IRENA
International Renewable Energy Agency

COLOMBIA POWER SYSTEM FLEXIBILITY ASSESSMENT

IRENA FLEXTOOL CASE STUDY

October 2018

FlexTool Engagement Process

The engagement with Colombia on flexibility assessment started with analysis as part of REmap, the global roadmap from the International Renewable Energy Agency (IRENA) for the world to scale up renewables in the years ahead.

Stakeholders from the country sought a deeper understanding of the potential technical challenges related to the integration of variable renewable energy (VRE). In response, IRENA suggested a flexibility assessment using the newly developed IRENA FlexTool. The process was formalised by sending an official invitation to the focal point entity for Colombia – the National Mining and Energy Planning Unit (Unidad de Planeación Minero Energética – UPME), a specialised unit attached to the Colombian Ministry of Mines and Energy in charge of expansion of the electrical system – to conduct a power system flexibility assessment using the FlexTool.

IRENA collaborated with experts from UPME, which provided information, data and guidance on the details of Colombia's power system. The initial study evaluated potential flexibility issues in the country's power system in 2030 with a high penetration of VRE, as identified in the REmap analysis. A first assessment was developed and delivered to UPME, based on a previous breakdown of the electricity network into five regions (in line with the 2015 national energy plan) (UPME, 2015) and using the REmap power generation mix. The results, together with the FlexTool and the input files used for the analyses, were shared with UPME for their revision.

IRENA received positive feedback from the country on the application of the FlexTool, and UPME requested a more granular representation of the power system. Meanwhile, Colombia finalised the revision of its power sector plan. The revised plan, thanks in part to discussions that took place during the REmap process, raised the ambition for VRE penetration beyond the REmap scenario while also increasing the spatial resolution from 5 to 15 nodes.

The capacity mix of Colombia's new Reference Generation Expansion Plan (UPME, 2018) was used as an input to carry out a second flexibility assessment, using the FlexTool, that was more geographically detailed and more ambitious in VRE penetration than the first one. The updated 15 nodes model in the FlexTool, together with the study results and a slide deck illustrating the main findings, were sent to UPME for review and discussion.

This brochure summarises the main findings from application of the FlexTool in the Colombia case study. Figure 1 shows the main challenges identified before starting the analysis, as well as the analyses undertaken to cope with these challenges.

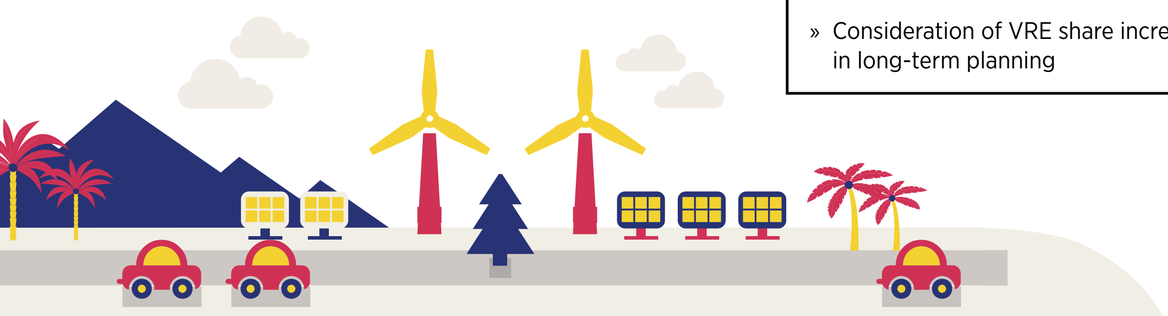
Figure 1: Main challenges of the Colombian power system and FlexTool analysis done

Country challenges

- High reliance on hydropower (with dry-year shortfall risk)
- Transmission congestion
- Weak interconnection
- Peak load after sunset

Analysis undertaken

- Simulation of different hydro inflows scenarios (eg. dry year)
- Development of a multinode model
- Assessment of the optimal generation capacity mix (including storage)
- Assesment of the transmission investments
- Consideration of VRE share increase in long-term planning



