USAID COLOMBIA YOUNG LEADERS WORKFORCE TRAINING PROGRAM ACTION PLANS: FORECASTING DISTRIBUTED PHOTOVOLTAIC ADOPTION IN BARRANQUILLA, COLOMBIA

INTRODUCTION

As part of the U.S. Agency for International Development (USAID)-National Renewable Energy Laboratory (NREL) Young Leaders Workforce Training Program in Colombia, the Association of Renewable Energies Colombia (SER) participants leveraged their training and professional experience to develop an action plan for modeling the projected adoption of distributed solar photovoltaics (PV) out to 2050 for the city of Barranquilla, Colombia. SER was one of four teams selected by the training program development team to receive continued technical assistance and strategic advisory support from the USAID-NREL Partnership for action plan implementation.[1]

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SER is a private nonprofit entity created in March 2016 that brings together more than 70 local and global companies committed to the implementation and development of nonconventional renewable energy in Colombia. SER's mission is to promote the development of nonconventional renewable energy sources for electricity generation and their use in new technologies, in a competitive and efficient electricity market and under a regulatory framework that equitably promotes the different technologies to achieve the diversification of the electricity matrix in Colombia.

This case study provides an overview of the key activities and outcomes of the Distributed Generation Market Demand Model (dGen™) Colombia project. Additional information on the results can be found in the NREL presentation, "[Forecasting Distributed PV Adoption in Barranquilla, Colombia](#)."

BACKGROUND

The objective of the dGen Colombia project, conducted in 2022 by NREL and SER, was to provide projections to 2050 on distributed PV deployment by sector for a range of scenarios for the city of Barranquilla using the dGen model adapted for international projects. SER intends for this information to be made available to and utilized by policymakers, power system operators, utilities, energy sector consultants, and other stakeholders. Some examples of how this information could be applied include reviewing and developing incentives to support rooftop PV adoption, targeting specific sectors for rooftop adoption, and allowing system operators to plan for future distributed energy adoption in their territories.

Four different scenarios were selected to provide insight on how the city of Barranquilla may plan for future PV deployment:

1. Base case scenario: Modeling adaption of both rooftop and groundmount PV deployment to 2050 based on the current policy and regulatory framework.
2. Time-of-use tariff implementation: Time-of-use tariffs were incorporated into the model to show how revised rate structures may impact the adoption of rooftop PV.
3. Increased energy demand from air conditioning use: The same base case policy and regulatory framework were used but the demand profiles reflected an increase in air conditioning use.

1. English: https://www.nrel.gov/docs/fy22osti/82855.pdf; Spanish: https://www.nrel.gov/usaid-partnership/assets/pdfs/nrel-usaid-colombia-brochure-fy22.pdf.

4. Increased energy demand from electric vehicle adoption: The same base case policy and regulatory framework was used, but the demand profiles reflected an increase in energy consumption from electric vehicle adoption.

NREL'S DGEN MODEL

The dGen model (Sigrin et al. 2016) developed by NREL was used in this analysis. The dGen model can be used to provide medium- to long-term projections on the adoption and operation of distributed energy systems, for example, rooftop solar, wind, and battery storage at high spatial fidelity for power system planning. The dGen model can be used to explore forward-looking topics, such as understanding infrastructure needs for distribution grids to accommodate distributed energy resource (DER) deployment and how retail electricity prices influence the deployment of distributed energy systems. The dGen model is open-source and can be downloaded at https://github.com/NREL/dgen. A modified version of the dGen model that includes data on representative customers for Barranquilla was used in the analysis for this action plan.

STAKEHOLDER ENGAGEMENT

SER Colombia was the primary stakeholder for this project. SER also worked to include other stakeholders who provided input and feedback. One of the main stakeholders relevant to advancing the action plan work was the Unidad de Planeación Minero Energética, who helped define the scope of work and provided inputs for scenarios, as well as suggested scenarios for the analysis. Other stakeholders were ERCO ENERGÍA SAS, who provided inputs on PV technology costs and incentives for Colombia, and Air-e, the utility in Barranquilla, who provided feedback on our results, as well as suggested additional scenarios for the analysis.

