared to the 2021 and 2024 goals.

Even though there is an increase of Clean Energy Generation in the three simulation scenarios, the use of Natural Gas as fuel to generate electricity did not decrease at the fifteen years analysis period, in fact, it increased, since technologies such as Turbo Gas, Combined Cycle and Efficient CHP increased their energy generation.

Scenario C had the cheapest CEL Prices but also the highest volatility of all scenarios, while Scenario A had the most expensive CEL Prices but also the lowest volatility. This means that in Scenario C the End Use Consumers will pay lower CEL prices compared to the Scenario A CEL prices.

Taking into consideration the Clean Energy Generation, the fulfillment of the Clean Energy Goals and the CEL Prices obtained from each scenario, it is concluded that Scenario A has the highest clean energy generation of all the scenarios, while also maintaining the lowest breach between the goals and the actual generation at a reasonable price, thereby making it the best option out of the three scenarios proposed. Scenario B also is considered as a second option since it presented a high clean energy generation with the second lowest CEL Prices, however, this scenario is the best option if the priority is to keep the actual clean energy generation the closest to the 2018, 2021 and 2024 goals.

Scenario C is considered as a third option given that this scenario requires new Nuclear Power Plants operating by 2022, meaning that the construction phase of these power plants should have already started at around the year 2016, making this scenario practically impossible to complete on time. Even if the CEL Prices obtained in this scenario are the lowest of all the three scenarios, the CEL system alone is not enough to promote the installation of new Clean Energy projects, which is reflected on the clean energy generation.

5.3. Proposals and Recommendations

The following changes on the energy policies are proposed:

- If the objective of the Mexican government is to fulfill only the Clean Energy Generation Goals established at the Electric Industry Law, then Guideline 6 of the Clean Energy Accreditation Criteria must be rewritten as follows:

"When fossil fuels are used, the Clean Generators will have the right to receive, at the Clean Power Plants they represent, one CEL per Megawatt-hour generated multiplied by the fuel free energy percentage, except for Efficient Combined Heat and Power Plants, which will have the right to receive one CEL per Megawatt-hour generated. To accomplish this guideline, the CRE has issued the Efficiency Criteria and the Calculation Methodology of the Fuel Free Energy Percentage Decree"

By doing this, each Combined Heat and Power plant credited, according to the Clean Energy Accreditation Criteria, as Efficient CHP will have the right to receive one CEL per MWh delivered.

- If the objective of the Mexican government is to promote only the generation from Renewable Sources, then the term "*Clean Energy*" found in every act, guideline, regulation, criteria, etc. should be replaced with the term *"Renewable Energy"* and, given that Scenario C proved that Renewable Energy alone is not enough to achieve the clean energy goals, a reduction to the Clean Energy Goals established at the Electric Industry Law is proposed, by first performing a new analysis of the opportunities found at the economic sectors to reduce their GHG emissions while at the same time complying with the GHG emissions Goals established at the Paris Agreement.

Regarding the CEL model developed in this paper and the data used to obtain the three different scenarios, the recommendations are:

- To carry out an in-depth analysis of the CEL Demand, given that the equation proposed in this paper to describe the CEL Demand behavior is a linear equation, while it can also be described with hyperbolic equations, logarithmic equations or 2nd Order equations.
- To develop a model dedicated to obtaining the price at which the Generators will sell their electricity, since this value will change the profits made by Electricity Sales and therefore, the Electricity Price will change the Cash Flow of every energy project.
- To improve the Cash Flow model for considering fuel prices, investment costs, O&M Costs, capacity factors and every technical and all the economic data from every technology power plant that could be affected due to the geographic location of the power plant.

- To improve the quality of the data concerning technologies, such as Bioenergy, Efficient CHP, Small Hydro Technology and Fluidized Bed, given that technical and economic parameters of these technologies are not specified in the PRODESEN.
- To include Distributed Generation in the CEL Market Model as a Clean Energy credited to receive CELs by following the Clean Energy Certification Criteria issued by the CRE.
- To include all the Clean Energy repowering projects into the CEL Market Model as Clean Energy credited to receive CELs by following the Clean Energy Certification Criteria issued by the CRE.
- To improve the CEL Model so that an hourly, daily or monthly analysis is included.

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Annex I. Calculation of the Fuel Free Energy in Efficient Combined Heat & Power Processes

According to (Comisión Reguladora de Energía, December 22, 2016), the calculation to obtain the fuel free energy in efficient Combined Heat & Power processes starts with the estimation of the electric and thermal efficiency of a power plant:

$$\eta_e = \frac{E}{F}$$

$$\eta_h = \frac{H}{F}$$

Where:

η_e is the electric efficiency of the CHP plant.

η_h is the thermal efficiency of the CHP plant.

E is the net electric energy delivered by the CHP through the "p" period, in MWh.

F is the fuel energy used by the CHP through the "p" period, measured over the lower heating value [MWh].

H is the net thermal energy or the useful heat generated by the CHP and employed in a productive process through the "p" period [MWh].

In this paper, it is assumed that the prototype CHP plant consists of a gas turbine, the thermal efficiency is also assumed that has a value 53.20% and the thermal regime of the CHP plant is 9,000 [MJ/MWh]. These assumptions are made following the specifications of some of the CHP plants installed in Mexico, which operate approximately with these values. The E, F and H values can be found with the thermal efficiency and the thermal regime besides the technical data shown in Table 4.6.

$$E = 25{,}958.946\ [MWh]$$

$$F = 66{,}904.5\ [MWh]$$

$$H = 35{,}593.194\ [MWh]$$

Subsequently, the reference performance is obtained following the next equation:

$$Ref\ E' = Ref\ E * fp$$

Where:

$Ref\ E$ is the reference efficiency to generate electricity coming from a fossil fuel of an efficient power plant with current technology, measured over the lower heating value of the fuel. The value of this efficiency is showed in Table I.1 and Table I.2

fp is the electricity loss factor due to transmission and distribution from the high voltage level till the voltage level that the power plant is connected. Table I.3 shows the different values of "fp".

$Ref\ E'$ is the reference performance to generate electricity coming from a fossil fuel of an efficient power plant with current technology, measured over the lower heating value of the fuel, measured at the voltage level that the power plant is connected.

