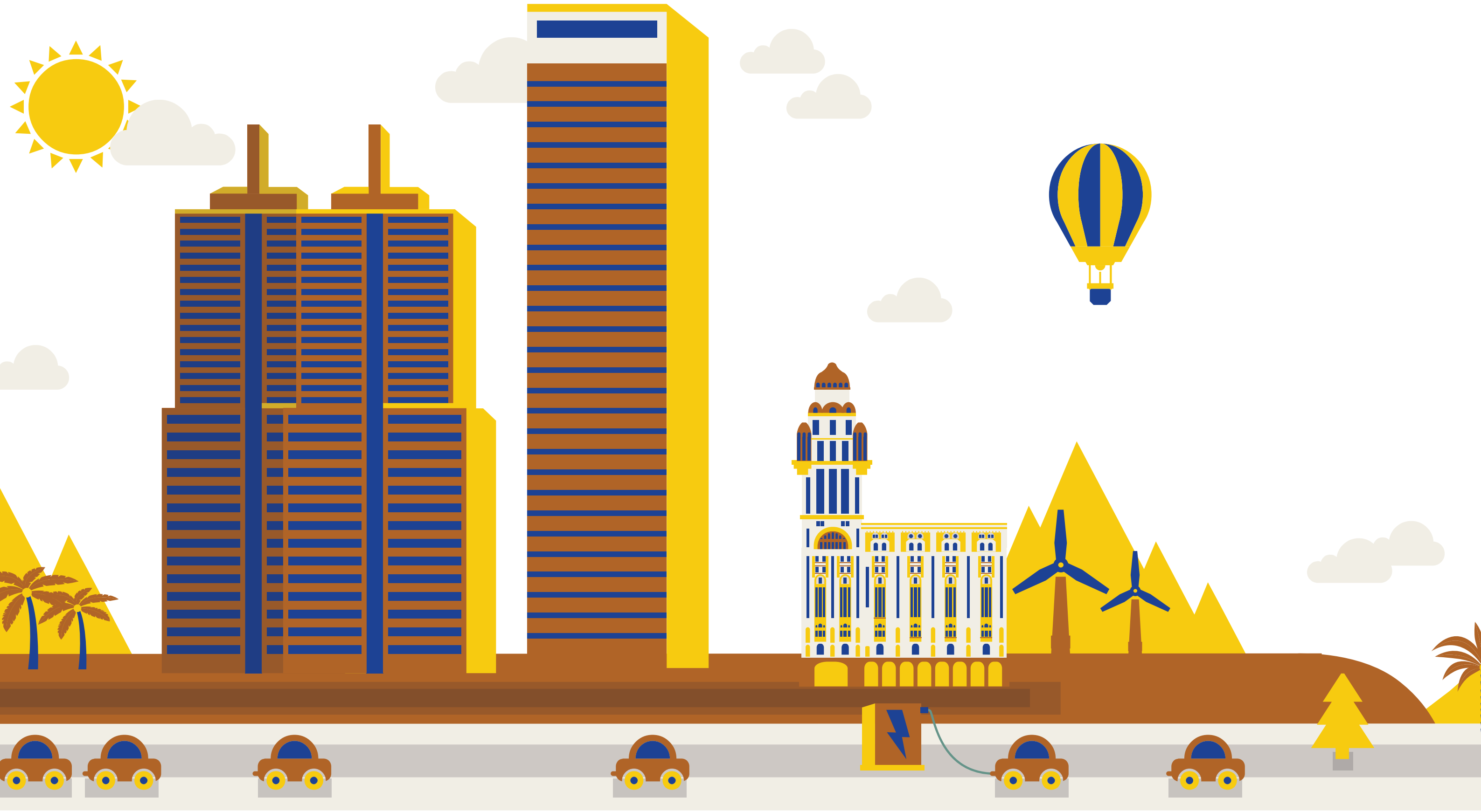
MIEM
MINISTERIO DE INDUSTRIA, ENERGÍA Y MINERÍA

IRENA
International Renewable Energy Agency

URUGUAY POWER SYSTEM FLEXIBILITY ASSESSMENT

IRENA FLEXTOOL CASE STUDY



October 2018

FlexTool Engagement Process

In August 2017 representatives from the International Renewable Energy Agency (IRENA) and Uruguay agreed to engage in a flexibility assessment. Representatives from Uruguay welcomed the opportunity to explore and analyse IRENA's approach, including the newly developed FlexTool, to see how these fit with the country's planning process and complement current national planning tools.

