CAPACITY EXPANSION PLANNING UNDER ECONOMIC UNCERTAINTY AND CLIMATE CHANGE

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Overview

The imminent consequences of climate change demand continuous efforts for mitigation and adaptation. Renewable generation is paramount to decarbonizing the power sector, which is the largest contributor to carbon emissions [1]. However, the inherent fluctuation of renewables and the current high cost of stationary batteries pose significant challenges to balance supply and demand in a cost-effective way [2]. Additionally, climate change has the dual potential to alter the performance of renewable generation technologies and increase the power demand for cooling–stressing the power system from the supply and demand side. Consequently, long-term investment in generation technologies faces considerable uncertainty due to these climate change effects.

Carbon capture is another important alternative for decarbonizing the power sector, competing directly with renewable generation. Meanwhile, electrical vehicles (EVs) are the primary alternative for decarbonizing the transportation sector, which is the second largest contributor to carbon emissions. Since EV adoption can both influence and be influenced by power sector decisions, evaluating investments from an integrated perspective is crucial.

Therefore, in this work, we develop a methodology to study the effect of climate change on power system investments, considering the interplay of renewable generation, carbon capture, and EVs. This integrated approach aims to offer a comprehensive understanding of optimal investment strategies under future climate scenarios.

Methods

An integrated framework involving a capacity expansion problem (CEP) defined by a stochastic program and climate change scenarios obtained from Global circulation models (GCMs) is proposed.

GCMs provide insights into the regional impact of climate change, which directly affects renewable generation potential. However, their implications for power system configuration, particularly in the context of integrated energy systems with point source carbon capture, direct air capture (DAC) and EVs, remain insufficiently explored.

Four climate scenarios based on representative concentration pathways (RCPs) are employed to evaluate the impact of climate change on photovoltaic (PV) power, wind turbines, concentrated solar power (CSP), and electricity demand. Data from multiple GCMs is used to define the RCPs. Technical parameters assess the impact of climate change on generation technologies, while elasticities quantify its effect on demand.

Each climate scenario parameterizes a deterministic capacity expansion problem (CEP) with hourly resolution. The linear CEP minimizes the total cost of investment and operation for a power system under fixed annual emission limits and technical constraints. The power system model is integrated with the road transportation sector through EVs, which introduce additional load but also provide emissions offsetting and increased flexibility via managed charging. Technical constraints, such as reserve requirements and ramping limits, are incorporated to ensure system resilience.

Investment options include generation, storage, and carbon capture technologies. The model is solved using an extensive formulation, with multiple instances processed in parallel. A sensitivity analysis is conducted on key technologies to identify the main cost drivers.

Finally, a two-stage decision framework is defined to evaluate the power system configuration under climate change and economic uncertainty. In this framework, the most influential economic parameters and RCPs define the scenarios. First-stage investment variables are continuous, while second-stage continuous variables represent the operation for each climate scenario, governed by a discrete probability distribution.

Results

The optimization framework is evaluated with the case study of Saudi Arabia, which has an annual emission target of 100 million tons of CO_2 annually by 2040. Ongoing analysis is focused on the RCP-2.45, which reflects an intermediate climate change scenario. In these results, we assume that EVs compose 10% of the passenger vehicle fleet, from which 50% incorporate managed charging with vehicle-to-grid technology (V2G).

Results demonstrate an average rise in surface temperature of 0.65°C between 2020 and 2040, with most effect caused during summer. Consequently, climate change contributes to an increment of 5.4% over the power demand for this climate scenario.

We use our deterministic model to identify optimum power system configurations. For the current RCP, the total annual cost is US$30.8 billion. From these, 66% corresponds to annualized investment costs and 34% to operation costs. At minimum cost, investment in renewable generation is limited, reaching 12% of the total capacity. Thermal units with carbon capture compose the remaining share.

Sensitivity analysis demonstrates that these initial results are caused by the high costs of batteries and, to a lesser extent, the aggressive natural gas subsidies in Saudi Arabia. Energy storage costs must fall by around 90% to achieve higher renewable shares. Additionally, direct air capture costs must fall below $130/ton of CO_2 to become competitive in this scenario.

We are conducting further analysis to compare these initial observations across climate change scenarios. Final results will include the determination of the optimal investment pathway, simultaneously incorporating all climate change scenarios into the two-stage stochastic programming framework.

Conclusions

This work proposes a methodology to study the effect of climate change on the capacity expansion planning decisions of power systems. The role of carbon capture and EVs is incorporated to attain an integrated perspective. Preliminary results with the RCP-2.45 demonstrate that this intermediate climate change scenario can raise the electricity demand by 5.4% as soon as 2040. A deterministic model is employed to prove that, for that climate change scenario, the competitiveness of renewable generation capacity is limited beyond 12% of the total capacity. A sensitivity analysis demonstrates that storage costs remain the bottleneck until prices fall below 90% of their current value. The analysis proves that the marginal abatement cost for this case is $130/ton of CO2.

Additional information is being collected for a comparative analysis of climate change scenarios. Afterward, the problem will be incorporated integrally into a two-stage stochastic programming workflow.

References

[1] D.-I. Y. Scholz and I. U. Wagner, “Renewable energy based electricity supply at low costs-Development of the REMix model and application for Europe,” tech. Rep., 2012.

[2] M. Alraddadi, A. J. Conejo, and R. M. Lima, “Expansion Planning for Renewable Integration in Power System of Regions with Very High Solar Irradiation,” Journal of Modern Power Systems and Clean Energy, vol. 9, pp. 485–494, 5 2021.