Power Plant Capacity (MW)	*Ref E*
Capacity < 0.5	40 %
0.5 ≤ Capacity < 6	44 %
6 ≤ Capacity < 15	47 %
15 ≤ Capacity < 30	48 %
30 ≤ Capacity < 150	51 %
150 ≤ Capacity < 300	52 %
Capacity ≥ 300	53 %

Table I.1: Reference Performance to Generate Electricity

The power plants with a Capacity equal or less to 30 MW, generating with internal combustion engines or gas turbines, will consider the next reference values:

Capacidad de la central eléctrica (MW)	*Ref E*
Capacidad < 0.5	40 %
0.5 ≤ Capacidad < 6	44 %
6 ≤ Capacidad < 15	45 %
15 ≤ Capacidad < 30	45 %

Table I.2: Reference Performance to Generate Electricity According to the Power Plant Equipment

Voltage Level [kV]	< 1.0	1.0-34.5	69-85	115-230	≥ 400
Loss Factor (*fp*)	0.91	0.94	0.96	0.98	1

Table I.3: Value of "fp" According to the Voltage Level

Since the Capacity of the prototype CHP plant is 4.7 MW, $Ref\ E$ has the next value:

$$Ref\ E = 0.44$$

To obtain the loss factor, it is considered that the prototype CHP plant is interconnected to the National Transmission Grid at the 115 kV level, meaning that the loss factor is as follows:

$$fp = 0.98$$

With both fp and $Ref\ E$ found, the value of $Ref\ E'$ for the prototype CHP plant is:

$$Ref\ E' = 0.4312$$

The next step is to calculate the value of Fh as follows:

$$Fh = \frac{H}{Ref\ H}$$

Where:

$Ref\ H$ is the reference efficiency of the thermal energy generation coming from an efficient fossil fuel thermal plant with current technology, measured over the base of the lower heating value of the fuel, as seen in Table I.4.

Fh is the energy coming from the fossil fuels of an efficient thermal plant attributable to the useful heat production [MWh].

Reference	$Ref\ H$
RefH (with steam or hot water as a heating medium)	90 %
RefH (with direct use of the combustion gases)	82 %

Table I.4: Reference Efficiency of the Thermal Energy

Considering that the prototype CHP plant uses steam or hot water as heating medium, the value of Fh is:

$$Fh = 39{,}547.99333\ [MWh]$$

The value of the energy of the fossil fuels and the efficiency attributable to the electricity generated are obtained with the next equations:

$$Fe = F - Fh$$

$$EE = \frac{E}{Fe}$$

$$E_{conv} = Fe * Ref\ E$$

Where:

Fe is the fossil fuels energy used at the power plant attributable to the electricity generated, in MWh.

EE is the efficiency attributable to the electricity generated.

E_{conv} is the electricity generated by an efficient thermal plant, interconnected to the SEN in High Voltage, using the same amount of energy that is attributable to the electricity generated at the power plant, in MWh.

The value of Fe, EE and E_{conv} is as follows:

$$Fe = 27{,}356.50667\ [MWh]$$

$$EE = 95\%$$

$$E_{conv} = 12{,}036.86293\ [MWh]$$

The primary energy of the power plant is obtained with the next equation:

$$EP = \frac{E}{Ref\ E'} + \frac{H}{Ref\ H}$$

Where:

EP is the primary energy, obtained from the independent analysis of the electricity generation process behavior and the thermal process of the power plant, in MWh.

The value of EP is:

$$EP = 103{,}607.9714\ [MWh]$$

The savings on primary energy can be calculated with the fuel energy used and the primary energy:

$$AEP = EP - F$$

$$APEP = \frac{EP - F}{EP}$$

Where:

AEP is the primary energy savings, obtained from the independent analysis of the electricity generation process behavior and the thermal process of the power plant, in MWh.

$APEP$ is the porcentaje savings on primary energy.

The value of AEP and $APEP$ is:

$$AEP = 36{,}703.47144\ [MWh]$$

$$APEP = 35.425\%$$

The Fuel Free Energy generated at the CHP plant is calculated with the next equation:

$$ELC = AEP * Ref\ E$$

Where:

ELC is the fuel free energy, or the electricity generated at the CHP plant above the one that could be generated on a thermal plant, using the same amount of fuel at a CHP plant, in MWh.

The value of ELC for the prototype CHP plant is:

$$ELC = 16{,}149.527\ [MWh]$$

The power plant is considered as efficient CHP if:

$$ELC > 0$$

The amount of CELs that an efficient CHP plant will receive per supplied MWh is equal to the fuel free energy percentage as shown in the next equation:

$$CELs\ per\ MWh = \%ELC = \frac{ELC}{E}$$

According to the previous equation, the prototype CHP plant should receive:

$$CELs\ per\ MWh = \%ELC = 62.212$$

Annex II. Scenario A's Tables

Table II.1: Scenario A's Capacity Evolution in GW per Technology, 2017-2032

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	CAGR
Hydro	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	0.0%
Efficient CHP	1.25	1.25	1.25	1.25	4.09	4.40	5.36	6.11	6.37	7.28	8.00	8.00	8.00	8.00	8.00	8.00	12.3%
Turbo	5.14	7.24	7.24	9.29	9.29	9.11	8.92	9.83	11.48	12.85	14.20	17.40	21.61	26.72	29.94	33.18	10.0%
Combined Cycle	28.08	27.86	27.86	27.65	27.65	27.42	27.18	26.95	26.95	26.95	26.95	26.46	26.46	26.46	26.46	26.46	-0.3%
Wind	4.20	4.20	4.20	4.20	4.20	4.20	4.41	4.71	7.29	10.90	14.82	15.84	15.97	17.62	18.68	18.78	9.8%
Solar	0.21	0.21	1.70	1.70	1.77	3.58	6.33	9.83	11.05	11.18	11.33	11.33	11.59	11.86	11.86	11.86	28.5%
Thermal	12.55	11.71	11.71	8.30	7.48	7.16	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	-5.0%
Coal	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	3.98	3.98	3.98	3.98	-1.9%
Internal Combustion	1.63	1.63	1.63	1.63	1.63	1.56	1.56	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	-0.4%
Bioenergy	1.01	1.01	1.21	1.21	1.56	1.56	1.63	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	3.1%
Nuclear	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	0.0%
Geothermal	0.93	0.95	0.94	0.91	0.89	0.89	0.90	0.95	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.2%
Small Hydro	0.00	0.00	0.38	0.38	1.09	1.09	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	9.9%
Fluidized Bed	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.0%
Total	75.21	76.27	78.33	76.72	79.85	81.17	83.02	88.28	94.20	100.20	106.35	110.08	113.28	120.31	124.59	127.93	