INSTITUTIONAL FRAMEWORK

Outputs from the dGen analysis can provide critical insight to the Government of Colombia, power system operators, local consultants, and other stakeholders on how and where to focus efforts and DER deployment to reach their goal of increasing nonconventional renewable energy capacity to 30% of total generation by 2030. Depending on the specific scenarios analyzed, potential impacts include:

- **Colombia's Ministry of Mines and Energy (MME) and Energy Planning Unit (UPME)—Load Forecasting and Integrated Resource Planning:** Projecting how many DERs will be adopted and where.
- **MME—Policy Analysis:** Manipulate national and local policy and market factors within the model to simulate how DER deployment is impacted.
- **Multiple Stakeholders—Locational Value of DERs:** The spatial layers used in dGen modeling allow dGen to identify the most promising sites and regions for DER deployment.
- **Planners and Policymakers—Understanding the Role of DERs in Future Energy Systems:** Projection of infrastructure needs for DER deployment, how DERs will impact retail electricity prices, and synergies between distributed-scale resources and transmission-scale resources.

OBJECTIVES

The analytical objectives of this action plan focused on the key metric outputs produced by dGen, such as technical potential, total capacity of economic systems, adoption projections, cumulative and annual installed capacity, generation, and market value. These metrics can be used in setting renewable energy targets, policies, and goals for energy generation in Colombia. They can also be used for energy planning by understanding what fraction of renewable energy from PV can be locally generated and what needs to be procured through bulk power. Additionally, the results can be used to identify regions in Barranquilla that need to be prioritized for distribution system upgrades. The dGen model scenario results are a powerful tool for exploring pathways through which the Colombia distributed energy market could develop.

DECISION-MAKING METRICS

Some of the key impact metrics were to understand the impact of time-of-use tariffs, as well as increased demand from electric vehicles and air conditioning on distributed PV adoption. Other metrics, such as the total technical potential for rooftop and groundmount PV and their market value and potential adoption, are informative and can be used to set renewable energy targets and goals for the city of Barranquilla.

DATA

The dGen model used for the analysis has numerous input parameters. Some of the most important data are listed in **Table 1** (page 3). While there was uncertainty in data related to future utility rates, future PV costs, and future demand growth, these were addressed by running multiple scenarios.

METHODOLOGY

As part of the action plan, the technical potential, economic potential, and adoption projections of rooftop and groundmount PV for the city of Barranquilla are modeled and presented. Four main scenarios were also modeled to provide insight on the impact of increased demand from electric vehicles, air conditioning, electric vehicles and air conditioning combined, and time-of-use tariffs.

Table 1. Key Input Data and Their Source Used in the dGen Modelfor Barranquilla, Colombia

DATA	SOURCE
Utility Rates	Air-e rates for 2021 (Air-e 2021)
PV Costs	Unidad de Planeación Minero-Energética (Gobierno de Colombia 2021)
Future Utility Rates	NREL assumptions
Future PV Costs	NREL assumptions
Base Case Demand Data	SUI, Generation Sole (Programa de las Naciones Unidas para el Medio Ambiente)
Scenario Demand Data	Andersen et al., EVI-Pro Lite, Almedia and Fonseca
Future Demand Growth	Assumptions
Solar Irradiation	NREL NSRDB
Building Data (Roofs)	Processing of VRICON 3D Digital Surface Model data
Historic Deployments	Sistema De Information Eléctrico Colombiano, NREL assumptions
Incentives and Policies	Comisión de Regulación de Energía y Gas
Financing Costs	NREL Annual Technology Baseline, World Bank Group

The identification of technical potential was done by purchasing the VRICON 3D Digital Surface Model dataset from Maxar Intelligence Inc. and processing it to obtain roof planes, orientation, and tilt. The roof planes for each building were then used to determine the technical potential and generation profiles at building scale for the city of Barranquilla. The technical potential, along with other input data, were used within the dGen model, which simulates a detailed lifetime cash flow analysis considering resource potential on an hourly basis, hourly load data, retail electricity rates, incentives, and net metering.

