Pp. 79-99 in Paul Ganster, Oscar Arizpe C., and Vinod Sasidharan, editors. 2020. *Loreto, Mexico: Challenges for a Sustainable Future.* San Diego, CA: SDSU Press and IRSC. ISBN 978-1-938537-17-2

Chapter 4.
Electric Power in Loreto

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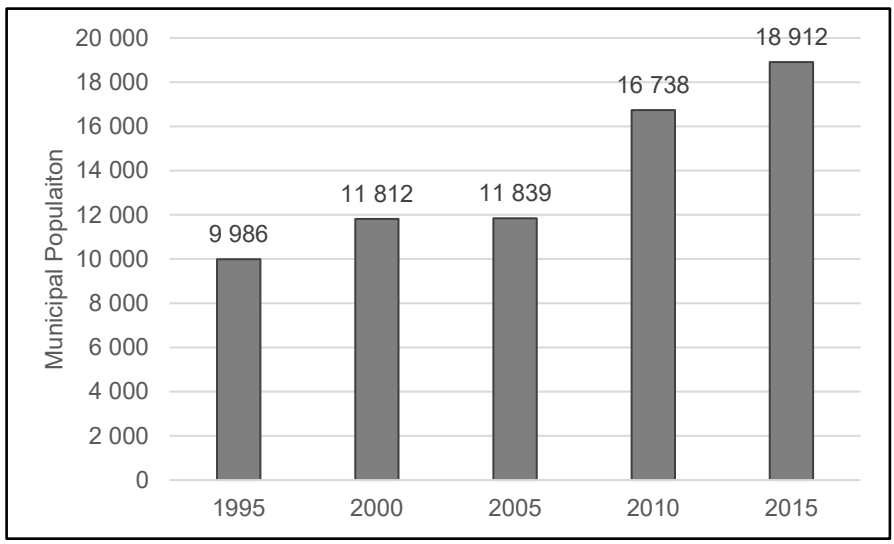
Introduction

Loreto became a municipality in 1992 and is the youngest municipality in Baja California Sur (BCS) and that with the lowest number of inhabitants. Figure 4-1 shows the growth of the municipal population in the last 20 years. During this period, the population grew on average 4.8% per year, with some years as high as 7.2%.

Figure 4-1. Population Growth in the Municipality of Loreto, 1995-2015



Source: Elaborated by the authors with data from SDEMARN GBCS, 2017.

In the 1960s, Loreto was still isolated from the state electrical grid and had to generate its own electricity locally. According to Ernesto Bernal, who was responsible for the installation of the generation plants in Loreto, in 1964 there were two electricity generators; one was 100 kW and the other was 150 kW. Subsequently, there was a 350 kW Caterpillar

plant and another 500 kW General Motors plant. By 1979 and 1980, electric generators of 600 kW, 3,502 kW, and 500 kW were in place. In 2011, the last local generating unit in Loreto (20 MW gas turbine running on diesel fuel) was moved to a different location and since then the municipality has been totally dependent on the electrical grid of Baja California Sur.

Table 4-1 shows some socioeconomic indicators for the municipality of Loreto and for the other municipalities of Baja California Sur. The data indicate Loreto is the municipality with the highest gross income

Table 4-1. Socioeconomic Indicators of Baja California Sur Municipalities (2015)

Municipality	Population	Total Gross Income (million pesos)	Direct Taxes (million pesos)	Total Gross Production* (million pesos)	Gross Income Per Capita (pesos/)	Taxes Per Capita (pesos)	Production Per Capita (pesos)
Comondú	72,564	466	28	2,784	6,421	*382*	*38,372*
La Paz	272,711	1,052	169	16,866	*3,858*	621	61,845
Loreto	*18,912*	*232*	31	*813*	**12,265**	1,658	42,998
Los Cabos	**287,671**	**1,614**	**600**	**24,536**	5,611	**2,086**	85,291
Mulegé	60,171	332	*24*	6,829	5,522	405	**113,491**
BCS	712,029	3,696	853	51,828	5,191	1,198	72,789

Note: The numbers in **bold** indicate the maximum value for each area; the numbers in *italics* indicate the minimum value.
Source: Elaborated by the authors with data from INEGI, 2017.

per capita and that it is in a close second place in taxes collected per capita. Additionally, according to the marginalization indexes, Loreto is the second least marginalized of the municipalities in the state (CONAPO, 2016). This might suggest that the situation of the inhabitants of Loreto is better than for other municipalities. However, in relation to the other

municipalities of Baja California Sur, the results of CONEVAL for 2010 (CONEVAL, 2013) placed Loreto in third place among the five municipalities of the state in terms of its Gini coefficient for income inequality. Furthermore, CONEVAL estimated that in 2015 Loreto had 41.3% of its population living in poverty and 3.4% in extreme poverty, placing the municipality in first place in these two areas (CONEVAL, 2017).