Table II.2: Scenario A's Electricity Generation Evolution in TWh per Technology, 2017-2032

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	CAGR
Bioenergy	1.9	7.0	7.1	8.5	8.6	10.9	10.9	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.9%
Coal	30.6	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	23.5	23.5	23.5	-1.6%
Combined Cycle	165.2	177.4	176.9	177.5	177.3	177.5	177.2	175.8	174.6	174.8	175.0	175.0	171.7	171.8	171.9	172.1	0.3%
Efficient CHP	6.9	3.6	3.9	4.2	6.2	18.9	24.4	26.9	31.6	31.7	34.8	34.9	38.1	42.1	36.7	37.4	11.1%
Internal Combustion	4.0	0.6	0.6	0.6	1.4	0.8	1.4	1.9	2.0	1.7	1.6	1.2	1.0	1.1	0.5	0.4	-13.5%
Wind	10.6	8.0	8.0	8.0	8.0	8.0	8.0	8.4	9.7	14.5	20.8	27.2	28.3	28.5	31.4	33.3	7.4%
Geothermal	6.0	6.5	6.7	6.6	6.4	6.3	6.3	6.4	7.0	8.1	8.1	8.1	8.1	8.1	8.1	8.1	1.9%
Hydro	31.8	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	2.3%
Fluidized Bed	4.3	3.0	2.7	2.7	3.0	1.6	2.3	2.4	2.4	1.9	1.9	1.4	1.6	1.9	1.2	1.1	-8.4%
Nuclear	10.9	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	0.8%
Small Hydro	0.0	0.0	0.1	2.8	2.9	8.1	8.1	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	39.2%
Solar	0.3	0.3	0.4	2.2	2.2	2.4	5.3	10.3	14.7	14.3	14.5	14.6	14.6	15.0	15.3	15.3	26.8%
Thermal	42.8	13.5	11.3	11.0	12.8	4.9	8.1	5.7	6.4	4.7	4.7	3.4	3.7	4.9	2.6	2.4	-16.5%
Turbo	12.8	14.3	24.3	25.3	35.7	32.6	35.6	35.8	40.9	45.5	51.5	55.4	70.4	88.6	102.6	117.0	14.8%
Total	328.3	324.3	332.0	339.4	354.5	361.9	377.6	385.3	401.2	409.0	424.8	433.2	449.3	465.7	474.0	490.7	

Table II.3: Scenario A's CEL Supply [Million CEL], 2018-2032

	Hydro	Wind	Geothermal	Solar	Nuclear	Bioenergy	Efficient CHP	Small Hydro	Total
2018	0.855	4.042	0.240	0.205	1.603	1.342	1.099	0.000	9.386
2019	0.855	4.041	0.251	0.372	1.603	2.336	1.169	0.102	10.728
2020	0.855	4.041	0.255	2.108	1.603	2.789	1.270	2.785	15.706
2021	0.855	4.041	0.251	2.113	1.603	4.113	3.275	2.911	19.162
2022	0.855	4.041	0.247	2.355	1.603	5.209	10.030	8.069	32.409
2023	0.855	4.248	0.314	5.233	1.603	5.456	13.387	8.115	39.209
2024	0.855	4.711	0.655	10.212	1.603	5.721	14.959	10.407	49.122
2025	0.855	6.954	1.822	14.595	1.603	5.746	17.671	10.407	59.653
2026	0.855	11.744	2.110	14.203	1.603	5.746	17.967	10.407	64.634
2027	0.855	17.849	2.110	14.407	1.603	5.746	19.928	10.407	72.905
2028	0.855	23.643	2.110	14.559	1.603	5.746	19.979	10.407	78.902
2029	0.855	24.601	2.110	14.563	1.603	5.746	21.793	10.407	81.679
2030	0.855	25.134	2.110	14.909	1.603	5.746	24.106	10.407	84.870
2031	0.855	27.941	2.110	15.212	1.603	5.746	20.989	10.407	84.862
2032	0.855	29.628	2.110	15.212	1.603	5.746	21.390	10.407	86.950

Table II.4: Scenario A's Obligation Percentage and CEL Demand, 2018-2032

Year	Obligation Percentage [CEL/MWh]	CEL Demand [Million CEL]
2018	5.00%	13.814
2019	5.80%	16.600
2020	7.40%	21.905
2021	10.90%	34.073
2022	13.90%	44.905
2023	17.33%	58.409
2024	20.18%	69.441
2025	22.48%	80.538
2026	24.70%	90.265
2027	26.67%	101.267
2028	28.50%	110.383
2029	30.53%	122.673
2030	32.66%	136.156
2031	35.07%	148.887
2032	37.45%	164.238

Table II.5: Scenario A's CEL Price, 2018-2032

Year	Price [USD/CEL]
2018	$ 20.879
2019	$ 14.556
2020	$ 27.885
2021	$ 54.079
2022	$ 55.850
2023	$ 51.603
2024	$ 46.531
2025	$ 41.820
2026	$ 40.423
2027	$ 37.831
2028	$ 36.234
2029	$ 37.087
2030	$ 37.842
2031	$ 39.707
2032	$ 51.273

Table II.6: Scenario A's Clean Energy Goals and Clean Energy Generation Percentage, 2018-2032

Year	Clean Energy Goals	Clean Energy Generation	Difference
2018	25.00%	25.83%	0.83%
2019	26.67%	25.44%	-1.23%
2020	28.33%	26.67%	-1.66%
2021	30.00%	26.13%	-3.87%
2022	31.67%	31.17%	-0.50%
2023	33.33%	32.14%	-1.20%
2024	35.00%	34.26%	-0.74%
2025	35.45%	35.68%	0.22%
2026	35.91%	36.37%	0.46%
2027	36.36%	37.27%	0.91%
2028	36.82%	38.10%	1.28%
2029	37.27%	37.68%	0.41%
2030	37.73%	37.34%	-0.39%
2031	38.34%	36.23%	-2.12%
2032	38.95%	35.52%	-3.44%

Table II.7: Scenario A's Internal Rate of Return for each Clean Technology, 2018-2032