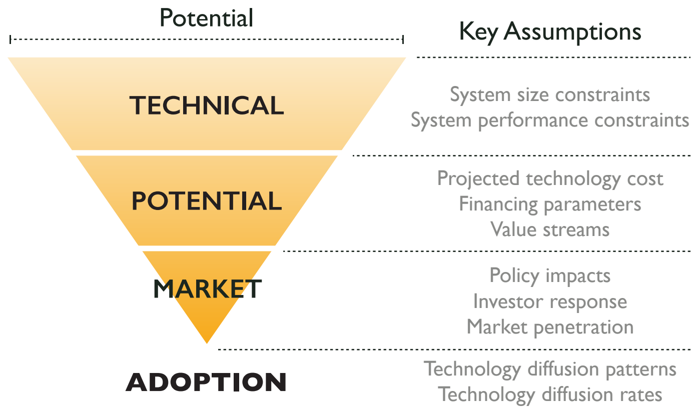


Figure 1. Methodology of the dGen model (Prasanna et al. 2021)

The dGen model also calculates the economic potential and the market potential based on the electricity bill savings of representative customers when they install rooftop PV. Based on these electricity bill savings, the net-present-value and payback period of the PV system is identified. The payback period is used to determine market potential (i.e., the maximum market share that would be adopted based on the payback period). Following the identification of market potential, the Bass diffusion framework within the model is used to project adoption over time at high spatial resolution. dGen model users can customize numerous input parameters representing current and future PV performance improvements, cost reductions, customer financing structures, changes in load and utility rates, siting criteria, incentives, and policies. By modifying these inputs, model users can identify the critical market factors that drive adoption of distributed PV.

KEY TAKEAWAYS

The results of the dGen model highlight the technical potential for both rooftop and groundmount distributed PV, the projected adoption to 2050, and the expected payback period. Technical potential is shown by sector (residential, commercial, and

Table 2. Summary of base case rooftop PV potential and forecasted adoption by sector for Barranquilla

SECTOR	ANNUAL LOAD (TWH)	ANNUAL GENERATION FROM ROOFTOP PV IN 2030 (TWH)	ANNUAL GENERATION FROM ROOFTOP PV IN 2030 (%)
Residential	0.64	0.82	128%
Commercial	4.24	1.37	32%
Industrial	1.84	0.25	14%
Total	**6.25**	**2.44**	**36%**

SECTOR	TECHNICAL POTENTIAL (GW)	NB. BUILDINGS (1000S)	BUILDINGS WITH PV IN 2020	BUILDINGS WITH PV IN 2030	BUILDINGS WITH PV IN 2050
Residential	3.9	191	2%	24%	33%
Commercial	1.9	35	1%	14%	19%
Industrial	2.6	4	1%	15%	19%
Total	**8.4**	**230**	**2%**	**22%**	**31%**

Table 3. Names and descriptions of the four scenarios modeled, as well as the base case and groundmount PV

SCENARIOS	ABBREVIATED NAME	DESCRIPTION
Base Case	Base Case	Considers current policy and regulatory framework, which includes net-energy metering and tax incentives on PV cost. Only Adoption of rooftop PV is evaluated.
Time-of-Use Tariffs	TOU	Considers current policy and regulatory framework, along with a time-of-use tariff, which is applied additionally for the residential sector Estratos 4, 5, and 6.
Electric Vehicle Adoption	EV	Considers current policy and regulatory framework, along with electric vehicle adoption by the residential sector Estratos 4, 5, and 6. The annual consumption of these specific estratos increases accordingly.
Air Conditioning Adoption	AIRCON	Considers current policy and regulatory framework, along with air-conditioning adoption by the residential sector Estratos 4, 5, and 6. The annual consumption of these specific estratos increases accordingly.
Electric Vehicle and Air Conditioning Adoption	EV + AIRCON	Considers current policy and regulatory framework, along with both electric vehicle and air-conditioning adoption by the residential sector Estratos 4, 5, and 6. The annual consumption of these specific estratos increases accordingly.
Groundmount PV Adoption	GM PV	Considers current policy and regulatory framework, which includes net-energy metering and tax incentives on PV cost; however, only adoption groundmount PV is evaluated.

industrial), district, and tariff class. The key outcomes are illustrated here, and additional information on the results can be found in the NREL presentation, "[Forecasting Distributed PV Adoption in Barranquilla, Colombia](#)."