Electricity in Loreto

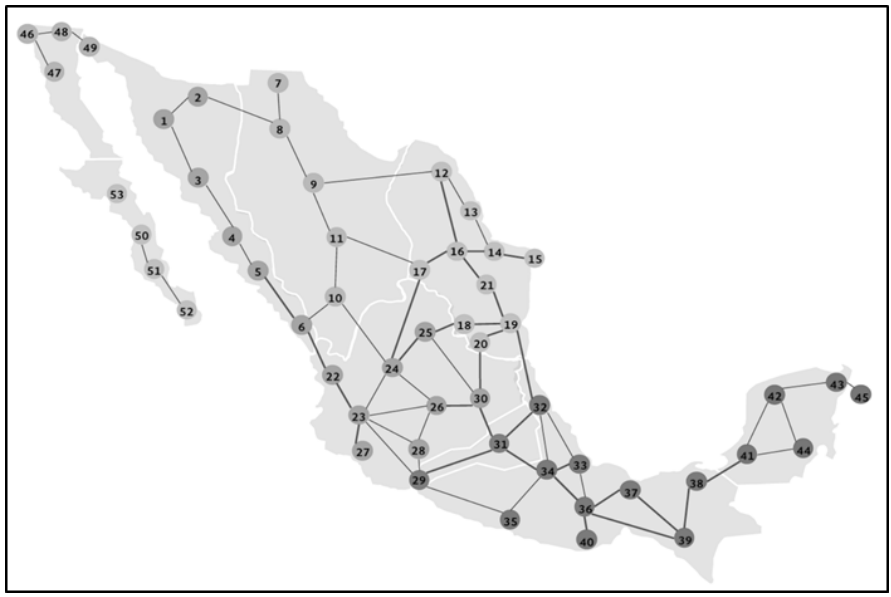
Supply

The National Electric System in Mexico comprises a main system called the National Interconnected System (SIN, acronym in Spanish) and three isolated systems (see Figure 4-2). The first covers most of the country, from Sonora to Quintana Roo (nodes 1 to 45 in Figure 4-2). The isolated systems are the Baja California System (SBA, acronym in Spanish; nodes 46 to 49), the Baja California Sur System (SBS, acronym in Spanish; nodes 50 to 52), and the Mulegé System (SMG, acronym in Spanish; node 53). It should be mentioned that although the SBA cannot exchange electricity with the SIN, it has interconnections with the United States, which makes the flow of electricity possible to and from the SBA. Conversely, the SMG and SBS are completely isolated and without the possibility of exchanging electricity with any other system. This means that both in the SMG and the SBS, all the electricity consumed must be generated within the same system; this is carried out by burning mainly heavy fuel oil and diesel fuel. As shown in Figure 4-3, the municipality of Loreto receives electrical coverage within the Baja California Sur System.

Consumption

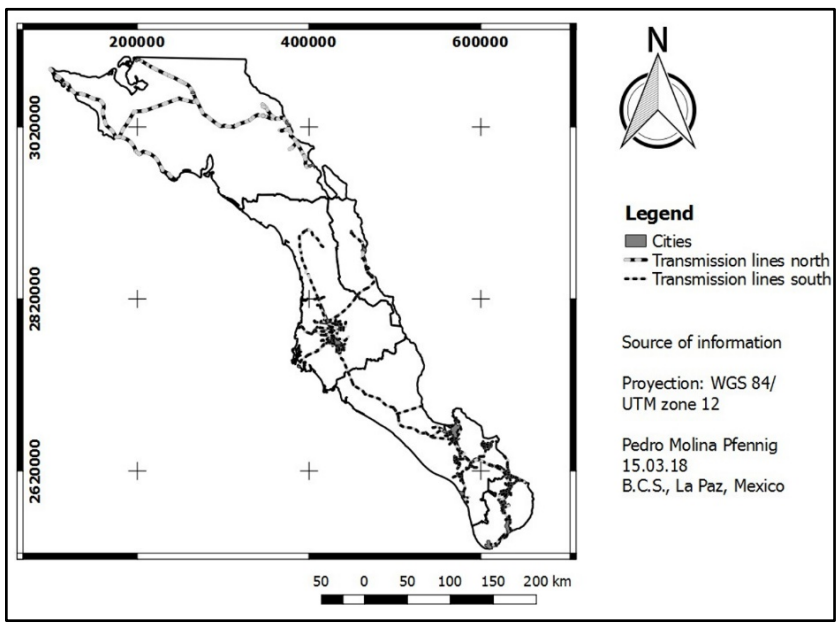
The electricity consumption in Loreto has been growing in recent years, as shown in Figure 4-4. Electricity sales in 2015 were 2.4 times that of 10 years earlier. In this period, there were periods with very important consumption increases and others with decreases. Despite this, the average annual growth rate of electricity consumption in Loreto between 2005 and 2015 was approximately 9.3%. During the same period, the electricity consumption of the entire state also increased (see Figure 4-5), but with an annual rate of 5.4%. Although both values are high when compared to other regions of Mexico, Loreto's growth rate is significantly higher. This can be explained by the population growth of 4.8% per year average and the growth in electricity demand in medium voltage rates, as in Figure 4-9, which suggests a growth in economic activity.

Figure 4-2. Transmission Nodes of the SEN: SIN (1-45), SBA (46-49), SBS (50-52), SMG(53)



Source: Adapted from SENER, 2018.

Figure 4-3. Baja California Sur System (South) and Mulegé System (North)



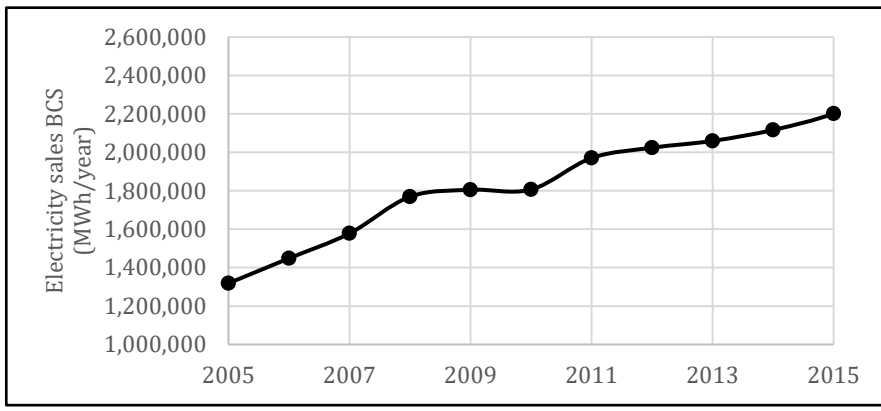
Source: Elaborated by the authors with information from INEGI.

