Caracas increased renewable energy penetration

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Along the technology availability dimension, we explore three variations. The Baseline and FullTech scenarios assume that the full suite of power sector technologies represented by GCAM is available globally. However, the FullTech scenario includes CCS technologies that are only deployed in the context of decarbonization. The NoCCS & NoNewNuc scenario assumes no deployment of CCS technologies globally, and no new deployment of nuclear technologies in LAC. The NoCCS & NoNewNuc scenario represents a high renewable scenario--which is important within the context of LAC where future mitigation strategies are expected to rely heavily on renewables. These scenarios are consistent with many prior mitigation studies36,37,51.

Differences are calculated by technology using cumulative generation (Terawatt-hours - TWh) during the 2020-2100 period and are relative to the corresponding No-Climate impacts scenarios. LAC regions covered include Brazil, Central America, and the Caribbean (C. Am/Car.), Mexico, South America_Northern (S. Am. (N)), South America_Southern (S. Am. (S)), Argentina, Colombia, and Uruguay (Supplementary Table 4 provides a breakdown of countries per GCAM LAC region). Note the different y-axis scales. Results for the period 2020-2050 are provided in Supplementary Fig. 16.

Absolute differences computed under the Combined impacts scenarios (a) and Hydropower scenarios (b). Changes are calculated using cumulative capital costs (United States dollar - USD) in the 2020-2100 period and are relative to the No-Climate impacts scenarios (i.e., positive values mean that scenarios with climate impacts on renewables show increased costs). Full range of estimated costs: USD -48 to +54 billion. Results for the period 2020-2050 are provided in Supplementary Fig. 45.

Differences are calculated by technology using cumulative investments (USD) in the 2020-2100 period. Differences are relative to the No-Climate impacts scenarios (i.e., positive values mean that scenarios with climate impacts show increased costs). The red squares indicate the net of the positive and negative changes for a given scenario (and are equal to the total investment changes plotted in Fig. 2). Note the different y axis scales. Results for the period 2020-2050 are provided in Supplementary Fig. 46.

The key overarching insight from all scenarios explored herein is the risk of misrepresentation of climate change effects on the electric power sector if climate impacts on all renewables are not accounted for. This is particularly evident for the energy pathway with the most pronounced intermittent renewables deployment (i.e., the NoCCS & NoNewNuc), characterized by greatly underestimated capital investment requirements across most of the LAC region when climate impacts only on hydropower are considered. Such an underestimation may result in enhanced power-sector vulnerabilities to climate change.

To further highlight the importance of a comprehensive analysis, we performed ancillary model experiments assuming climate impacts on each renewable individually (similar to the approach conducted by Turner et al.20 for hydropower and by Kyle et al.25 for agricultural yields). These ancillary experiments show that, when all impacts are jointly accounted for in the three Combined impacts scenarios defined earlier, bioenergy and solar generation undergo more pronounced changes than in the experiments where these climate impacts are incorporated individually (Supplementary Figs. 11-14). This results from the compounding price and demand effects of climate impacts on all renewables (see more details on these ancillary experiments in the Supplementary Note 6).

We employ the GCAM30,63, a global IAM, which maps the interlinkages between human and Earth systems. GCAM is a five-year step dynamic-recursive market-equilibrium model, which is calibrated to a historical base year (2010). The core modeling framework couples: (1) a technology-detailed energy model with representations of supplies and demands; (2) a land and agricultural submodule that provides projections of commodity supply and prices as well as land use and cover changes; (3) a water module that tracks demands in six major sectors; and (4) a reduced-complexity climate model Hector64.

This work was carried out in a research version of GCAM best suited for analyses in LAC (GCAM-LAC)44, in which important model assumptions have been refined. These include socioeconomic drivers, the disaggregation of Uruguay as a distinct geopolitical region as well as altered parameters related to energy supply, energy demand, and end-use (see Supplementary Table 5 for a list of parameters modified). In GCAM-LAC, the global economy is disaggregated in 33 geopolitical regions, and LAC is represented as eight distinct regions: Argentina, Brazil, Central America and Caribbean, Colombia, Mexico, South America Northern, South America Southern, and Uruguay.

Within our impacts modeling framework, GCAM was forced with representations of changing agricultural productivity and hydropower production as well as with climate-impacted solar and wind cost-supply curves. These inputs are based on bias-corrected projections from the GFDL-ESM2M, HadGEM2-ES and IPSL-CM5A-LR general circulation models (GCMs) obtained from the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP)49,50 under the representative concentration pathways 2.6 (RCP2.6) and 6.0 (RCP6.0). Below we describe how climatic impacts on RE are modeled in GCAM. Further details are provided in the Supplementary Note 3.

Hydrology simulations from the global hydrological model (GHM) Xanthos67 were used to modify GCAM default hydropower assumptions, which do not account for climate change impacts. Specifically, hydropower default assumptions (derived from the economic and technical potentials estimated by the International Hydropower Association30) are exogenous inputs in GCAM containing predetermined quantities of hydroelectricity production (in EJ) for all time steps and regions. These prescribed quantities that are read in at the start of a simulation then determine the temporal evolution of hydropower production by GCAM region. This means that hydropower production does not result from the modeled economic competition like all other power-sector technologies represented in GCAM.