The overall rooftop PV results are summarized in **Table 2** (page 3). Barranquilla could meet 36% of its annual demand through rooftop PV by 2030. However, there is an excess of generation compared to consumption in the residential sector, so the excess generation would have to be utilized across all sectors. 22% of buildings in Barranquilla are projected to have rooftop solar by 2030 and 31% of buildings by 2050.

After determining the technical potential, four main scenarios (not including the base case and groundmount PV) were modeled to provide insight on the impact of increased demand from electric vehicles, air conditioning, and time-of-use tariffs. For the time-of-use tariff, electric vehicle adoption, and air conditioning adoption scenarios, only Estratos 4, 5, and 6 were considered for the

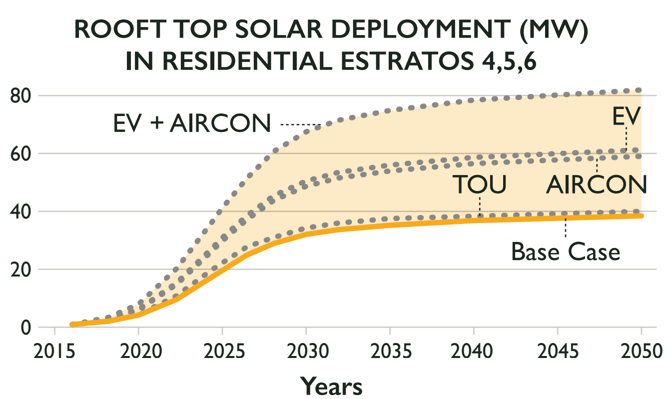
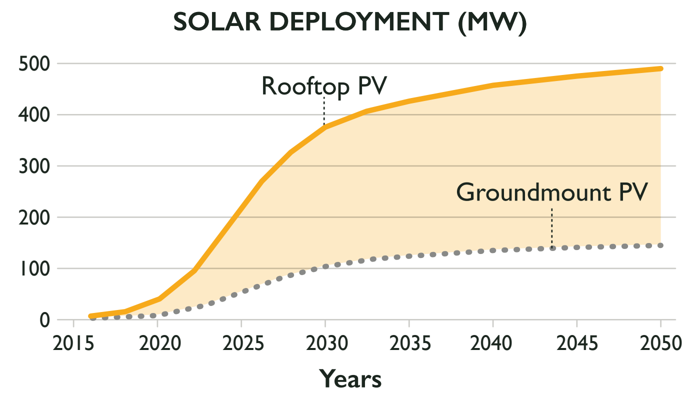


Figure 2. Rooftop solar deployment to 2050 across the scenarios. The results by scenario are shown only for the residential Estratos 4, 5, and 6 because time-of-use tariffs and changes in annual demand due to electric vehicle and air conditioning adoption are applied only for these specific estratos.

SECTOR	NB. BUILDINGS (1000S)	TECHNICAL POTENTIAL (MW)
Residential	22	201
Commercial	8	80
Industrial	2	204
Total	**32**	**485**

Figure 3. Groundmount area in Barranquilla available for PV installation generated after processing the Digital Surface Model dataset



SECTOR	TECHNICAL POTENTIAL (MW)	PROJECTED ADOPTION (MW) IN 2050
Rooftop PV (Base Case)	8,400	493
Groundmount PV	485	146
Total	**8,885**	**639**

Figure 4. Illustration of rooftop PV and groundmount PV technical potential and projected adoption in 2050

purposes of this study. Estratos 4, 5, and 6 are designated as higher income areas and pay higher electricity prices and are also more likely to be early adopters of electric vehicles and air conditioning. Estratos 1, 2, and 3 pay lower or subsidized electricity prices.