Table 4-2. Sales per Capita per Municipality in Residential Rates in 2015

Municipality	Comondú	La Paz	Loreto	Los Cabos	Mulegé
Sales (kWh/inhabitant)	762	1 178	1 366	999	784
Predominant Residential Rate	1C	1E	1E	1C	1A
Average Annual Invoice ($/user)	2 885	3 297	4 369	4 847	3 170

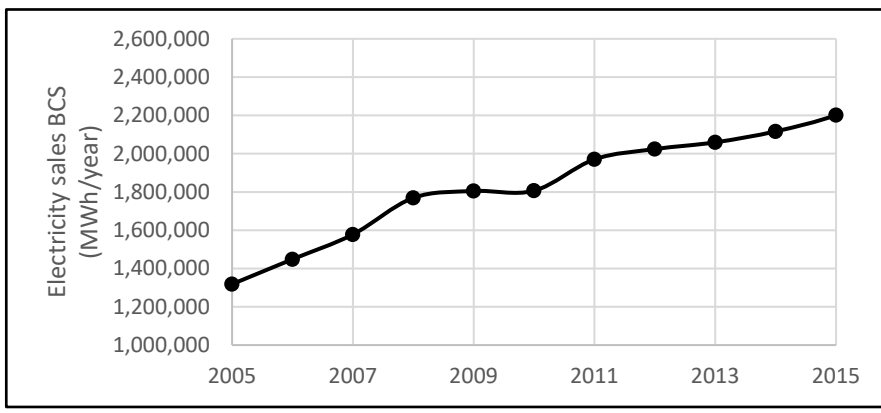
Source: Elaborated by the authors with data from CFE and INEGI, 2017.

Figure 4-4. Electricity Sales at the Loreto Agency



Source: CFE local office.

Figure 4-5. Internal Electricity Sales in Baja California Sur

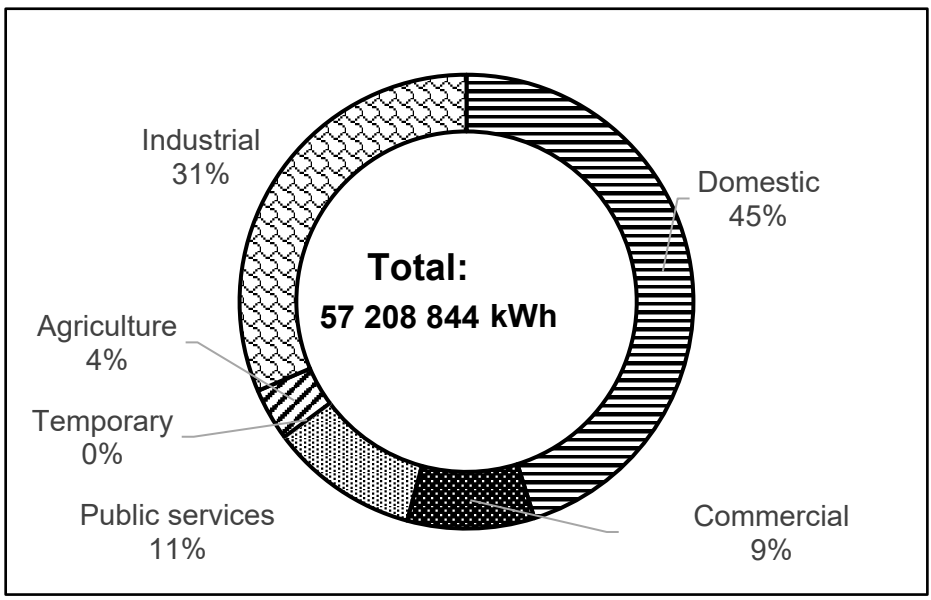


Source: Elaborated by the authors with data from SIE-SENER, 2018.

The analysis of electricity consumption of Loreto by sector and rates (Figure 4-6) shows that the dominant sector is residential. In fact, Loreto's per capita residential consumption is the highest in the state, as shown in Table 4-2. This table also shows an estimate of the average annual payment per residential user, where Loreto stands out as the second highest. Considering information on poverty in Loreto in the background section, electric bills could be a considerable economic burden for many Loreto households.

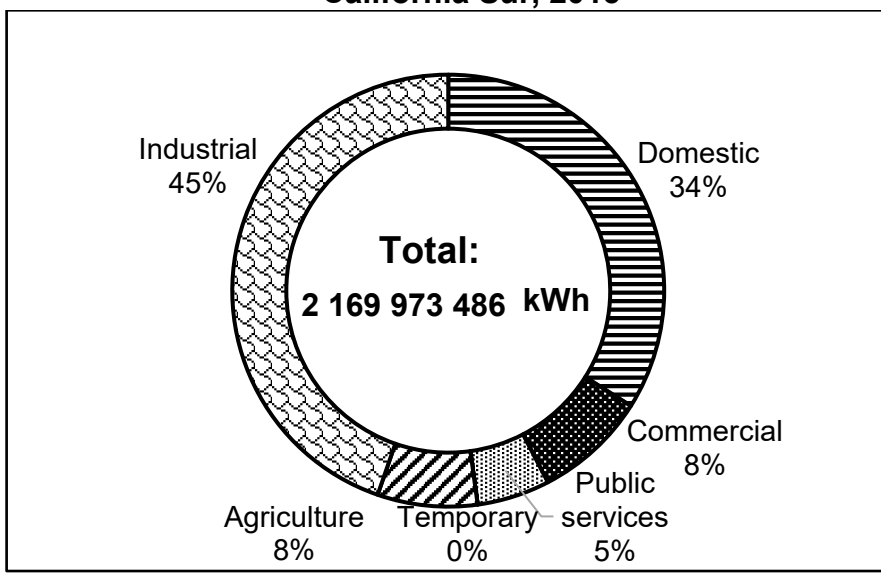
Data are also available for consumption at medium voltage rates (also often called industrial). Here, for example, hotels of medium and large size could be included. In third place are public services (street lighting and water pumping). When contrasting the previous with the entire state's pattern of consumption (Figure 4-7), it is observed that the main sectors of electricity consumption are also residential and industrial, although at the state level the order between them is reversed. Figure 4-8 shows the relative importance of sales in each rate sector for each municipality.