Year	Bioenergy	Efficient CHP	Wind	Geothermal	Hydro	Small Hydro	Nuclear	Solar
2018	25.2%	15.0%	9.4%	18.5%	10.4%	15.5%	6.8%	8.5%
2019	21.3%	13.5%	8.4%	17.1%	9.5%	14.3%	6.1%	7.6%
2020	29.3%	16.6%	10.4%	20.0%	11.2%	16.8%	7.6%	9.4%
2021	43.2%	22.2%	14.0%	25.2%	14.3%	21.2%	10.1%	12.6%
2022	44.1%	22.5%	14.2%	25.5%	14.4%	21.5%	10.2%	12.8%
2023	41.9%	21.7%	13.7%	24.7%	14.0%	20.8%	9.8%	12.3%
2024	39.3%	20.6%	13.0%	23.7%	13.4%	20.0%	9.4%	11.7%
2025	36.9%	19.6%	12.4%	22.8%	12.9%	19.2%	8.9%	11.1%
2026	36.1%	19.3%	12.2%	22.5%	12.7%	18.9%	8.8%	11.0%
2027	34.8%	18.7%	11.8%	22.0%	12.4%	18.5%	8.6%	10.6%
2028	33.9%	18.4%	11.6%	21.7%	12.2%	18.2%	8.4%	10.4%
2029	34.4%	18.6%	11.7%	21.8%	12.3%	18.4%	8.5%	10.5%
2030	34.8%	18.8%	11.8%	22.0%	12.4%	18.5%	8.6%	10.6%
2031	35.8%	19.2%	12.1%	22.4%	12.6%	18.8%	8.7%	10.9%
2032	41.8%	21.6%	13.6%	24.6%	13.9%	20.7%	9.8%	12.3%

Table II.8: Scenario A's Net Present Value for each Clean Energy Technology in Million Dollar, 2018-2032

Year	Bioenergy	Efficient CHP	Wind	Geothermal	Hydro	Small Hydro	Nuclear	Solar
2018	$0.14	$1.53	-$4.79	$91.40	$16.16	$5.21	-$877.31	$11.53
2019	$0.10	$1.05	-$12.24	$63.88	-$20.10	$3.98	-$1,050.16	$4.73
2020	$0.18	$2.05	$3.37	$121.90	$55.83	$6.57	-$686.72	$19.07
2021	$0.34	$3.99	$33.51	$235.90	$203.21	$11.60	$17.84	$47.23
2022	$0.36	$4.12	$35.53	$243.61	$213.11	$11.94	$64.89	$49.13
2023	$0.33	$3.80	$30.68	$225.13	$189.36	$11.12	-$48.58	$44.57
2024	$0.30	$3.43	$24.88	$203.05	$161.00	$10.15	-$184.83	$39.12
2025	$0.27	$3.08	$19.49	$182.55	$134.66	$9.24	-$311.39	$34.05
2026	$0.26	$2.98	$17.89	$176.47	$126.84	$8.98	-$348.92	$32.55
2027	$0.25	$2.79	$14.91	$165.18	$112.16	$8.48	-$418.55	$29.76
2028	$0.24	$2.67	$13.06	$158.23	$103.11	$8.17	-$461.45	$28.04
2029	$0.24	$2.73	$14.05	$161.95	$107.94	$8.34	-$438.54	$28.96
2030	$0.25	$2.79	$14.92	$165.23	$112.22	$8.48	-$418.24	$29.77
2031	$0.26	$2.93	$17.08	$173.35	$122.78	$8.84	-$368.14	$31.78
2032	$0.33	$3.78	$30.30	$223.69	$187.52	$11.06	-$57.44	$44.21

Annex III. Scenario B's Tables

Table III.1: Scenario B's Capacity Evolution in GW, 2017-2032

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	CAGR
Hydro	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	0.0%
Efficient CHP	1.25	1.25	2.92	3.45	4.85	5.07	6.47	7.20	7.47	8.00	8.00	8.00	8.00	8.00	8.00	8.00	12.3%
Turbogas	5.14	7.24	7.24	7.46	7.46	7.28	7.67	9.50	15.09	19.07	22.33	24.79	24.79	25.04	25.44	30.46	9.4%
Combined Cycle	28.08	27.86	27.86	27.65	27.65	27.42	27.18	26.95	26.95	26.95	26.95	26.43	26.43	26.43	26.43	26.43	-0.3%
Wind	4.20	4.20	4.20	4.20	4.20	4.20	4.41	4.41	4.41	4.41	4.41	4.41	7.31	11.09	16.23	16.97	9.1%
Solar	0.21	0.21	0.45	0.45	1.64	4.36	7.48	10.92	11.05	11.08	11.08	11.08	11.12	11.82	11.86	11.86	28.5%
Thermal	12.55	11.71	11.71	8.30	7.48	7.16	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	-5.0%
Coal	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	3.98	3.98	3.98	3.98	-1.9%
Internal Combustion	1.63	1.63	1.63	1.63	1.63	1.56	1.56	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	-0.4%
Bioenergy	1.01	1.01	1.21	1.21	1.56	1.57	1.63	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	3.1%
Nuclear	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	0.0%
Geothermal	0.93	0.95	0.94	0.91	0.89	0.89	0.90	0.90	0.90	0.90	0.90	0.90	0.90	2.56	2.56	2.56	6.4%
Small Hydro	0.00	0.00	0.10	0.10	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	1.15	1.40	1.40	1.40	20.8%
Fluidized Bed	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.0%
Total	75.21	76.27	78.48	75.56	77.93	80.09	83.01	88.75	94.73	99.28	102.53	104.47	106.79	113.43	119.01	124.78	

Table III.2: Scenario B's Electricity Generation per Technology in TWh, 2017-2032