The projected rooftop solar adopted capacity in Barranquilla by 2050 increases to 536 MW, compared to 493 when considering the impact of both air conditioning and EV adoption in the residential estratos. **Figure 2** (page 4) shows the adoption rates for the four scenarios and the resulting differences in solar adopted capacity.

In addition to rooftop PV, 33,408 properties in 189 districts in Barranquilla were found to have groundmount PV technical potential. The total technical potential for groundmount PV in Barranquilla, Colombia, is 485 MW.

The projected rooftop and groundmount solar adopted capacity in Barranquilla by 2050 is 639 MW in the base case scenario. A higher percentage of the developable groundmount solar is adopted because most of the technical potential is found on commercial and industrial properties where payback periods drop to below 5 years by 2030.

Figure 5 below shows the projected adoption of rooftop PV over time in the districts of Barranquilla. Darker shares of red indicate higher adoption, and the top 10 districts with the highest adoption are indicated on the maps.

Figure 6 (page 6) shows the results by sector. The commercial sector has both the highest economic potential (total capacity with positive net present value) and highest projected adoption of PV, with 244 MW of rooftop PV and an additional 24 MW of groundmount PV by 2050.

Figure 7 (page 7) illustrates the technical and economic potential for the high and low estratos within the residential sector. The residential tariff classes Estratos 1, 2, and 3 have higher technical potential and economic potential compared to Estratos 4, 5, and 6. However, model projections show that a higher proportion of economic systems in Estratos 4, 5, and 6 are adopted by 2050 compared to Estratos 1, 2, and 3. This is primarily due to longer payback periods for rooftop PV for these tariff classes.