The process was formalised once IRENA's main counterpart, the Ministry of Industry, Energy and Mining (Ministerio de Industria, Energía y Minería, – MIEM), agreed to conduct a power system flexibility assessment using the IRENA FlexTool.

IRENA collaborated with a group of technical experts from MIEM during data collection and development of the model. MIEM provided information and guidance on the details of Uruguay's power system. Part of the data collection was based on publicly available sources (ADME, 2018; MIEM, 2018; UTE, 2018), while other information was provided directly by MIEM.

Given that Uruguay's power system already has close to 100% renewable generation, there is no room to explore a more ambitious renewable energy scenario for the power sector. The penetrations of both renewables and variable renewable energy (VRE) in future scenarios were taken from the national projections produced by MIEM for 2030. Data and assumptions for Uruguay's power system were consolidated by IRENA and validated by MIEM. Once MIEM confirmed the correctness of the data, the FlexTool model was built and the flexibility analysis was performed.

The FlexTool model, together with the results of the study and the slide deck illustrating the main findings, were shared with MIEM for review and discussion.

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

Figure 1: Main challenges of Uruguay's power system and FlexTool analysis done

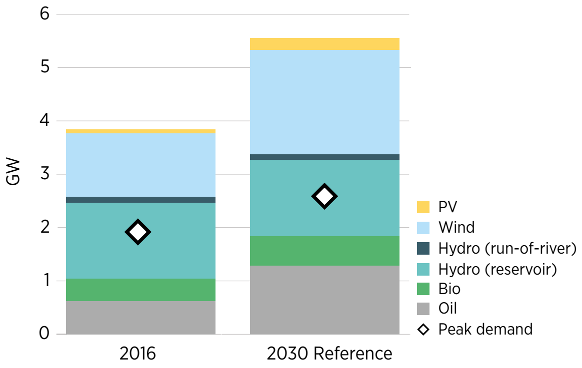
Country challenges	Analysis undertaken
» High reliance on hydropower » Peak load after sunset » High VRE penetration » No active cross-border market with neighbouring countries, despite high interconnection capacity	» Simulation of different hydro inflows scenarios (eg. dry year) » Assessment of the optimal generation capacity mix (including storage) » Consideration of VRE share increase in long-term planning (mostly solar PV)

URUGUAY'S POWER SYSTEM

In 2016, Uruguay's power system had a very high share of renewable installed capacity (around 80%), comprising half VRE (mainly wind) and half hydro and biomass plants. Electricity was almost 100% renewable, with hydro contributing 56%, wind 22%, biomass 18%, solar photovoltaics (PV) 1%, and fossil fuels 3%. Under MIEM's 2016-2030 projections, installed VRE capacity should increase by 900 megawatts (MW), mostly wind, by 2030.

Uruguay recently installed 540 MW of diesel engines, and the latest plan suggests adding a 120 MW diesel-fired gas turbine by 2030 and a 134 MW biomass project in 2024. Total power demand is expected to grow 33% by 2030, with peak demand rising from 1.9 gigawatts (GW) to 2.7 GW. Installed capacity (3.8 GW in 2016 and 5.5 GW in 2030) exceeds peak demand in both years, so generation adequacy issues are not expected[1] (see Figure 2).

Figure 2: Expected evolution of the generation capacity mix in Uruguay's power system, 2016-2030

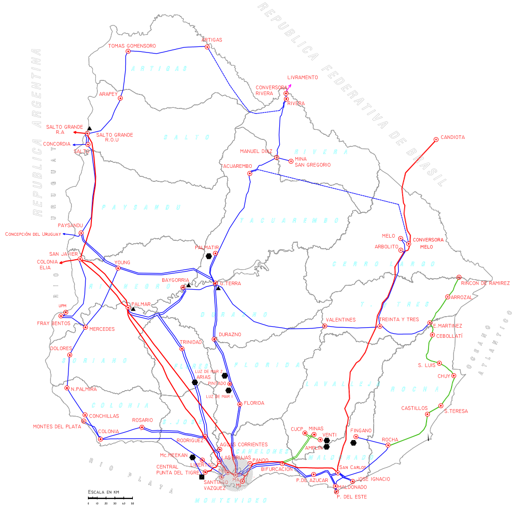


Uruguay has large interconnection capacity with Argentina (2000 MW) and Brazil (570 MW); however, without an active cross-border market, the energy is traded via ad hoc short-term agreements. Even with interconnection capacity exceeding peak demand, the power system experiences high VRE curtailment, mostly at night when wind generation exceeds demand. Consequently, electricity imports have started giving way to exports (Wynn, 2018).