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	CAGR
Bioenergy	1.9	7.0	7.1	8.5	8.6	10.9	11.0	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.9%
Coal	30.6	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	23.5	23.5	23.5	-1.6%
Combined Cycle	165.2	177.4	176.9	177.6	177.3	177.9	177.4	176.1	174.9	175.1	175.5	175.7	172.5	172.6	172.6	172.6	0.3%
Efficient CHP	6.9	3.6	4.1	12.9	19.5	24.9	29.8	33.5	38.3	36.1	38.0	37.4	40.5	43.7	37.6	39.1	11.4%
Internal Combustion	4.0	0.6	0.6	0.5	1.1	1.0	1.8	2.2	2.1	1.3	0.9	0.6	0.6	1.3	1.0	1.0	-8.1%
Wind	10.6	8.0	8.0	8.0	8.0	8.0	8.3	8.4	8.4	8.4	8.4	8.4	8.9	13.5	20.3	29.4	6.6%
Geothermal	6.0	6.5	6.7	6.6	6.4	6.3	6.3	6.4	6.4	6.4	6.4	6.4	6.4	8.2	18.0	18.0	7.1%
Hydro	31.8	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	2.3%
Fluidized Bed	4.3	3.0	2.7	2.0	2.7	2.2	2.8	2.5	2.4	1.3	1.3	1.0	1.2	2.5	1.6	1.7	-5.6%
Nuclear	10.9	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	0.8%
Small Hydro	0.0	0.0	0.0	0.7	0.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	8.6	10.4	10.4	81.1%
Solar	0.3	0.3	0.3	0.6	0.8	2.8	6.8	12.4	14.1	14.2	14.3	14.3	14.3	14.4	15.2	15.3	26.8%
Thermal	42.8	13.5	11.3	7.1	11.3	7.4	11.0	6.7	6.6	3.4	3.0	2.0	3.3	6.1	3.7	4.2	-13.5%
Turbo	12.8	14.3	24.3	24.9	28.0	27.7	29.7	33.0	43.9	58.6	72.9	83.2	97.2	101.5	100.2	105.6	14.1%
Total	328.3	324.3	332.0	339.4	354.5	361.9	377.6	385.3	401.2	409.0	424.8	433.2	449.3	465.7	474.0	490.7	

Table III.3: Scenario B's CEL Supply [Million CEL], 2018-2032

	Hydro	Wind	Geothermal	Solar	Nuclear	Bioenergy	Efficient CHP	Small Hydro	Total
2018	0.855	4.042	0.240	0.205	1.603	1.342	1.767	0.000	9.386
2019	0.855	4.041	0.251	0.249	1.603	2.336	3.165	0.003	10.728
2020	0.855	4.041	0.255	0.513	1.603	2.789	10.487	0.737	15.706
2021	0.855	4.041	0.251	0.734	1.603	4.084	16.940	0.776	19.162
2022	0.855	4.041	0.247	2.748	1.603	5.238	21.778	2.785	32.409
2023	0.855	4.394	0.315	6.739	1.603	5.483	26.849	2.785	39.209
2024	0.855	4.437	0.317	12.343	1.603	5.721	30.502	2.785	49.122
2025	0.855	4.437	0.317	13.992	1.603	5.746	35.017	2.785	59.653
2026	0.855	4.437	0.317	14.152	1.603	5.746	33.177	2.785	64.634
2027	0.855	4.437	0.317	14.193	1.603	5.746	34.945	2.785	72.905
2028	0.855	4.437	0.317	14.193	1.603	5.746	34.356	2.785	78.902
2029	0.855	6.382	0.317	14.197	1.603	5.746	37.289	2.794	81.679
2030	0.855	11.013	5.478	14.315	1.603	5.746	40.171	8.584	84.870
2031	0.855	17.748	12.012	15.149	1.603	5.746	34.566	10.407	84.862
2032	0.855	25.834	12.012	15.212	1.603	5.746	35.985	10.407	86.950

Table III.4: Scenario B's CEL Demand and Obligation Percentage, 2018-2032

Year	Obligation Percentage [CEL/MWh]	Obligation [Million CEL]
2018	5.00%	13.814
2019	5.80%	16.600
2020	7.40%	21.912
2021	10.90%	34.068
2022	13.90%	44.874
2023	17.00%	57.264
2024	18.74%	64.453
2025	20.08%	71.931
2026	22.43%	81.961
2027	26.37%	100.090
2028	30.45%	117.914
2029	33.99%	136.501
2030	36.38%	151.566
2031	38.14%	161.740
2032	39.64%	173.656

Table III.5: Scenario B's CEL Price, 2018-2032

Year	Price [USD/CEL]
2018	$ 22.365
2019	$ 17.657
2020	$ 41.032
2021	$ 56.321
2022	$ 50.510
2023	$ 18.574
2024	$ 18.400
2025	$ 17.116
2026	$ 13.375
2027	$ 13.916
2028	$ 37.045
2029	$ 55.205
2030	$ 37.144
2031	$ 34.183
2032	$ 32.264

Table III.6: Scenario B's Clean Energy Goals and Clean Energy Generation Percentage, 2018-2032

Year	Clean Energy Goals	Clean Energy Generation	Difference
2018	25.00%	25.83%	0.83%
2019	26.67%	25.44%	-1.23%
2020	28.33%	28.16%	-0.17%
2021	30.00%	28.86%	-1.14%
2022	31.67%	31.49%	-0.17%
2023	33.33%	32.63%	-0.70%
2024	35.00%	34.54%	-0.46%
2025	35.45%	34.80%	-0.65%
2026	35.91%	33.63%	-2.28%
2027	36.36%	32.84%	-3.53%
2028	36.82%	32.06%	-4.76%
2029	37.27%	31.74%	-5.53%
2030	37.73%	33.96%	-3.77%
2031	38.34%	36.15%	-2.19%
2032	38.95%	37.10%	-1.85%

Table III.7: Scenario B's Internal Rate of Return for each Clean Technology, 2018-2032

Year	Bioenergy	Efficient CHP	Wind	Geothermal	Hydro	Small Hydro	Nuclear	Solar
2018	26.1%	18.3%	9.6%	18.8%	10.5%	15.8%	7.0%	8.7%
2019	23.3%	16.7%	8.9%	17.8%	9.9%	14.9%	6.5%	8.0%
2020	36.5%	24.5%	12.3%	22.6%	12.8%	19.0%	8.9%	11.0%
2021	44.3%	29.2%	14.3%	25.6%	14.5%	21.5%	10.3%	12.9%
2022	41.4%	27.5%	13.5%	24.5%	13.9%	20.6%	9.7%	12.2%
2023	23.8%	17.0%	9.1%	18.0%	10.1%	15.0%	6.6%	8.2%
2024	23.7%	17.0%	9.0%	18.0%	10.0%	15.0%	6.6%	8.1%
2025	22.9%	16.5%	8.8%	17.7%	9.9%	14.8%	6.4%	8.0%
2026	20.6%	15.1%	8.3%	16.9%	9.4%	14.0%	6.0%	7.4%
2027	20.9%	15.3%	8.4%	17.0%	9.5%	14.1%	6.0%	7.5%
2028	34.3%	23.3%	11.7%	21.8%	12.3%	18.4%	8.5%	10.5%
2029	43.8%	28.9%	14.1%	25.4%	14.4%	21.4%	10.2%	12.7%
2030	34.4%	23.3%	11.7%	21.9%	12.3%	18.4%	8.5%	10.5%
2031	32.8%	22.3%	11.3%	21.3%	12.0%	17.9%	8.2%	10.2%
2032	31.8%	21.7%	11.0%	20.9%	11.8%	17.5%	8.0%	9.9%