Figure 4-6. Electricity Sales by Rate Sector in Loreto, 2015



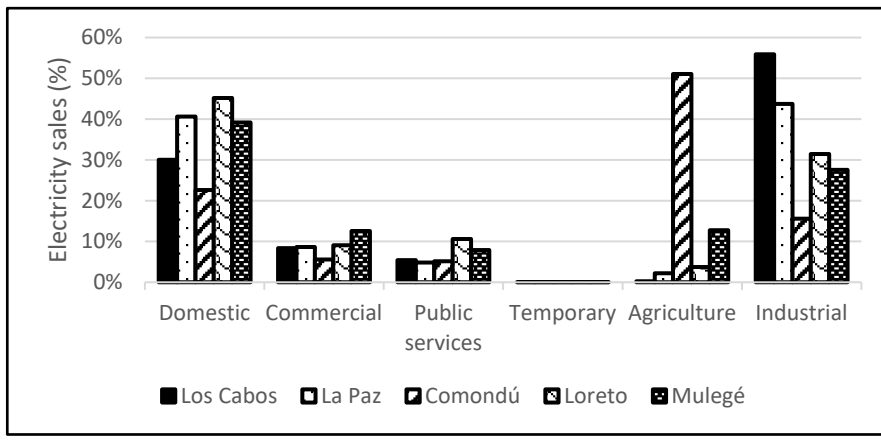
Source: Elaborated by the authors with data from CFE. "Temporary" refers to occasional users such as special events (e.g., certain festivals).

Figure 4-7. Electricity Sales by Rate Sector in Baja California Sur, 2015



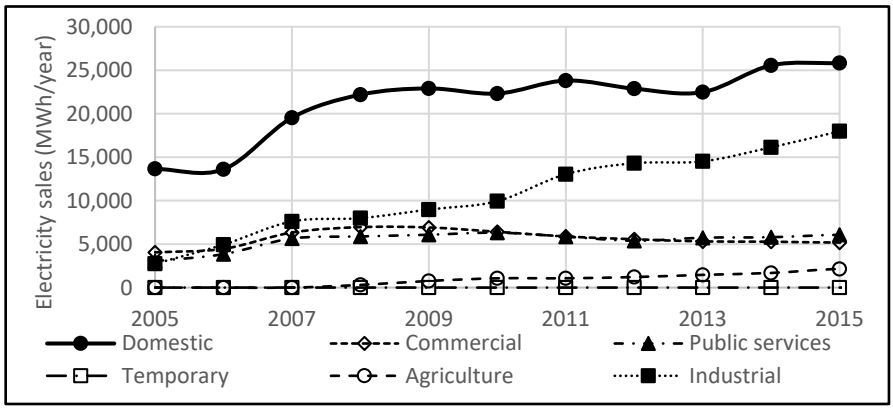
Source: Elaborated by the authors with data from CFE. "Temporary" refers to occasional users such as special events (e.g., certain festivals).

Figure 4-8. Percentage Contribution to Sales by Sector for the Municipalities of Baja California Sur (2015)



Source: Elaborated by the authors with data from CFE.

Figure 4-9. Evolution of Electricity Sales by Rate Sector in the Loreto Agency



Source: Elaborated by the authors with data from CFE.

Historically, the rate sectors with the highest growth between 2005 and 2015 in Loreto were residential and industrial, as shown in Figure 4-9. Consumption in agricultural irrigation has also been increasing, although consumption in absolute terms has still been small. In contrast, consumption at commercial rates declined during the same period.

Electricity in Households

In 2015, with regard to electricity coverage, 98.7% of homes nationwide had electricity. In Baja California Sur, this number was 98.4% and for the municipality of Loreto it was 95.84% for 2015 (INEGI, 2015). Among the five municipalities of Baja California Sur, Loreto has the least coverage, while the highest is that of Los Cabos with 98.91% (INEGI, 2017). Table 4-3 shows data corresponding to the availability of electricity in the households of Baja California Sur by municipality and the availability of appliances and other consumer products, which all consume energy. The table shows that Loreto has the highest percentage of households with air conditioning equipment (70.14%), which is the type of equipment that consumes the most electric energy in a home. The high summer temperatures and humidity levels in Loreto can explain increases in residential electricity consumption. Additionally, Loreto households also have the highest percentage of solar water heaters (2.40%), and solar panels for electricity (6.33%). Loreto households also have the highest rate of automobile ownership in the state, at 73.54%.