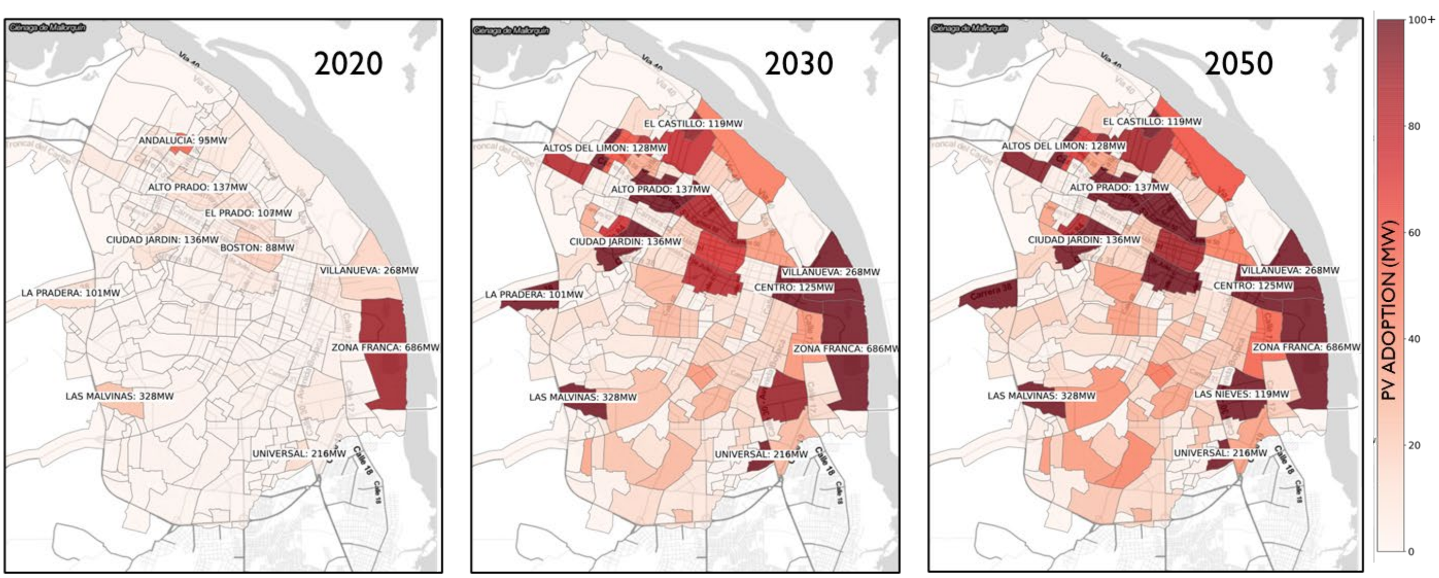
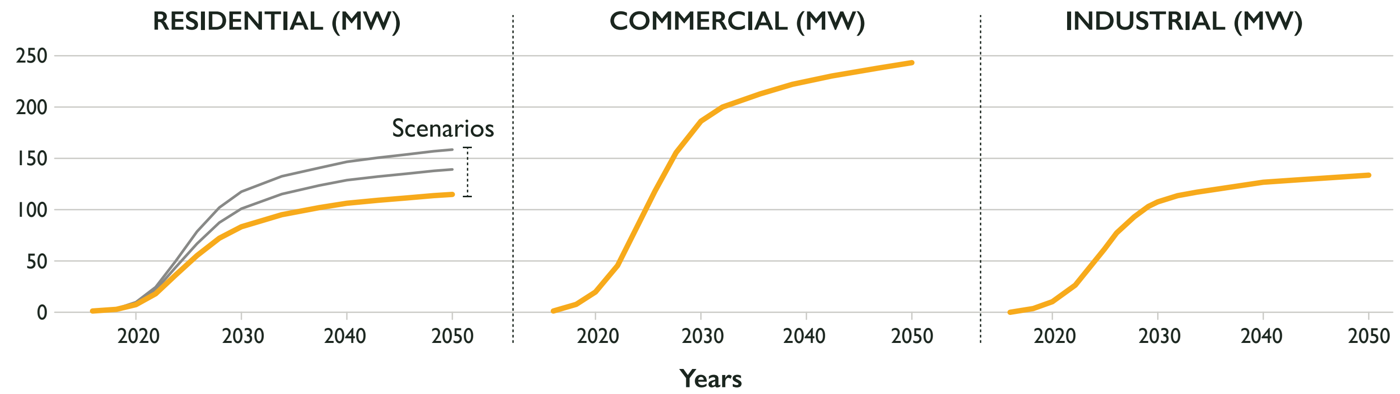


Figure 5. Rooftop PV adoption by district



SECTOR	ECONOMIC POTENTIAL (MW)	ROOFTOP PV (MW) 2050	GROUNDMOUNT PV (MW)
Residential	2,913	115	70
Commercial	5,911	244	24
Industrial	1,923	133	52

Figure 6. Rooftop PV economic potential and adoption by sector to 2050

Figure 8 (page 7) shows the payback periods by year and sector for the Base Case scenario. The average payback period of the residential sector decreases from 9 years to 5 years by 2050 due to reductions in PV costs. Similarly, the average payback for the commercial and industrial sectors decreases from 6 years to 3 years by 2050.

Additional information on the results can be found in the NREL presentation, "Forecasting Distributed PV Adoption in Barranquilla, Colombia."

WHAT'S NEXT?

The key metrics and results for distributed PV and its value to customers in Colombia will be disseminated broadly across stakeholders in Colombia who can use this data in their decision-making. The data produced from the analysis will also be made available publicly so it can be used in future analysis and modeling efforts or by local universities, researchers, and industry professionals in Colombia and other countries.

Some proposed activities following the completion of the modeling activities in this action plan are listed below.