Colombia's Power System

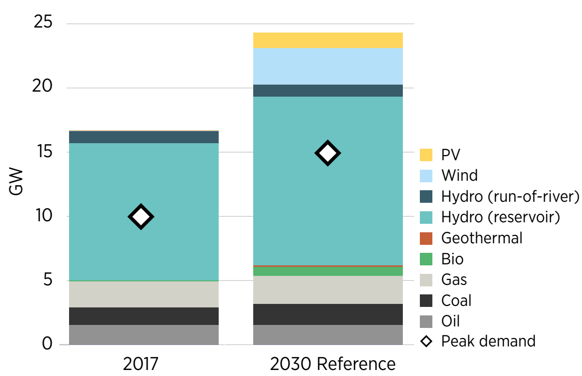
Colombia's power system is characterised by large installed capacity for hydropower (70% of total capacity), mostly from plants with significant reservoir capacity. VRE generation capacity, below 1% in 2017, would reach 17% by 2030 under the revised energy plan (UPME, 2018). Additional biomass power by 2030 would account for 3% of capacity.

Total capacity, like total power demand, is expected to rise 3% annually during 2017-2030. Peak demand, at 10 gigawatts (GW) in 2017, is expected to reach 15 GW in 2030 (XM, 2018). In both years, installed capacity exceeds peak demand – rising from 16.8 GW in 2017 to 24.3 GW in 2030 – so generation adequacy issues are not expected[1] (see Figure 2).

Colombia requires a strong transmission grid because its wind and hydro resources are concentrated in a few regions with limited demand, and electricity must be transported long distances to supply other regions where demand is concentrated. In 2017 and 2030 the largest hydro capacity is seen in Antioquia and Choco, the best wind resources are along the Atlantic coast, and the largest demand is in Bogotá. See the country map (Figure 3) for an overview of the 15 nodes used in the analysis.[2]

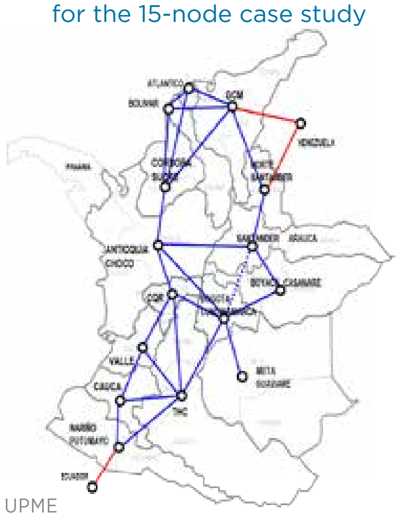
Table 1 characterises enablers of flexibility in Colombia's power system, based on historical information and the latest generation and transmission expansion plans (UPME, 2018).

Figure 2: Expected evolution of Colombia's generation capacity mix, 2017-2030



Note: "2030 Reference" refers to the expected energy mix based on existing plans and policies.

Figure 3: Simplified transmission map for the 15-node case study



Source: UPME
Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.

Table 1: Flexibility enablers in Colombia's power system*

Flexibility enablers	High	Medium	Low
Interconnection capacity vs. average demand			●
Generator ramping capabilities	●		
Matching of demand with VRE generation		●	
Hydro inflow stability		●	
Strength of internal grid**	●		
Storage vs. annual demand (MWh)	●		
Geographical dispersion of VRE generation and demand			●
Minimum demand vs. VRE capacity		●	

* These flexibility enablers are defined in IRENA (2018b).
** There are no significant congestion events and Colombia is planning to reinforce the grid in 2030.

Note: Flexibility enablers' levels are an indication of: very good enabling conditions when level/value is "High"; normal enabling condition when "Medium"; bad enabling conditions when "Low".

1 In the simulations, generation adequacy issues may arise because VRE sources does not have 100% firm capacity and hydropower resources have limited energy; challenges may appear if VRE production is low and the year of analysis is dry. However, the flexibility assessment can be performed for specific cases where low rainfall or low wind might create adequacy challenges, and the tool is capable of addressing these cases by investing in a least-cost mix of technologies.

2 The internal transmission network within each of the 15 areas was not considered in the analysis; each area was aggregated as a single node.