Table 4-3. Availability of Electricity, Goods, and Equipment in Households of Loreto and Other Municipalities of Baja California Sur, 2015

Item*	Baja California Sur	Comondú	La Paz	Loreto	Los Cabos	Mulegé
Inhabited private households	208,972	21,384	82,919	5,865	80,615	18,189
Availability of electrical energy	98.44	97.01	98.63	*95.84*	**98.91**	97.94
Air conditioner	44.23	*28.81*	57.31	**70.14**	37.55	23.96
Solar water heater	1.22	*0.45*	0.88	**2.40**	1.76	0.92
Solar panel	2.08	2.50	1.82	**6.33**	*1.69*	3.17
Refrigerator	90.78	88.98	**93.73**	85.08	90.54	*82.30*
Washing machine	68.48	69.53	**73.25**	72.96	63.87	*64.47*
Microwave	51.52	*42.36*	**58.56**	55.57	48.12	43.91
Automobile	66.47	70.01	72.31	**73.54**	59.68	*63.53*
Some device to listen to the radio	66.22	59.82	**72.98**	62.30	64.89	*50.12*
Television	94.16	92.77	**95.54**	*89.63*	94.14	90.99
Flat screen television	46.10	*28.18*	**50.30**	37.14	48.13	41.87
Computer	42.80	*28.45*	**51.67**	45.05	38.88	35.94
Landline	37.55	*28.95*	**46.69**	35.75	31.62	32.87
Cellular phone	92.67	86.90	93.89	*86.72*	**94.53**	87.50
Internet	43.48	*27.27*	**50.72**	42.32	43.37	30.41
Paid television service	62.18	*57.70*	63.80	61.89	59.93	**70.10**

*Inhabited private households expressed in total numbers; does not include premises not constructed for housing, mobile homes, or shelters. The rest of the items are in percentages.
Note: The numbers in **bold** indicate the maximum value for each item; the numbers in *italics* indicate the minimum value.
Source: Elaborated by the authors with data from INEGI, 2016.

Renewable Energy in Loreto

Based on the electricity consumption recorded in Loreto in 2015 (see Figure 4-6) and considering a greenhouse gas emission factor of 0.892 kg CO^2e per kWh of electricity consumed in Baja California Sur (Bermudez-Contreras, et al., 2014), the municipality of Loreto was responsible for the emission of approximately 51,030 tons of CO^2e in that year. Fortunately, Baja California Sur has excellent solar resources and wind resources, in addition to other renewable energy resources with which a considerable part of the electricity required locally could be generated. Some of these resources are already used today. For example, in the Baja California Sur System, the Aura Solar I and Aura Solar III photovoltaic solar plants in La Paz, which a combined capacity of 55 MW (2019), are in operation. In addition, the facilities for the use of renewable energy in small and medium scale (less than 500 kW) in Baja California Sur have been increasing exponentially in recent years, as shown in Figure 4-10. The vast majority of these facilities are in photovoltaic solar technology, although there are also some that are biomass (biogas).

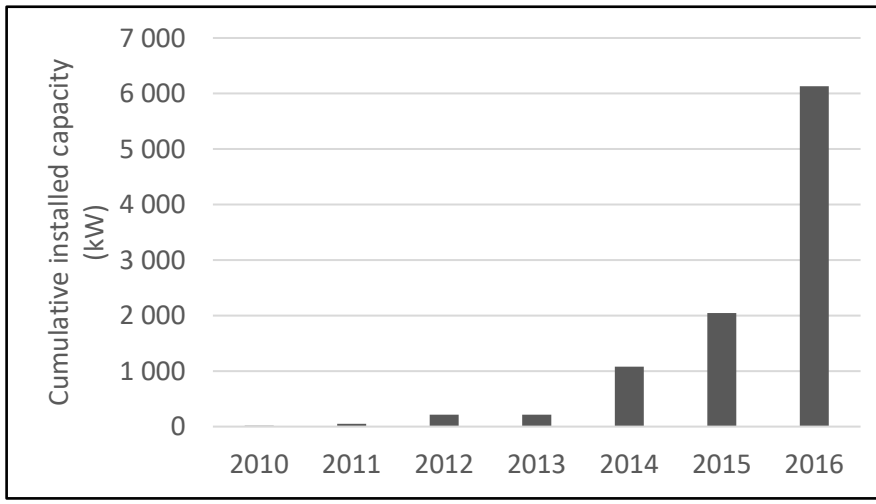
The municipality of Loreto is not the exception and also has important solar and wind energy resources that could be used to supply the energy requirements of this municipality. The following sections present the results of some studies on the renewable energy potential of the municipality of Loreto and some theoretical exercises to put these potentials in perspective.

Satellite data on wind speed, wind power, and solar radiation obtained from the National Renewable Energy Laboratory (NREL) of the United States were used to evaluate the potential of solar and wind energy for the municipality of Loreto. The wind data used originates from mesoscale simulations corresponding to 15 years (2000-2015) with 3 kilometers of horizontal resolution. The solar radiation data used correspond to the monthly and annual average of the 1998-2014 period, and have a spatial resolution of 4 kilometers of horizontal resolution.

Based on the NREL data, maps of the annual average wind power density at 50, 80, and 120 m of elevation above ground level were generated using geographic information systems (GIS). In order to evaluate the potential density in W/m2, the data of a wind turbine from the Vestas company of 2 MW capacity was used, considering a total efficiency of

90% with a Weibull distribution and power curve of the form factor k=2. This approach enabled the authors to estimate the wind potential throughout the municipality and locate the best sites in Loreto.

Figure 4-10. Cumulative Installed Capacity of Distributed Generation Systems in Baja California Sur



Source: Elaborated by the authors with data provided by the Energy Regulatory Commission (Comisión Reguladora de Energía–CRE), CRE, 2017.

