IMPACT OF GLOBAL AND LOCAL EMISSION MITIGATION POLICIES ON THE CHILEAN POWER SYSTEM EXPANSION PLANNING

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Overview

Emission taxes can be an efficient way of reducing fossil-fuel energy use, improving energy efficiency, and promoting the development of renewable energy. However, it may also decrease economic growth and social welfare, damage the competitiveness of related industries and lead to emission leakage (Lin and Li, 2011). Thus, looking closely at the expansion-planning-level consequences of pollutant-emission taxes is an essential task in determining the optimal allocation of resources. In this work, we achieve this by modelling the power system expansion as an optimization problem.

The work presented in this paper analyzes the impact of implementing CO2 and local-pollutant emission taxes on the Chilean power system expansion planning. To do this, we have formulated and implemented an optimization model based on a mixed-integer linear program, which considers the current expansion plan of the Chilean electric system, as well as renewable-based distributed generation. The analysis considers a 10-year horizon. The proposed methodology is general, thus, it applies to other jurisdictions (it is not limited to the Chilean power system). On the contrary, it corresponds to a general formulation for planning power system expansion under local and global environmental policies. Therefore, our qualitative results about planning and operational impacts of taxes should be valid in general.

Methods

We analyze the impact of implementing CO2 and local-pollutant emission taxes on the Chilean power system expansion planning. To do this, we have formulated and implemented an optimization model based on a mixed-integer linear program, which considers the current expansion plan of the Chilean electric system, as well as renewable-based distributed generation. The objective function minimizes the total system cost, which is composed of four terms: the annualized investment capital cost of new generating units and lines to be built (CC), operations and maintenance cost (O&M), load and renewable curtailment costs (IB), and pollutant-emission (environmental) costs (EM).

Our model captures the essential features of power networks by considering the granularity of investment decisions (through the use of integer variables) and the physical complexity of the power flow (through the formulation of the DC approximation of both the Kirchhoff's Current Law, or energy balance constraint, and the Kirchhoff's Voltage Law). As well, the model includes constraints modeling the power flow limits through lines, the power generation limits, the availability of resources, spinning-reserve requirements, and investment limits. We also include in the model a mathematical definition of pollutant emissions, taking into account the location and production of power plants. In addition, the model accounts for the possibility of having unserved demand, renewable generation curtailments, and renewable-based distributed energy generation. To avoid end-effects in new capacity installation, we use annualized capital costs.

The main elements of the model are: nodes, lines, and power plants, following a nodal-pricing system scheme. The main decision variables are: new power plants installation, new transmission lines installation, power generation, loss of load, and renewable-energy spillage. There is an energy balance constraint for every node, in which we allow for having an excess or insufficient amount of energy in each period (imbalances). Nodes can contain generation and/or demand, as every power plant is located in a node, but not every node has a power plant. Demand is considered inelastic and uncertain. We consider five demand scenarios (blocks) for every node and for every month (sub-period) modeled.

The availability of power plants depends on whether they already exist or they are candidates for investments, the former meaning an investment decision can be made to install the capacity at any period. Candidates are either part of the wholesale-market expansion plan (modelled by binary variables) or part of the renewable distributed investments (modelled as continuous variables). For simplicity reasons, power generation is modelled deterministically.

The capacity expansion of new distributed generation is constrained by a maximum amount of power capacity that can be installed in each period, and by certain locations where the resource is available. These limits affect all candidates being installed in the horizon and all the nodes, independently of the technology used. There is also a limit on the amount of power that can be installed per year (technical potential limit). All these constraints are made in order to mimic the strategic behavior of market agents in a more realistic manner. Furthermore, to ensure system reliability, we consider certain levels of security. Specifically, spinning reserves of thermal-based generation (for covering the renewable generation and demand operation variability) are deterministically modeled.

We implement the proposed power expansion model in a stylized version of the Chilean network, considering its two main systems: the SIC (Central Interconnected System) and SING (Northern Interconnected System), which jointly account for more than 99% of the energy produced and consumed in the country. We also consider the transmission lines connecting both systems.

The power system is simplified to a total of 143 nodes, 505 generating plants (of which 168 are candidates for new installations) and 285 transmission lines (of which 29 are candidates for construction). The study considers a planning horizon of 10 periods (years), 12 sub-periods (months) and 5 load blocks per sub-period. All the information regarding operational costs, capital costs, plant capacity factors, generation capacity and location is retrieved from the Chilean National Energy Commission and the Load Economic Dispatch Center of each system. The information regarding emission mitigation technologies of both existing and candidate plants was provided directly by the Environmental Superintendence of Chile.

Results

We focus our analysis on comparing a no-tax scenario with an scenario describing the implementation of both global- and local-pollutant emission taxes. We consider a \$20/ton CO_2 tax as well as taxes of \$5.72/kg Particular Matter (PM), \$62/ton SO_X and \$159/ton NO_X. The chosen local pollutant tax levels are the weighted average of the tax levels that are expected to be implemented in Chile in the following years.

In the case of no taxes, results show a total investment of 10.44 GW of installed capacity, which is composed of 78% renewable energy and 22% fossil fuels. The main technology installed is solar PV, with 3.74 GW installed, followed by coal with 2.24 GW installed. There are significant investments during the first year due to the last-decade underinvestment in the Chilean power sector. An expansion of 2.2 GW was optimally installed in transmission lines, which are specially built in the regions where solar energy was installed.

Implementing both global- and local-pollutant emission taxes encourage the use of more environmental efficient power plants. In this scenario, 10.45 GW are installed, with 251 MW of natural gas installed earlier than the no-taxes case, which allows the delay of the installation of 375 MW of coal power plants. Renewable energy is installed earlier as well. These modifications increase the generation of natural gas, while the generation of coal decreases. The same lines as in the base case are installed, increasing the transmission capacity in 2.2 GW. But the installation timing differs as it depends on the generators that are installed.

Conclusions

This work analyses the effects of global- and local-pollutant taxes on the joint transmission and generation expansion plan of the Chilean power matrix. Our analysis is based on the formulation and implementation of a mixed-integer linear programming optimization model for the power system expansion planning problem considering renewable-based distributed generation resources and global and local emission taxes.

Our results show that the tax levels considered could, indeed, lower the overall emissions of the country. However spatial distributive effects, produced by some leakage effects, will impair some regions increasing their emissions. Total cost and prices increase as the tax levels rise.

References

Lin, B., & Li, X. (2011). The effect of carbon tax on per capita CO_2 emissions. Energy Policy, 39(9), 5137–5146.