Highlights from the Analysis

Flexibility analysis in Colombia's 2030 power system

Using the information sent by UPME, the 2017 power system was simulated to calibrate the FlexTool model. No flexibility issues were identified. Next, the 2030 reference scenario, with average hydro inflows, was simulated, again with no issues (see Figure 4 and Table 2).

Finally, given high dependence on hydropower, a low hydro inflow (2030 dry-year) scenario was simulated. While system flexibilty was sufficient, coal and oil use rose to compensate for less hydropower output. This meant higher system costs and carbon dioxide (CO_2) emissions.

Colombia is not expected to face flexibility issues in 2030 even with lower rainfall. This is due largely to solid planning by UPME, which in its latest national expansion plan (UPME, 2018) explicitly considers a set of measures to avoid flexibility issues.

These measures include:

- Reinforcement of transmission lines, including boosting transmission capacity between the wind-rich Guajira (ATL) region and the centre of the country.
- Development of the new 2.4 GW Ituango hydropower plant in Antioquia. However, the government is considering not building this plant due to challenges in project construction. The FlexTool analysis indicated no flexibility issues in this scenario.
- Reinforcement of the internal transmission network in some areas, especially near the Atlantic coast. The government identified transmission within such areas as an issue, although this was not addressed by the FlexTool analysis.

Figure 4: Power generation (annual share) and hourly dispatch over a representative week in 2030: Reference and dry-year scenarios

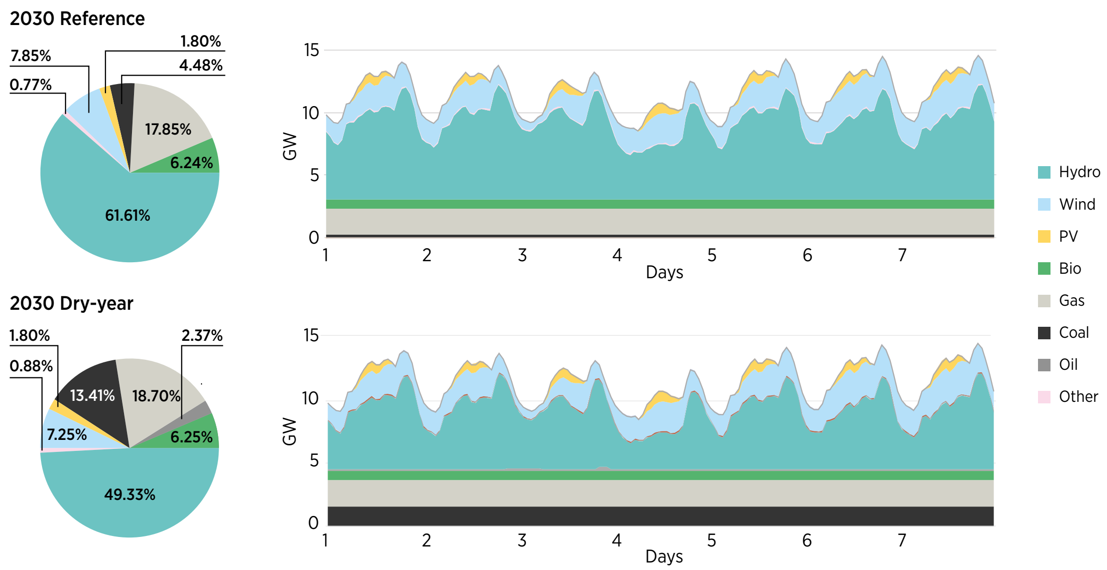


Table 2: Main flexibility indicators for Colombia's power system in 2030: No flexibility issues identified

	2030 Reference		2030 Dry Year	
	Total (GWh)	Peak (MW)	Total (GWh)	Peak (MW)
Curtailment	0	0	0	0
Loss of load	0	0	0	0
Spillage	0	0	0	0
Reserves inadequacy	0	0	0	0

Note: These flexibility indicators are defined in IRENA (2018b).

Evaluating additional investments for optimal capacity mix

With no flexibility issues foreseen in 2030, a sensitivity analysis was done to explore cost-efficient investments for an optimal capacity mix[3]. The FlexTool expansion mode identified investments to add 4.3 GW more of solar photovoltaics (PV), boosting installed PV capacity to 5.5 GW (Figure 5).