Table III.8: Scenario B's Net Present Value for each Clean Energy Technology in Million Dollar, 2018-2032

Year	Bioenergy	Efficient CHP	Wind	Geothermal	Hydro	Small Hydro	Nuclear	Solar
2018	$0.15	$2.65	-$3.05	$230.55	$24.57	$5.50	-$836.91	$13.13
2019	$0.12	$2.09	-$8.59	$201.82	-$2.29	$4.59	-$965.00	$8.07
2020	$0.26	$4.85	$18.59	$344.45	$130.25	$9.09	-$332.55	$33.20
2021	$0.36	$6.65	$36.07	$437.73	$215.75	$12.03	$77.41	$49.64
2022	$0.32	$5.97	$29.43	$402.28	$183.26	$10.91	-$77.93	$43.39
2023	$0.13	$2.20	-$7.51	$207.42	$2.98	$4.76	-$940.03	$9.05
2024	$0.13	$2.18	-$7.71	$206.36	$1.98	$4.73	-$944.77	$8.87
2025	$0.12	$2.02	-$9.23	$198.52	-$5.40	$4.48	-$979.70	$7.49
2026	$0.10	$1.57	-$13.63	$175.70	-$26.88	$3.75	-$1,082.73	$3.46
2027	$0.10	$1.64	-$12.99	$178.99	-$23.78	$3.86	-$1,067.82	$4.05
2028	$0.24	$4.39	$14.00	$320.12	$107.71	$8.33	-$439.64	$28.92
2029	$0.35	$6.52	$34.80	$430.92	$209.51	$11.82	$47.75	$48.44
2030	$0.24	$4.40	$14.11	$320.72	$108.27	$8.35	-$436.99	$29.02
2031	$0.22	$4.05	$10.68	$302.66	$91.50	$7.78	-$516.53	$25.84
2032	$0.21	$3.82	$8.45	$290.95	$80.63	$7.41	-$568.08	$23.77

Annex IV. Scenario C's Tables

Table IV.1: Scenario C's Capacity Evolution in GW, 2017-2032

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	CAGR
Hydro	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	0.0%
Efficient CHP	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	0.0%
Turbogas	5.14	7.24	7.24	9.30	9.30	9.12	8.45	14.38	18.82	21.51	24.22	26.63	30.14	34.72	38.17	38.17	11.0%
Combined Cycle	28.08	27.86	27.86	27.65	27.65	27.42	27.18	26.95	26.95	26.95	26.95	26.43	26.43	26.43	26.43	26.43	-0.3%
Wind	4.20	4.20	4.20	4.20	5.76	8.05	8.05	8.05	8.05	8.05	8.05	8.05	8.05	8.05	8.05	8.05	4.2%
Solar	0.21	0.21	2.08	2.08	2.08	2.59	6.63	6.63	6.63	6.63	6.63	6.63	6.63	6.63	6.63	9.85	27.0%
Thermal	12.55	11.71	11.71	8.30	7.48	7.16	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	-5.0%
Coal	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	3.98	3.98	3.98	3.98	-1.9%
Internal Combustion	1.63	1.63	1.63	1.63	1.63	1.56	1.56	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	-0.4%
Bioenergy	1.01	1.01	1.21	1.21	1.21	1.21	1.28	1.28	1.28	1.28	1.64	1.64	1.64	1.64	1.64	1.64	3.1%
Nuclear	1.61	1.61	1.61	1.61	2.78	5.61	5.61	5.61	5.61	5.61	5.61	5.61	5.61	5.61	5.61	5.61	8.1%
Geothermal	0.93	0.95	0.94	0.91	2.11	2.11	2.11	2.11	2.11	2.11	2.11	2.11	2.11	2.11	2.11	2.11	5.1%
Small Hydro	0.00	0.00	0.00	0.00	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.0%
Fluidized Bed	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.0%
Total	75.21	76.27	78.33	76.74	80.23	85.06	86.20	91.88	96.32	99.01	102.07	103.96	106.07	110.65	114.10	117.32	

Table IV.2: Scenario C's Electricity Generation per Technology in TWh, 2017-2032

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	CAGR
Bioenergy	1.9	7.0	7.1	8.5	8.5	8.5	8.5	8.9	9.0	9.0	9.0	11.4	11.4	11.4	11.4	11.4	11.9%
Coal	30.6	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	23.5	23.5	23.5	-1.6%
Combined Cycle	165.2	177.4	176.9	177.6	177.3	162.6	168.8	168.7	171.0	172.0	173.6	173.7	171.2	172.2	172.4	172.6	0.3%
Efficient CHP	6.9	3.6	3.9	4.4	5.6	1.9	2.3	2.5	2.5	2.4	2.9	2.6	3.1	3.9	3.5	3.6	-3.9%
Internal Combustion	4.0	0.6	0.6	0.7	1.5	1.1	1.7	2.4	1.5	0.7	0.7	0.7	0.7	1.2	0.6	0.5	-11.8%
Wind	10.6	8.0	8.0	8.0	8.1	10.9	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	1.4%
Geothermal	6.0	6.5	6.7	6.6	6.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	5.8%
Hydro	31.8	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	2.3%
Fluidized Bed	4.3	3.0	2.7	2.9	3.2	2.1	2.7	2.8	2.0	1.1	1.3	1.1	1.4	2.5	1.6	1.5	-6.3%
Nuclear	10.9	12.4	12.4	12.4	12.7	46.1	43.2	43.2	43.2	43.2	43.2	43.2	43.2	43.2	43.2	43.2	9.0%
Small Hydro	0.0	0.0	0.0	0.0	0.4	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	16.7%
Solar	0.3	0.3	0.5	2.7	2.7	2.7	5.3	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	9.0	22.6%
Thermal	42.8	13.5	11.3	12.3	13.8	6.6	9.3	7.2	4.3	2.3	2.9	1.9	3.1	5.0	2.6	2.7	-15.9%
Turbo	12.8	14.3	24.3	25.7	36.0	24.1	27.3	32.6	50.8	61.2	74.1	81.6	98.1	117.5	129.8	145.8	16.4%
Total	328.3	324.3	332.0	339.4	354.5	361.9	377.6	385.3	401.2	409.0	424.8	433.2	449.3	465.7	474.0	490.7	