Internal transmission is not reflected in this study, as MIEM opted for a single-node model.

Table 1 shows key enablers of flexibility in Uruguay's power system based on historical information and the latest generation expansion plans.

Figure 3: Uruguay's transmission network, including interconnections with Argentina and Brazil



Source: UTE

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

Table 1: Flexibility enablers in Uruguay'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		N/A	
Storage vs. annual demand (MWh)			●
Geographical dispersion of VRE generation and demand		N/A	
Minimum demand vs. VRE capacity			●

* These flexibility enablers are defined in IRENA (2018b).

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". N/A (not applicable) due to the fact that the system was modelled as a single node.

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[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.*

HIGHLIGHTS FROM THE ANALYSIS

FLEXIBILITY ANALYSIS IN URUGUAY'S 2030 POWER SYSTEM

Uruguay's 2016 power system was simulated to calibrate the FlexTool model, and 22% excess VRE was identified. After calibration, two 2030 scenarios were tested: a reference scenario with average hydro inflows, and a dry-year scenario, which considers a low-inflow[2] probability of 5% (see Figure 4 and Table 2[3]).

Although the reference scenario is 100% renewable, oil generation is required in the dry year scenario (leaving 86% renewables), and excess wind power drops from 25% to 8% (Figure 4). In a dry year there is no water spillage, whereas in the reference scenario, excess wind power (if not exported) could result in water spillages.

Curtailment can be avoided through exports, however additional measures being explored to store or transform Uruguay's excess wind generation include power-to-heat, power-to-hydrogen and electric vehicles.

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

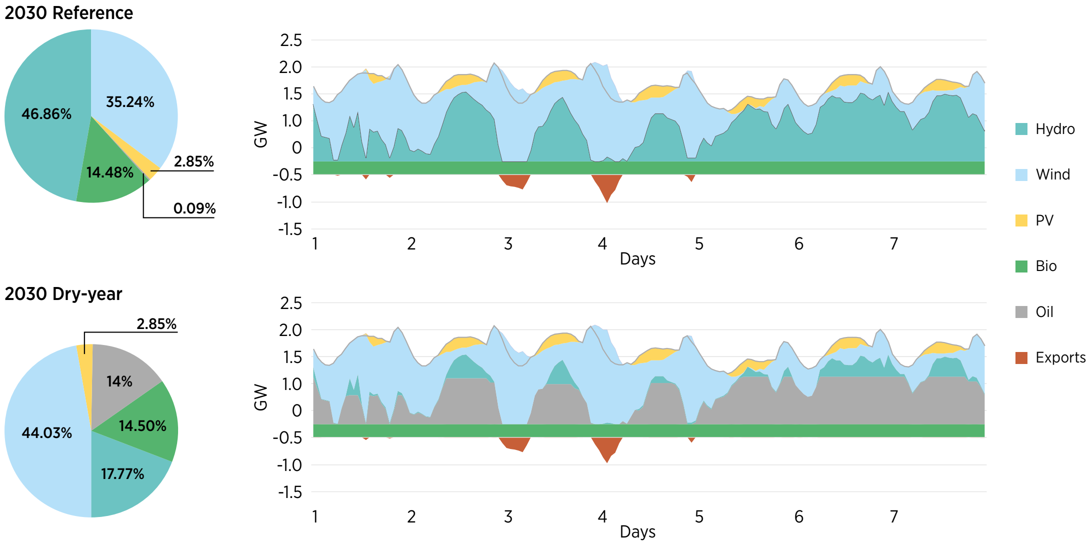

Table 2: Main flexibility indicators in Uruguay's power system in 2030 reference and dry-year scenarios: No flexibility issues identified

	2030 Reference		2030 Dry Year	
	Total (GWh)	Peak (MW)	Total (GWh)	Peak (MW)
Curtailment*	1 920	2 397	609	1 102.7
Loss of load	0	0	0	0
Spillage	0	0	0	0
Reserves inadequacy	0	0	0	0

* With the modelling assumptions used, the FlexTool turns VRE curtailment into exports and VRE curtailment is zero. However, in reality not all the excess VRE generation can be exported since this requires an agreement with the neighbouring countries, resulting in high curtailment levels.