More wind power investment would not be cost-efficient, because wind use in the Guajira-César-Magdalena (GCM) node is already high, and adding capacity would increase total system costs[4].

Likewise, no additional transmission needs were identified. However, solar PV investment and higher fixed costs are offset by savings in operational costs. Figure 6 shows total system costs in 2030, both in the reference scenario and with more investments.

Figure 5: Generation capacity in 2030 reference scenarios with and without investments for optimised system costs

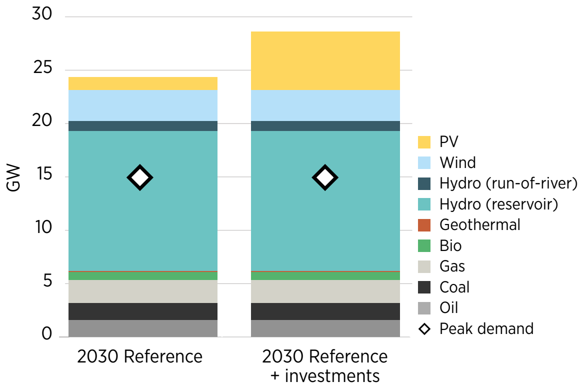
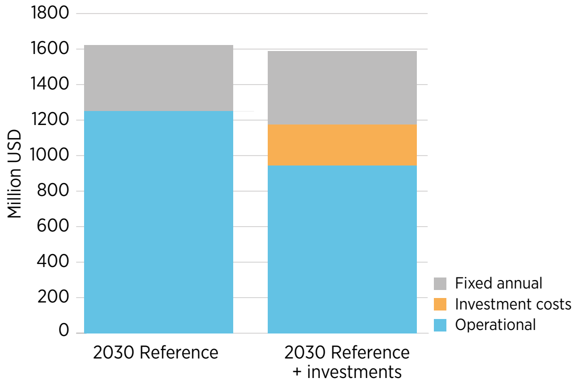


Figure 6: Annualised cost comparison between 2030 reference scenarios with and without investments for optimised system costs



Finally, additional flexibility indicators were estimated to measure the flexibility that remains in the system in each given scenario. Table 3 presents estimated values for these indicators for Colombia in the scenario with optimised investments.

Colombia's power system has flexibility to handle a higher penetration of VRE in the 2030 reference scenario with optimised investments, even if investing in more VRE does not appear to be economically optimal under the current assumptions.

With the Ituango hydropower plant removed from the scenario, the FlexTool finds cost-efficient options to increase solar PV further, to 7.8 GW in total. Like in the reference scenario, no wind or transmission capacity needs were identified.

Table 3: Remaining flexibility indicators for the 2030 reference scenario with optimised investments: Annual average and most critical period*

	Average	Most critical
Residual ramping capability (MW/min)	165.3 MW/min	80 MW/min
Share of time when transmission is not congested (%)	87.19%	**Most congested lines:** ACH-BOG: 10.68% SAR-BCS: 16.23%
Remaining interconnection capacity (%)**	N/A	N/A
Unused hydro reservoirs capacity (%)	86.7%	74.5%

*Most critical period represents the worst conditions for each of the indicators under the modelled scenario. Period, or time interval, is one hour in the Colombian FlexTool model.

**An interconnection between Colombia and Panama is expected to be added in 2020. However, it was not modelled and is therefore not applicable.

Note: These remaining flexibility indicators are defined in IRENA (2018b).

3 In the case of Colombia, the expansion includes renewable energy generation capacity and transmission.

4 The FlexTool quantifies this by using dual variables, which express how the total system costs change by investing in an extra megawatt of wind power.

Gradually integrating more solar and wind power into the system

As a sensitivity analysis, additional solar PV is gradually integrated into the system until significant curtailment emerges. In total, 18 scenarios were analysed. Figure 7 shows the curtailment at different shares of VRE penetration. In all scenarios, wind generation capacity remains constant at 2.8 GW.

In the 2030 reference scenario with optimal investments, the solar PV installed capacity is around 5.5 GW. This results in annual shares of 18.6% VRE generation and 84% renewable energy. Because flexibility indicators are almost zero in this scenario, the system could further accommodate VRE.