Table IV.3: Scenario C's CEL Supply [Million CEL], 2018-2032

	Hydro	Wind	Geothermal	Solar	Nuclear	Bioenergy	Efficient CHP	Small Hydro	Total
2018	0.855	4.042	0.240	0.205	1.603	1.342	0.000	0.000	9.386
2019	0.855	4.041	0.251	0.473	1.603	2.336	0.000	0.000	10.728
2020	0.855	4.041	0.255	2.602	1.603	2.789	0.000	0.000	15.706
2021	0.855	5.213	4.120	2.602	6.304	2.789	0.000	0.436	19.162
2022	0.855	8.100	8.851	2.651	34.611	2.789	0.000	2.785	32.409
2023	0.855	9.778	8.851	5.272	32.423	3.067	0.000	2.785	39.209
2024	0.855	9.778	8.851	8.498	32.423	3.253	0.000	2.785	49.122
2025	0.855	9.778	8.851	8.498	32.423	3.271	0.000	2.785	59.653
2026	0.855	9.778	8.851	8.498	32.423	3.271	0.000	2.785	64.634
2027	0.855	9.778	8.851	8.498	32.423	4.508	0.000	2.785	72.905
2028	0.855	9.778	8.851	8.498	32.423	5.746	0.000	2.785	78.902
2029	0.855	9.778	8.851	8.498	32.423	5.746	0.000	2.785	81.679
2030	0.855	9.778	8.851	8.498	32.423	5.746	0.000	2.785	84.870
2031	0.855	9.778	8.851	8.498	32.423	5.746	0.000	2.785	84.862
2032	0.855	9.778	8.851	8.934	32.423	5.746	0.000	2.785	86.950

Table IV.4: Scenario C's CEL Demand and Obligation Percentage, 2018-2032

Year	Obligation Percentage [CEL/MWh]	Obligation [Million CEL]
2018	5.00%	13.814
2019	5.80%	16.600
2020	7.40%	21.898
2021	10.90%	34.064
2022	13.90%	44.829
2023	13.90%	46.779
2024	13.90%	47.755
2025	14.33%	51.309
2026	15.61%	57.007
2027	18.01%	68.308
2028	20.60%	79.688
2029	23.85%	95.701
2030	27.39%	114.040
2031	32.24%	136.685
2032	36.89%	161.522

Table IV.5: Scenario C's CEL Price, 2018-2032

Year	Price [USD/CEL]
2018	$ 18.435
2019	$ 14.807
2020	$ 70.156
2021	$ 77.864
2022	$ 20.364
2023	$ 17.239
2024	$ 13.396
2025	$ 9.962
2026	$ 7.164
2027	$ 6.164
2028	$ 6.954
2029	$ 10.572
2030	$ 11.032
2031	$ 18.729
2032	$ 40.565

Table IV.6: Scenario C's CEL Inventory, 2018-2032

Year	Inventory [Million CELs]
2018	0.00
2019	0.00
2020	0.00
2021	0.00
2022	4.550
2023	20.801
2024	39.487
2025	54.638
2026	64.091
2027	63.479
2028	52.728
2029	25.962
2030	0.00
2031	0.00
2032	0.00

Table IV.7: Scenario C's Clean Energy Goals and Clean Energy Generation Percentage, 2018-2032

Year	Clean Energy Goals	Clean Energy Generation	Difference
2018	25.00%	25.83%	0.83%
2019	26.67%	25.44%	-1.23%
2020	28.33%	26.06%	-2.27%
2021	30.00%	25.64%	-4.36%
2022	31.67%	36.96%	5.29%
2023	33.33%	36.05%	2.71%
2024	35.00%	36.32%	1.32%
2025	35.45%	34.89%	-0.57%
2026	35.91%	34.21%	-1.70%
2027	36.36%	33.06%	-3.31%
2028	36.82%	32.91%	-3.90%
2029	37.27%	31.85%	-5.42%
2030	37.73%	30.89%	-6.84%
2031	38.34%	30.27%	-8.07%
2032	38.95%	29.36%	-9.60%

Table IV.8: Scenario C's Internal Rate of Return for each Clean Technology, 2018-2032

Year	Bioenergy	Efficient CHP	Wind	Geothermal	Hydro	Small Hydro	Nuclear	Solar
2018	24%	10%	9%	18%	10%	15%	7%	8%
2019	21%	10%	8%	17%	10%	14%	6%	8%
2020	51%	10%	16%	28%	16%	24%	11%	14%
2021	55%	10%	17%	30%	17%	25%	12%	15%
2022	25%	10%	9%	18%	10%	15%	7%	8%
2023	23%	10%	9%	18%	10%	15%	6%	8%
2024	21%	10%	8%	17%	9%	14%	6%	7%
2025	18%	10%	8%	16%	9%	13%	6%	7%
2026	17%	10%	7%	15%	9%	13%	5%	7%
2027	16%	10%	7%	15%	8%	13%	5%	6%
2028	16%	10%	7%	15%	9%	13%	5%	7%
2029	19%	10%	8%	16%	9%	13%	6%	7%
2030	19%	10%	8%	16%	9%	14%	6%	7%
2031	24%	10%	9%	18%	10%	15%	7%	8%
2032	36%	10%	12%	23%	13%	19%	9%	11%

Table IV.9: Scenario C's Net Present Value for each Clean Energy Technology in Million Dollar, 2018-2032