In addition, solar potential maps were produced. The selection of the most viable sites for solar use considers economic and technical factors. In addition to solar resource data, these factors include proximity to the electricity network, proximity to roads, terrain slopes, and orientation, among others. Descriptions that are more detailed are in Domínguez (2002); Orellana (2009); Quijano (2011); and Rodríguez Gámez (2012). GIS programs and Saaty's (1980) analytical hierarchy method were used to calculate the areas with the greatest potential and are shown in the following sections.

Wind Potential

Figure 4-11 is a map of wind power density for the municipality of Loreto. Seven classifications of wind power density were used for this map. Each of the classifications was qualitatively defined for commercial scale applications (poor to excellent), as shown in Table 4-4. In general, places with an annual average wind resource greater than 400 W/m2 or

approximately 7 m/s at 50 m above ground level are the best for commercial scale applications. The applications of rural electrification or for small populations can be viable in places with lower levels of wind resource. In Baja California Sur, such applications can be viable with a wind resource from 200 W/m2 or approximately 5.5 m/s to 50 m above ground level.

Table 4-4. Classification of Wind Potential

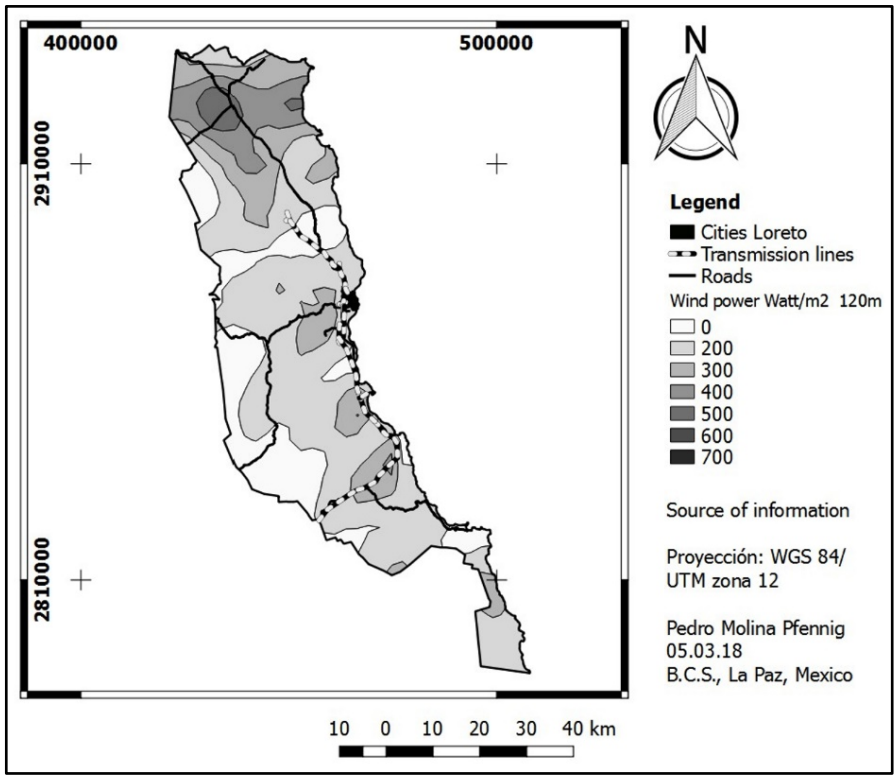
Category	Resource Potential (Commercial Scale)	Density of Wind Potential (W/m^2) at 50 m agl*	Wind Speed (m/s) at 50 m agl*
1	Poor	0-200	0 - 5.3
2	Scarce	200-300	5.3 - 6.1
3	Moderate	300-400	6.1 - 6.7
4	Good	400-500	6.7 - 7.3
5	Excellent	500-600	7.3 - 7.7
6	Excellent	600-800	7.7 + 8.5
7	Excellent	> 800	> 8.5

*Above ground level.

The analysis determined that in the municipality of Loreto there are 429 km2 of land where wind power densities in excess of 400 W/m2 and even greater than 500 W/m2, distributed as shown in Table 4-5. This surface represents 9.7% of the total area of Loreto. A conservative estimate is that on each km2 wind turbines equivalent to a power of 5 MW can be installed. That means that the area of Loreto with good wind potential could produce 2,145 MW total. To put this in perspective, the installed capacity of all the generation plants in BCS in 2015 was 961 MW; the maximum demands of the Baja California Sur and Mulegé systems in 2015 were 432 and 28 MW, respectively (SENER, 2017b). Loreto had a maximum demand of 12 MW in 2014 (CFE, 2014). If the 2,145 MW of wind capacity operated with a plant capacity of 35%, then 1% of the potential wind energy production would be sufficient to cover electricity sales recorded in 2015 in Loreto (57,209 MWh, see Figure 4-4).

As a reference, the Peñoles Wind Farm (Eólica de Coahuila) entered into operation in April 2017 and had an investment cost of approximately US$1.50 per Watt of installed capacity (Ramírez, 2017). Considering this value, a wind farm to supply the energy of Loreto (21.45 MW) would require an investment of about US$32 million.

Figure 4-11. Map of Density of the Wind Potential in the Municipality of Loreto



Source: Elaborated by the authors with data from Gulstad (2017) via SENER, 2017a.

Solar Potential

In Baja California Sur, the solar resource is very abundant. On average, the amount of solar energy received daily varies between 4.4 kWh/m2 and 6.9 kWh/m2 (Almanza, et al., 1997). In particular, an average daily value of 5.2 kWh/m2 has been reported for Loreto (Perea-Moreno, et al., 2016). In comparison, in Germany, between 2.6 and 3.7 kWh/m2 are received daily on average (Šúri, et al., 2007), and Germany is, after China and Japan, the country with the most photovoltaic capacity installed worldwide (REN21, 2017). This indicates a great potential in photovoltaic energy in Loreto, which has been widely recognized. There have been several proposals for its use, such as generating electricity for municipal public lighting (Castro López, 2017).