When solar PV installed capacity reaches 12.5 GW and the VRE share approaches 30%, then VRE curtailment starts. At this point, the renewable energy share is 93%. From here, curtailment increases rapidly as solar PV capacity increases, while the renewable energy share increases but never reaches 100%. This is mainly because solar PV generation is available only during the day. At night, although wind and hydropower installed capacity are also high, the system still requires gas turbines to cover the demand. Wind and hydro are also located in only some regions, and transmission is not enough to cover the entire demand with renewables in some periods.

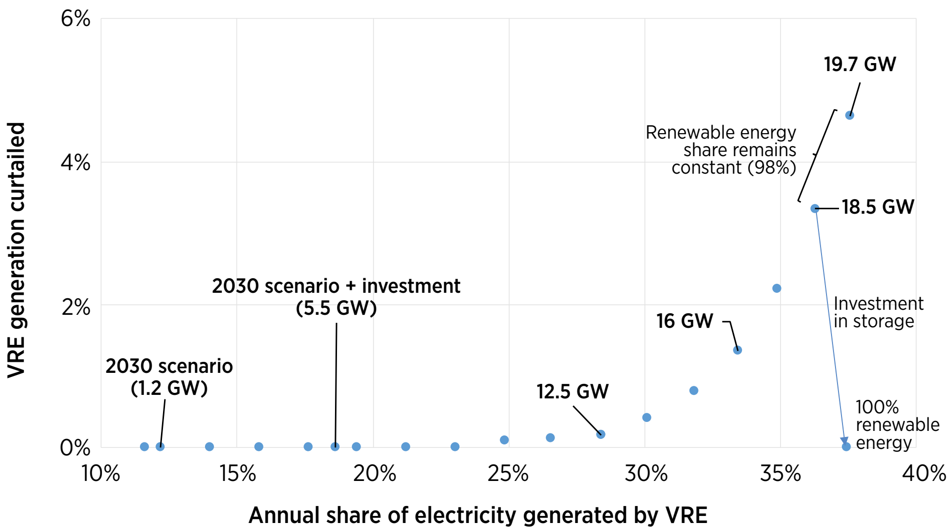
For this reason, in the last scenarios analysed – when solar PV capacity is higher than or equal to 18.5 GW – while VRE curtailment increases, the renewable energy share remains constant at around 98%, and any additional solar PV will be fully curtailed. This is the point when system flexibility issues must be resolved to keep integrating solar PV and to achieve 100% renewable energy use.

The FlexTool's investment mode was run using some of the scenarios in which curtailment is produced. The result was that by investing in energy storage, the power system could reduce VRE curtailment, increase the shares of VRE and renewable energy, and reduce total system costs. This is because storage can absorb excess VRE generation during the solar peak hours, when most VRE generation is curtailed, to use it later when VRE penetration is lower.

From the investment scenarios analysed, a 100% renewable energy share is first achieved in the scenario with 18.5 GW of solar PV. Therefore, the optimal pathway to reach 100% renewable power using solar PV would be to install up to 18.5 GW of solar PV along with 12.5 GW (6.2 gigawatt-hours, GWh) of energy storage, mostly in the GCM and Cordoba Sucre areas where most of the VRE is deployed. In Colombia's case, pumped hydro storage could be the most suitable option to boost flexibility in the existing system.

Another possible solution would be to couple the power sector with other energy sectors via "sector coupling" (e.g., power-to-heat, power-to-gas or electric vehicles). This analysis can be performed with the FlexTool and will be investigated further in the future.

Figure 7: VRE curtailment at different levels of solar PV penetration in 2030



Conclusions and Recommendations

Colombia's power system currently has a high share of hydropower, low VRE capacity and a strong internal transmission grid that faces no flexibility issues.

In 2030 the VRE installed capacity will grow to 17%; however, Colombia will still have enough flexibility – even in dry years with limited hydropower generation – thanks to plans to greatly expand transmission capacity and to add another 2.4 GW of hydropower capacity (Ituango project) on top of the large hydro resources already in the system. In an additional scenario analysis that excluded this 2.4 GW hydropower plant, the system proved flexible as well.