Year	Bioenergy	Efficient CHP	Wind	Geothermal	Hydro	Small Hydro	Nuclear	Solar
2018	$0.13	-$0.05	-$7.67	$206.57	$2.18	$4.74	-$943.83	$8.90
2019	$0.10	-$0.05	-$11.94	$184.43	-$18.66	$4.03	-$1,043.22	$5.00
2020	$0.44	-$0.05	$51.78	$522.14	$293.11	$14.67	$445.06	$64.52
2021	$0.49	-$0.05	$60.48	$569.18	$335.97	$16.14	$649.91	$72.81
2022	$0.14	-$0.05	-$5.40	$218.34	$13.23	$5.11	-$891.35	$10.98
2023	$0.12	-$0.05	-$9.08	$199.27	-$4.69	$4.50	-$976.36	$7.62
2024	$0.10	-$0.05	-$13.60	$175.83	-$26.76	$3.76	-$1,082.15	$3.49
2025	$0.07	-$0.05	-$17.69	$154.87	-$46.49	$3.09	-$1,176.92	-$0.21
2026	$0.06	-$0.05	-$21.03	$137.69	-$62.56	$2.55	-$1,254.13	-$3.21
2027	$0.05	-$0.05	-$22.23	$131.53	-$68.31	$2.35	-$1,282.08	-$4.29
2028	$0.06	-$0.05	-$21.29	$136.40	-$63.77	$2.51	-$1,259.95	-$3.44
2029	$0.08	-$0.05	-$16.96	$158.59	-$42.98	$3.21	-$1,160.08	$0.45
2030	$0.08	-$0.05	-$16.41	$161.40	-$40.34	$3.30	-$1,147.38	$0.95
2031	$0.13	-$0.05	-$7.33	$208.36	$3.87	$4.79	-$935.83	$9.22
2032	$0.26	-$0.05	$18.06	$341.59	$127.64	$9.00	-$345.10	$32.70

Annex V. Base Scenario's Results

Table V.1: Base Scenario's Capacity Evolution in GW, 2017-2032

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	CAGR
Hydro	12.64	12.64	12.67	12.67	12.67	12.67	12.67	13.13	13.20	13.20	13.24	13.68	13.75	14.39	14.39	14.86	1.0%
Efficient CHP	1.25	1.93	1.93	1.93	1.93	1.93	2.01	2.13	2.13	2.59	2.97	2.97	3.63	3.63	3.63	3.63	6.9%
Turbo	5.14	5.06	5.06	5.75	5.75	5.66	5.31	5.31	5.31	5.34	5.30	5.30	5.30	5.30	5.30	5.30	0.2%
Combined Cycle	28.08	30.13	33.73	34.28	35.16	36.87	40.59	41.24	42.57	44.71	45.78	47.51	49.77	50.58	52.38	54.53	4.2%
Wind	4.20	4.88	6.59	8.13	8.86	11.23	12.42	14.41	15.53	15.75	16.60	16.90	17.30	17.66	18.27	19.02	9.9%
Solar	0.21	1.97	4.43	5.63	7.55	7.75	8.05	8.35	8.69	9.03	9.38	9.73	10.08	10.58	11.08	11.62	28.4%
Thermal	12.55	11.71	11.71	8.30	7.48	7.16	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	-5.5%
Coal	5.38	5.38	5.51	5.51	5.51	5.51	5.51	5.51	5.51	5.51	5.51	5.51	4.11	4.11	4.11	4.11	-1.7%
Internal Combustion	1.63	1.63	1.66	1.66	1.77	1.70	1.74	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	0.3%
Bioenergy	1.01	1.01	1.01	1.01	1.05	1.29	1.58	1.73	1.73	1.82	1.82	1.95	1.95	1.95	1.95	1.95	4.2%
Nuclear	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	2.97	4.33	5.69	5.69	8.2%
Geothermal	0.93	0.95	0.94	0.91	0.89	0.89	0.89	0.89	0.92	1.07	1.32	1.45	1.45	1.55	1.66	1.71	3.9%
Fluidized Bed	0.58	0.58	0.58	0.58	0.58	0.58	0.58	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	3.7%
Total	75.21	79.48	87.42	87.95	90.80	94.85	98.07	102.19	105.06	108.49	111.39	114.46	118.16	121.93	126.31	130.27	40.3%

Table V.2: Base Scenario's Electricity Generation in TWh, 2017-2032

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	CAGR
Bioenergy	1.9	4.2	4.2	4.2	4.6	6.2	8.3	9.4	9.4	10.1	10.1	11.0	11.0	11.0	11.0	11.0	11.7%
Coal	30.6	35.3	36.2	36.3	36.2	36.2	36.2	36.2	36.1	36.1	36.1	36.1	36.0	29.3	29.3	29.4	-0.2%
Combined Cycle	165.2	168.5	174.6	180.7	187.1	190.0	195.6	193.5	201.2	204.8	212.7	216.4	224.9	235.7	242.9	250.7	2.6%
Efficient CHP	6.9	11.6	11.8	10.7	12.1	11.8	12.5	13.6	13.3	16.0	17.7	18.8	14.7	10.3	4.6	7.9	0.9%
Internal Combustion	4.0	2.6	2.2	2.6	2.4	2.2	1.8	1.5	1.4	1.4	1.4	1.4	1.5	1.4	1.4	1.3	-6.6%
Wind	10.6	14.2	18.6	24.1	26.9	36.9	41.0	47.8	51.4	52.1	54.9	56.1	57.3	58.4	60.5	63.2	11.8%
Geothermal	6.0	6.8	6.8	5.7	6.5	6.4	6.4	6.4	6.6	7.7	9.5	10.4	10.4	11.1	11.8	12.3	4.5%
Hydro	31.8	33.0	33.1	33.1	33.0	33.0	33.0	35.1	35.2	35.2	35.3	37.3	37.5	39.9	39.9	41.2	1.6%
Fluidized Bed	4.3	3.9	3.9	3.9	3.9	3.9	3.9	7.4	7.4	7.3	7.3	7.4	7.3	7.3	7.3	7.3	3.4%
Nuclear	10.9	11.2	11.2	11.2	11.2	11.2	11.1	11.2	11.1	11.1	11.1	11.1	20.5	29.9	39.3	39.4	8.4%
Solar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thermal	0.3	1.3	6.0	9.0	11.8	13.7	14.3	14.8	15.3	15.9	16.5	17.2	17.7	18.5	19.3	20.3	29.0%
Turbo	42.8	25.6	21.4	18.3	12.6	10.9	9.7	9.5	9.5	9.5	9.5	9.5	9.4	9.4	9.4	7.7	-10.2%
Total	12.8	2.4	1.2	2.0	4.1	1.4	1.3	0.2	0.2	2.9	0.3	2.6	0.3	0.4	0.4	0.4	-19.0%