Table 4-5. Area of Polygons with "Good" and "Excellent" Potential in Loreto

Density of Potential (W/m^2)	Polygon	Area (km^2)
400 - 500	1	329.27
	2	6.28
	3	0.19
	Subtotal	335.74
500 - 600	1	83.72
	2	9.73
	Subtotal	93.45
	Total	429.19

Source: Elaborated by authors.

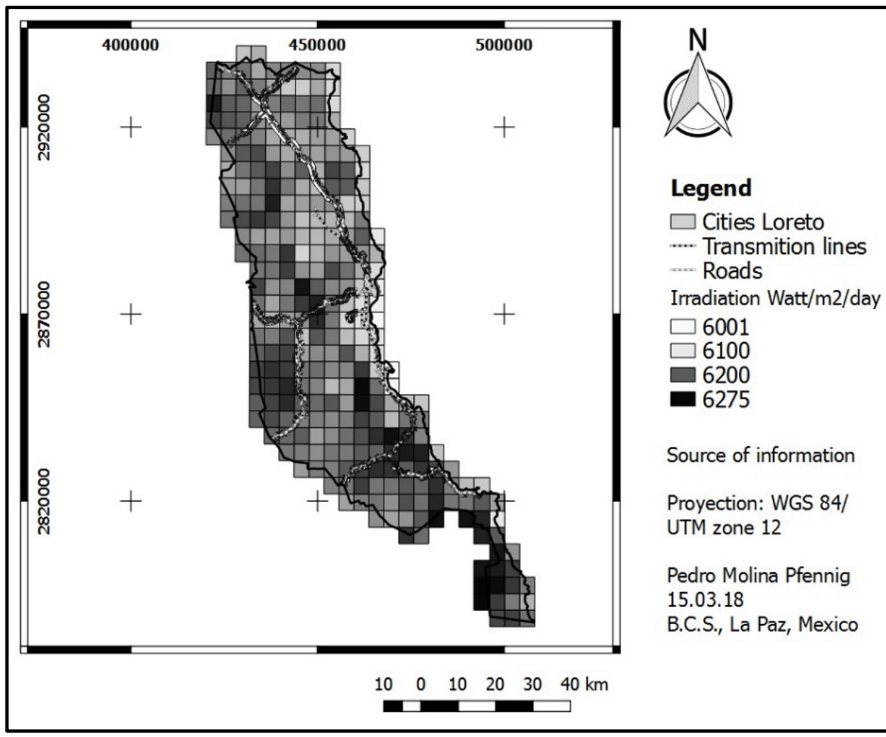
The map in Figure 4-12 was generated with the methodology described previously. As can be seen, the solar resource is excellent throughout the municipality, with daily average values above 6 kWh/m2, which is greater than those reported by Perea-Moreno, et al. (2016).

To identify the areas with the greatest suitability for solar in the municipality, the information about the solar potential was taken as a basis and additional layers of information were superimposed on it through a GIS. These included the slopes and orientation of the land; proximity to transmission lines and roads; and other information. With this information, polygons with an area of at least 3 hectares, with small southward-facing slopes, and less than 1 km from the road were identified. These polygons total 115 km2 and correspond to 2.6% of the Loreto territory. As a conservative rule, it has been found that 1 MW of photovoltaic capacity can be installed on fixed structures for every 2 hectares of surface. This would theoretically give an installable potential of 5,750 MW of photovoltaic solar generation in the identified polygons.

As in the case of wind potential, this solar capacity is much higher than what is required in the municipality of Loreto. In fact, considering five daily peak sun hours, 0.5% of the energy generated by the potential 5,750 MW would be enough to generate the equivalent of the electricity sales

of the Loreto agency in 2015. As a reference, the first phase of the project named Don José of Enel Green Power Mexico, located in Guanajuato, had an investment cost of US$0.92 per watt installed (Enel, 2018). With this cost, 0.5% of the installable potential in Loreto would cost about US$27 million.

Figure 4-12. Global Solar Irradiation for the Municipality of Loreto



Source: Elaborated by the authors with data from NREL (2017) via SENER, 2017a.

Sustainability and Costs

As mentioned earlier, the municipality of Loreto does not have local generation plants, so the electricity consumed in Loreto is generated in other parts of the state. A small photovoltaic plant combined with its own wind farm would contribute to the solution of not only the municipality's energy dependence, but also contribute to reducing the polluting emissions derived from the current conventional generation. In addition, taking into account that tourism is one of the main elements of Loreto's economy,

the local generation of renewable electricity would give the region a real sustainability focus, since these types of projects are generally:

1. Technically sustainable; construction is possible within the limits of current technology and the operation of the project's critical elements is reasonably secure into the future.

2. Economically viable; the project is cost effective, considering the costs of technology, conventional energy, and environmental and social aspects.

3. Socially sustainable; the community accepts the system and is willing to collaborate with its development and the project promotes the social development of its users (e.g., by making traditional land owners partners in the project, including the community in important discussions).

4. Environmentally sustainable; the project provides benefits to the environment, compared to the traditional power system and helps meet Mexico's national and international commitments.