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

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[2] *Uruguay is highly dependent on hydro resources, and the annual variability of inflows is high, with historical extremes of -50% and +70% compared to the long-term average inflow using 100 years of data.*

[3] *High curtailment levels are not due to lack of flexibility, but because VRE generation exceeds demand. Additionally, the model turns these into exports.*

EVALUATING ADDITIONAL INVESTMENTS FOR OPTIMAL CAPACITY MIX

Since no flexibility issues were identified in the two 2030 scenarios, a sensitivity analysis was carried out to identify potential additional cost-efficient investments.[4] In the 2030 reference scenario, the FlexTool's expansion mode did not identify any additional cost-efficient investments. In the dry year scenario, however, the limited energy from hydro reservoirs could justify investment in additional capacity[5] (see Figure 5).

In this scenario the FlexTool identifies as cost-efficient investments another 500 MW of solar PV, 280 MW of wind and 10 MW of biogas. These investments are cost effective in reducing fuel cost (see Figure 6) only if most future years will be dry. Since hydro inflows in most years will be considerably higher, such investments are not recommended.

Figure 5: Generation capacity in 2030 dry-year scenario with and without investments for optimised system costs

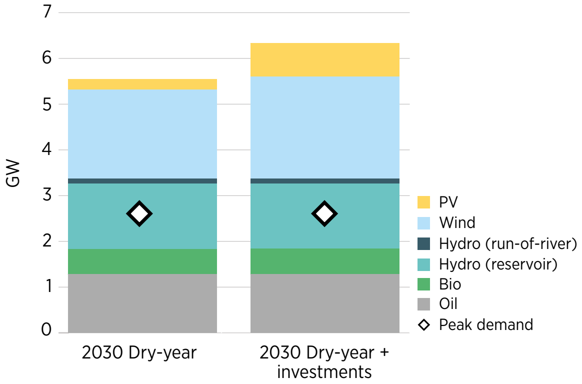
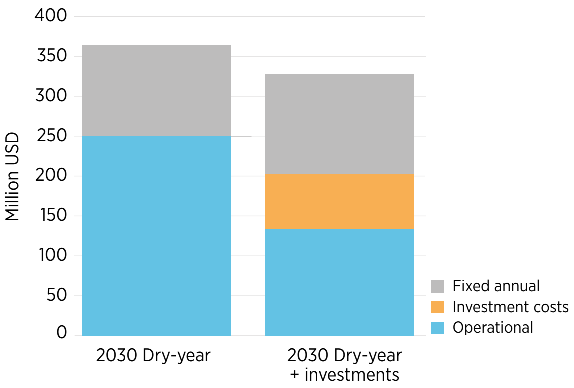


Figure 6: Annualised cost comparison between 2030 dry year scenarios, with and without investments for optimised system costs



Finally, a set of additional flexibility indicators were calculated to measure the remaining flexibility in the system, as presented in Table 3 for the 2030 reference scenario.

In the most critical period of unused reservoir capacity, the remaining capacity is 0%, suggesting that spillage might be necessary. However, 0% here means only that the reservoirs are full, but there is no spillage and the power system would have remaining flexibility to handle higher VRE penetration.

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)	77.84 MW/min	52.2 MW/min
Share of time when transmission is not congested (%)**	N/A	N/A
Remaining interconnection capacity (%)***	91.47%	6.73%
Unused hydro reservoirs capacity (%)	71.3%	0%

* "Most critical" represents the worst conditions for each indicator under the modelled scenario. The period, or time interval, is one hour in the Uruguayan FlexTool model.