Based on the analysis, the IRENA FlexTool suggests that in 2030 additional solar PV capacity can improve the regional balance of supply and demand and reduce total system costs as well as further reducing CO_2 emissions. The optimal amount of solar PV identified in the analysis is 5.5 GW, up from 1.2 GW in the current plan. Under this optimisation, there are no additional cost-effective investments in wind power or additional transmission capacity.

Additional investments beyond the identified 5.5 GW of solar PV power may be driven by users, as has been the case in many countries, particularly for distributed generation. This study concludes that even if the solar PV capacity goes beyond the assessed optimum, solar PV installed capacity can reach 12.5 GW without generating flexibility issues. After this point, curtailment increases exponentially as more capacity is added to the system. In this case, Colombia would need to evaluate the most cost-effective flexibility solution that enables integrating higher shares of VRE.

In all the scenarios and sensitivities assessed, no additional transmission investments were needed for the 15 nodes studied. The high VRE scenarios are complemented by investments in energy storage systems; however, sector coupling could also be an option.

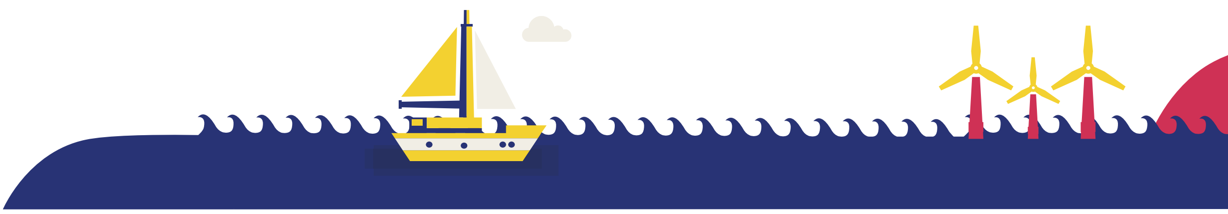
A 100% renewable energy share in the power sector can be achieved by increasing solar PV capacity to 18.5 GW and adding 12.5 GW (6.2 GWh) of electricity storage to the system, ideally in the GCM and Cordoba Sucre nodes. Pumped hydro storage appears to be the most practical storage option for the Colombian power system.

Impact

Colombia first engaged with IRENA to assess the flexibility of the electricity mix proposed in the 2015 national expansion plan (UPME, 2015). That plan suggested measures that would achieve reasonably high VRE penetration. Following positive feedback from the country, IRENA was then asked to produce a more granular analysis using the latest national expansion plan (UPME, 2018), which pointed to VRE penetration exceeding IRENA's REmap estimates.

This analysis provided insights into the flexibility of the planned power system, as well as indicators that could be suitable to assess this flexibility. Additionally, given the increase in nodal granularity requested, analysis of the transmission between areas could provide a more detailed overview of the system's flexibility.

Based on the results of this analysis, UPME plans to add a chapter on power system flexibility to the next national power expansion plan, looking at the period 2018-2032. The new chapter will add results from this flexibility analysis and explore other scenarios, such as one considering the potential 2.4 GW Ituango hydropower plant, or one considering higher granularity of nodes to capture possible transmission constraints within specific areas.



Further Reading

- **UPME (2018)**, *Generation-Transmission Reference Expansion Plan 2017-2031* (Plan de Expansión de Referencia Generación-Transmisión 2017-2031), 345.
- **UPME (2015)**, *Generation-Transmission Reference Expansion Plan 2015-2029* (Plan de Expansión de Referencia Generación-Transmisión 2015-2029), 616.
- **XM (2018)**, *Demand forecast* (Pronóstico de demanda) [web document], www.xm.com.co/Paginas/Consumo/pronostico-de-demanda.aspx (accessed 3 October 2018).
- **IRENA (2018a)**, *Power system flexibility for the energy transition, Part I: Overview for policy makers*, International Renewable Energy Agency, Abu Dhabi.
- **IRENA (2018b)**, *Power system flexibility for the energy transition, Part II: IRENA FlexTool methodology*, International Renewable Energy Agency, Abu Dhabi.

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