It should be mentioned that, in the past, one of the main disadvantages of electricity from renewable sources was its cost, since the necessary infrastructure was very expensive. However, this has changed significantly in recent years and today the cost of renewable electricity is highly competitive in relation to conventional electricity. In this regard, the International Renewable Energy Agency (IRENA) (2018) recently published the results of a comparison of the levelized costs of electricity (LCOE) from different sources, which are in Figure 4-13. The levelized costs of solar photovoltaic electricity and wind power on land are the options considered for Loreto. As can be seen, the photovoltaic and wind LCOE on land are within the range of conventional electricity. In addition, although it is not a levelized cost, this figure includes the average marginal cost of electricity generated in Baja California Sur during 2017, which is greater than the projected photovoltaic and wind LCOE.

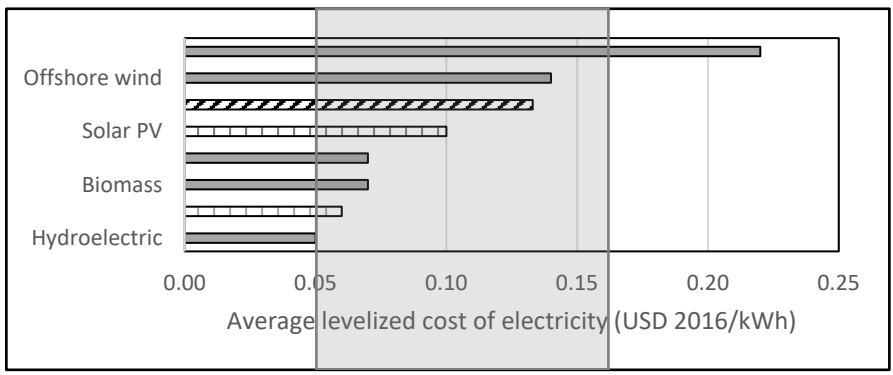
BCS-SIN Interconnection

One of the largest energy infrastructure projects planned for Baja California Sur in the coming years has been the interconnection with the National Interconnected System as proposed by the National Electricity System Development Program (PRODESEN, acronym in Spanish) 2017-2031 (SENER, 2017b). This interconnection is planned as a direct current

link with a capacity of 850 MW, with a section of the interconnection taking place across the Gulf of California from Sonora (Bahía de Kino) to Baja California (Infiernito) and then continuing south on to the main load centers in Baja California Sur. It is expected that the use of the link in 2031 will reach an average of up to 50% of its capacity.

This project aims to contribute to the supply of electricity to Baja California Sur in the medium and long term, reduce electricity costs, and reduce environmental impacts of the expansion of electricity supply based on fuel oil and diesel. Furthermore, this link would allow for better operational control of the state's electricity networks and the incorporation of greater renewable generation capacities without jeopardizing the quality, reliability, continuity, and security of the electricity supply in the state. This link would also open the possibility of exporting renewable electricity from Baja California Sur to the rest of the country. From this perspective, Loreto's broad renewable potential becomes more interesting. However, it should also be considered that the proposed link, although it would reduce the pollutant emissions released in Baja California Sur, would not eliminate them completely since local power plants will continue to be used in some capacity to balance the system. In addition, the pollutants that are no longer emitted locally would be transferred to the regions of the country where the generation of electricity destined for the supply of Baja California Sur takes place.

Figure 4-13. Levelized Costs of Electricity from Renewable Energy in the World



Note: The grey rectangle indicates the range of conventional energy.
Source: Elaborated by the authors with data from BANXICO, 2018; CENACE, 2018; and IRENA, 2018.

The investment initially estimated for this project was US$999.8 million (current value 2019), as indicated by the Ministry of Energy (SENER, 2017b), with a probable date of entering into operation in 2022. Currently, the portal of investment opportunities of the Mexican government, Proyectos México (http://www.proyectosmexico. gob.mx), places it at an amount slightly higher than the US$1.6 billion (2018) and with the date of entering into operation in 2023. However, at the time of final editing of this work (September 2019), the project seems to have been discarded by the new federal administration. Nevetheless, a wider discussion about the best use of US$1.6 billion for energy infrastructure in Baja California Sur should be promoted or, alternatively, a discussion to identify other solutions with similar results but at lower cost.

Final Notes

Loreto is the newest municipality, with a smallest area and population in the state. It is the only municipality in Baja California Sur that does not have electricity generation plants. It is also the municipality with the lowest electricity coverage of households in the state and the highest residential electricity consumption per person. Moreover, Loreto has had a high growth rate in electricity sales at medium voltage rates, which suggests an important expansion of economic activity. Despite this, Loreto also has the highest poverty rates in Baja California Sur. This suggests that electric bills could be a significant economic burden for many Loreto households.

Loreto has broad potential for the generation of electricity from solar and wind energy. Considering that technology costs have decreased considerably in recent years, Loreto could supply all its electricity using less than 1% of the renewable energy potential identified for the municipality. This would reduce its responsibility for the polluting emissions currently generated in the state. Additionally, with the proposed interconnection of Baja California Sur with the National Interconnected System through an underwater link, Loreto would have important energy potential that could eventually constitute an export product to the rest of the country.

However, the interconnection project will require a large amount of investment and some years to complete it. Given the large investment required for this project, and considering that it will not completely replace the local generation, it will be of great interest to follow its

development closely and to analyze other options that could contribute to achieving similar objectives, but at a lower cost. For example, there could be studies of energy storage projects that allow a greater incorporation of renewable energy to the electricity network. This would take advantage of clean, free, and abundant local energy resources, strengthening the sustainability and energy security of Loreto and the other municipalities of the state. Renewables would stabilize electricity costs in the long term, contributing to reducing local electricity rates and reducing the environmental impacts of the conventional generation with fuel oil and diesel.

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