** N/A (not applicable) because the system was modelled as a single node.

*** Results from the model. In reality, use of the interconnection would not be so high.

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

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[4] *In the case of Uruguay, the expansion includes renewable energy generation capacity and battery storage. Domestic transmission capacity expansion is not relevant in this case given that it is a single-node model.*

[5] *However, such investments would be cost effective in 5% of the years, and likely not cost effective 95% of the years*

GRADUALLY INTEGRATING MORE SOLAR AND WIND POWER INTO THE SYSTEM

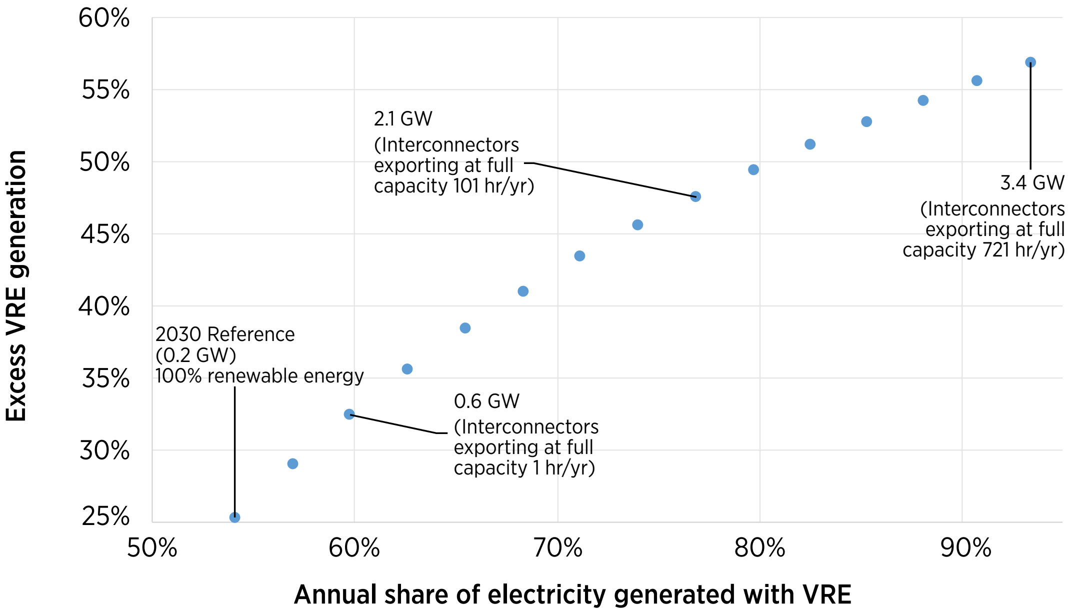
As a final sensitivity, a stress test was performed forcing investments in solar PV capacity into the power system until significant curtailment emerges. Wind sensitivities were not considered, since wind penetration in the system is already very high. In total, 15 solar PV scenarios were analysed using the 2030 reference scenario. The main outcome of this sensitivity analysis was that during each hour when VRE generation exceeds demand, this excess could be exported to Argentina and Brazil. Figure 7 shows how the need for exports or curtailment grows as the share of VRE penetration grows.

In the 2030 reference scenario solar PV installed capacity is around 0.2 GW, while wind installed capacity is 1.95 GW. This, together with run-of-river hydropower, amounts to 2.25 GW of VRE installed capacity. This results in a 54% VRE share and a 100% renewable energy share (the rest is hydro and biomass). Curtailment is high at 25%. However, most of it could be turned into exports if the interconnection with Brazil and Argentina is used. As VRE capacity increases, the level of curtailment also increases.

Figure 7 shows that even with 3.4 GW of solar PV installed (and thus 5 GW of VRE, about double the country's peak demand in 2030), enough interconnection capacity would remain to export nearly all the curtailed energy. In this scenario, the interconnectors would be congested 721 hours of the year. Therefore, VRE installed capacity would have to reach unrealistic levels before curtailment would appear, due to lack of flexibility.

This analysis highlights the opportunity that an active cross-border market between Argentina, Brazil and Uruguay could provide for reducing electricity cost in the three countries. Today, exports from Uruguay to these countries occur only on an ad hoc basis – although they are increasing steadily – and wind curtailment is high when demand is lower, as only part of the excess wind generation is exported. An active cross-border market would facilitate the integration of VRE in Uruguay; however, other options such as energy storage or sector coupling (i.e., power-to-heat, power-to-hydrogen, electric vehicles) are being explored.