1. Develop projections for other cities in Colombia for which we have purchased 3D surface model data (Cucuta, Medellin, Santa Marta, and Soledad).
2. Develop adoption projections for the whole country of Colombia.
3. Although only distributed PV adoption was modeled in this action plan, the dGen model could also be used to model battery storage. Thus, we could develop projections for distributed battery storage and PV for Colombia, with a focus on the commercial and industrial sectors.
4. Work closely with the utility in Barranquilla (Air-e) to identify how model outputs can be used to plan upgrades to their distribution grid.
5. Train staff at stakeholder organizations to use the model and develop projections for distributed energy technologies.

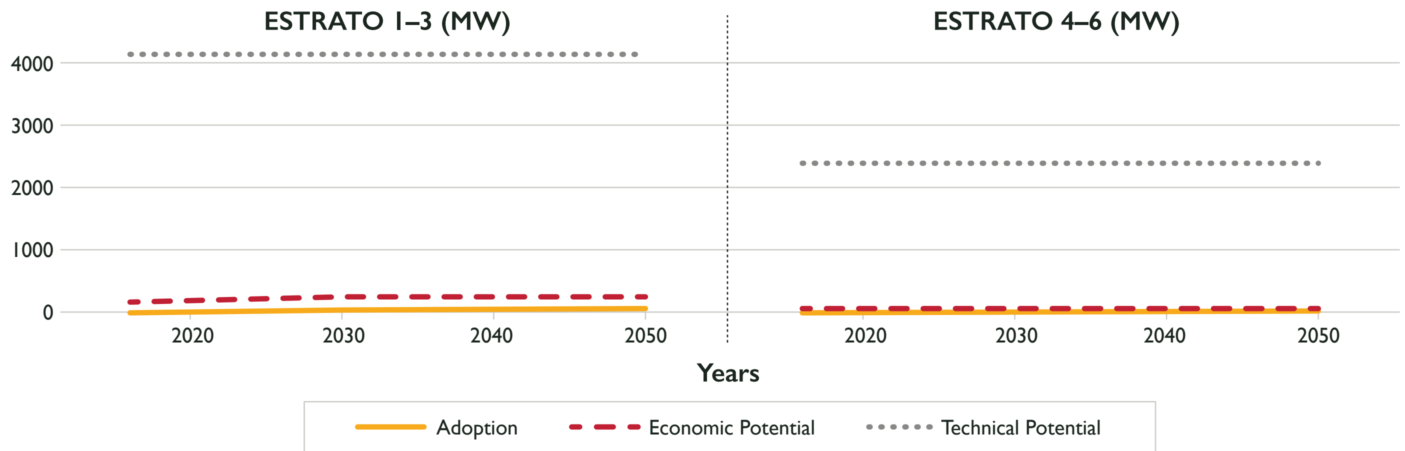
CHALLENGES

Some of the key challenges encountered during this project include:

- Difficulty of data collection and getting buy-in from stakeholders without any initial presentation materials.
- Due to the COVID-19 pandemic, there were no in-person interactions to facilitate the process of refining analytical questions and formulate clear action plan objectives.
- Difficulty in spurring interest among potential policymakers and government agencies to utilize the information. There was interest at a high level, but it was challenging to identify appropriate staff to present the findings to and provide capacity building on how to apply the information.
- Lack of staff to receive training and take ownership of model after project is completed.
- Personnel changes.

A few proposed solutions to improve future capacity building efforts include:

- Allow budget for modeling team to meet with stakeholders so that training and sharing of data is made easier.
- Create preparatory materials that can be used across multiple efforts (across countries) to explain modeling tools and their outputs and value.
- Assign at least two staff (for each stakeholder organization) to make sure someone can carry forward the project if staff leave or there are personnel changes. Also, planning for an alternate who can represent the organization also helps with scheduling meetings when main staff do not have availability.