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



CONCLUSIONS AND RECOMMENDATIONS

Already in 2016, Uruguay's power system had very high VRE installed capacity (40% of total installed capacity), most of it being wind generation, which, together with significant hydropower generation, led to a nearly 100% renewable energy share. In that year, 22% of generation from VRE was identified as excess.

Uruguay experiences high curtailment levels because generation exceeds demand and there is no active cross-border market to make full use of the country's interconnection capacity and be able to export this energy at short notice.

In 2030, VRE installed capacity should increase further, according to the latest national plan. Yet the power system is expected to be flexible enough even in a dry year to accommodate this increase. However, curtailment may increase further if no exports or measures such as sector coupling are in place by that time.

The FlexTool does not identify the need for economic investment in additional generation capacity in the 2030 reference scenario, and it suggests investment in additional capacity (mostly solar PV and wind) only in a very dry year scenario. Since this scenario is expected to occur only five years in a century, these investments are only indicative and should not be considered as a recommendation.

When more VRE is forced into the system, no flexibility issues appear if the high interconnection capacity of Uruguay's power system is actively used. However, unless an active cross-border market is in place, such additional investments would lead only to additional curtailment and are not recommended. The main recommendation is to explore how to best use existing interconnection capacity to balance existing and planned VRE generation.

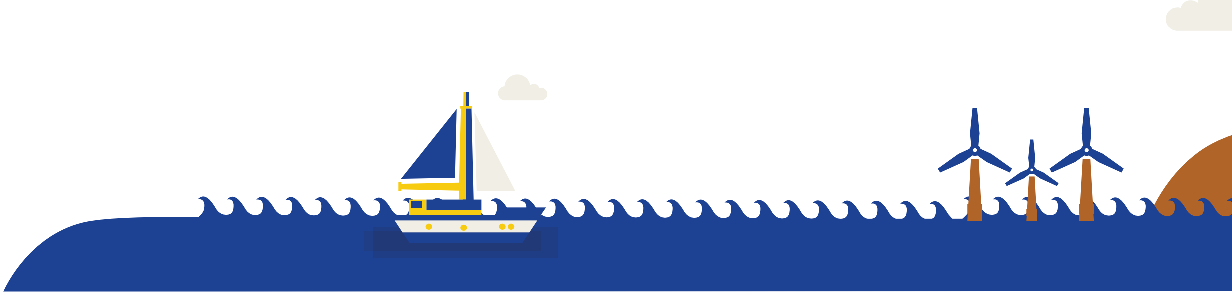
The assessment also should consider how electric vehicles, electric heating and, possibly, production of hydrogen through electrolysis could facilitate VRE integration and help Uruguay decarbonise beyond the power sector. The IRENA FlexTool can be used to perform such analysis and to assess the impacts of sector coupling.

IMPACT

Uruguay undertook this analysis to explore the use of IRENA's FlexTool methodology and see how this methodology could fit into the country's planning process.

Uruguay relies on two different tools in its power system planning. First, the WASP (Wien Automatic System Planning Package) model, developed by the International Atomic Energy Agency, is used to obtain the optimal capacity expansion over a long period. Outputs include investments required, how much capacity of which type, and in which year. Modellers then run the SimSEE (Electric Energy Systems Simulation) developed by the University of the Republic (Universidad de la Republica Oriental del Uruguay), which solves the economic dispatch problem and details whether the system with new investments fulfils established reliability criteria. If it does, this becomes the final expansion plan; if not, another WASP iteration is performed.

MIEM recognises the IRENA FlexTool as a useful complement to these tools, providing an added set of flexibility indicators and allowing integrated assessments of sector coupling. The FlexTool, therefore, reveals more options to boost flexibility.



FURTHER READING

- **ADME (2018)**, Uruguay's Electricity Market Administration (Administración del Mercado Eléctrico del Uruguay — ADME) website, adme.com.uy (accessed 16 October 2018).
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- **Wynn, G. (2018)**, *Power-Industry Transition, Here and Now: Wind and Solar Won't Break the Grid: Nine Case Studies, Institute for Energy Economics and Financial Analysis*, ieefa.org/wp-content/uploads/2018/02/Power-Industry-Transition-Here-and-Now_February-2018.pdf.
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