SECTOR	TECHNICAL POTENTIAL (MW)	ECONOMIC POTENTIAL (MW)	ADOPTION (MW)
Estrato 1–3	4,135	274	77
Estrato 4–6	2,392	76	38

Figure 7. Technical potential, economic potential, and adoption to 2050 by the upper and lower estratos

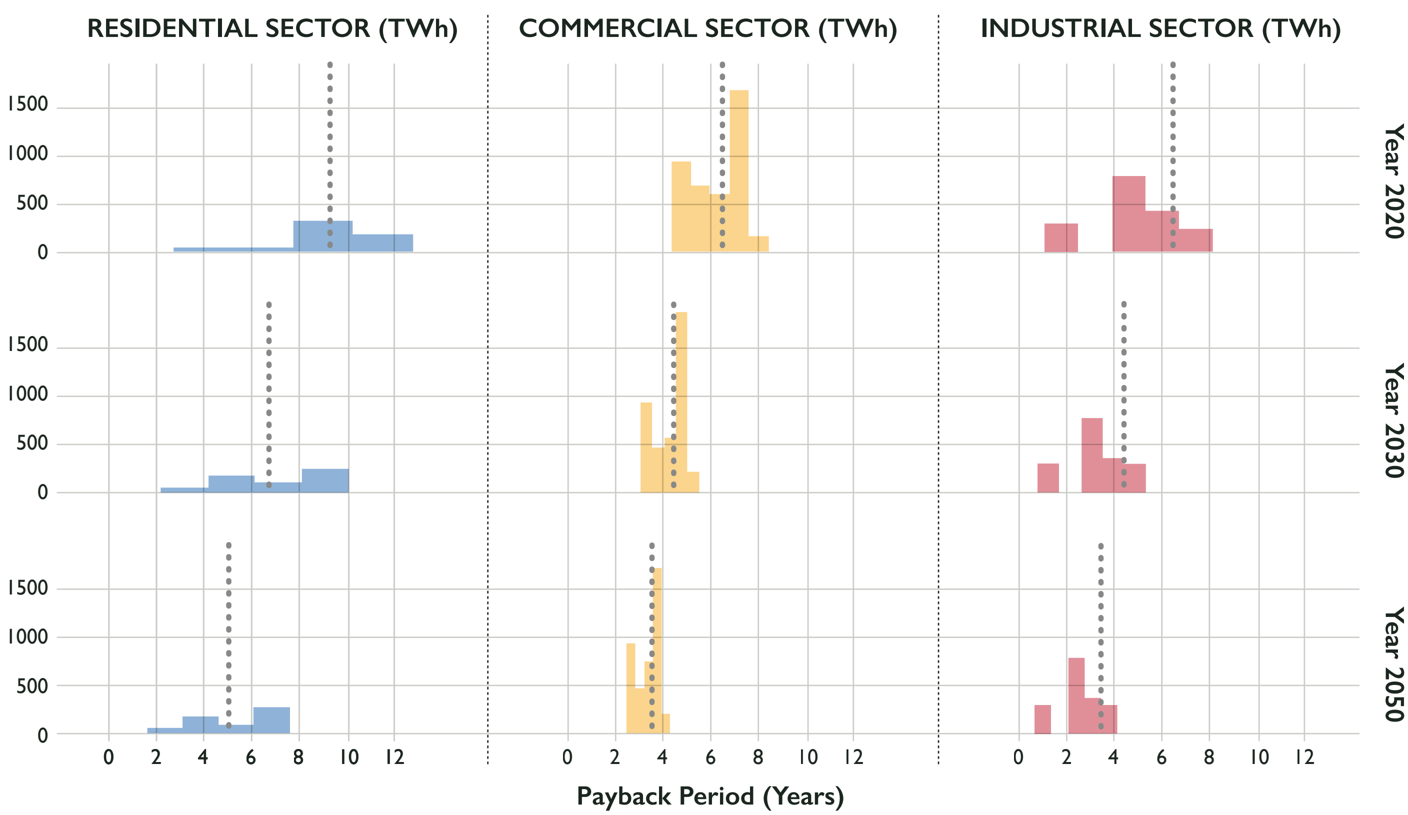


Figure 8. Payback periods by year and sector for the Base Case scenario

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INTEGRACIÓN EFICIENTE DE ENERGÍAS RENOVABLES VARIABLES AL SISTEMA COLOMBIANO

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