LP-CEM: A modeling tool for power systems planning incorporating climate change and macro-economic trends

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Research motivation

Climate change poses an ominous threat to human welfare. The environmental implications of climate change are especially serious for the electric power sector with a centralized and inter-connected network of generation, transmission and distribution assets spread over a wide geographic footprint. Some of the methodological advances introduced in this research are: the use of fine resolution temperature projections data in a power sector capacity expansion model; incorporating the changes in sectoral composition of electricity demand over time; modeling the climate change effects on both the demand and supply-side of power sector using parameters estimated in the literature and an inter-model coupling link with a macro-economic model to account for price elasticity of demand and other effects on the broader macro-economy.

The motivation for incorporating climate change effects in long-term power systems planning is grounded on two factors. First, the electric power sector is the single largest emitter of CO_2 and other pollutants like SO_2, NOx, mercury and particulate emissions. A transition to a low-carbon economy requires a rapid and inevitable de-carbonization of the current power generation portfolio. Secondly, the electric power sector is burdened with assets with an economic life spanning several decades. To ensure that the electricity sector is best suited to meet the challenges of climate change and variability in the coming decades, there is an urgent need to accurately project the multi-decadal trends in electricity markets and systems. We propose a generation/capacity expansion model (GEM/CEMs) at a state/regional scale incorporating the effects of a changing climate and the overall macro-economy on a multi-decadal basis. To accomplish this objective, we use a linear programming based CEM (hereafter referred to as LP- CEM).

Positioning the LP-CEM model in the existing literature
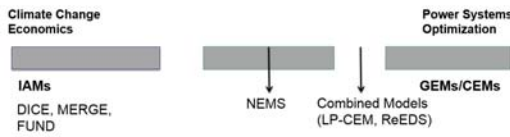
Innovative Features of LP-CEM
1. Use of localized, station-level climate data from global climate model runs (GCMs) ("bottom-up approach")
2. Coupling with a regional/state macro-economic model (for New Jersey's case)
3. Use of scenario analysis and emissions pathways in a CEM-like modeling framework
4. Use of LP-CEM to quantify the societal costs of interaction of policy mixes and projecting the retail/wholesale price trends for New Jersey

Overall research design and data pathways
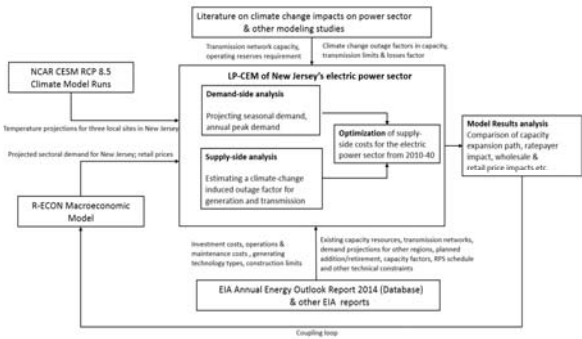

Problem formulation for the LP-CEM model

minimize (Net present value of the total supply-side cost of delivering electricity)

$$\min NPV(\sum_{region} \sum_{y=2010}^{Y=2050} \sum_{Seasons} \sum_{Unit\ Type\ i}^{B} \left(\frac{Investment\ Costs\ of\ new\ units + OM\ costs\ of\ all\ units +}{Generation\ costs\ from\ operating\ units + Transmission\ Costs} \right))$$

subject to the following set of constraints

- Total system demand + Operating reserve + Transmission losses = Total MWh Generation
- MWh generated in a time period = (Initial Capacity - Retirement + New Investments)* Availability factor * Climate Change Outage factor * Hours in a season
- Available capacity ≥ Peak demand+ Reserve margin
- Inter-subregion Transmission(MWh) ≤ Transmission capacity(MWh) for respective links
- MWh generation from renewable sources ≥ RPS limit for a given sub-region and year
- CO_2, NOx and SO_2 emission from generation ≤ Emission limit set by AEO-2013 emission output (except for CO_2 in the case of NJ & PA)
- Investment costs, fixed/variable operations costs, cost escalation rate are assumed based on scenario theme
- A uniform discount rate of 6% is assumed for all scenarios
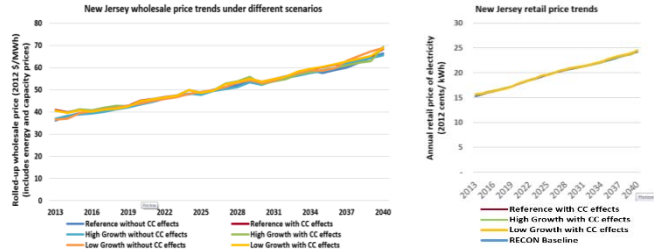- New Renewable MW addition ≤ Renewable Energy Potential(MW) for each sub-region

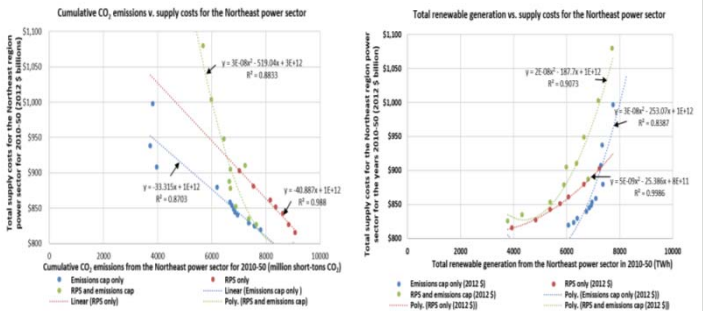## Demand trends for New Jersey under a stringent emissions pathway
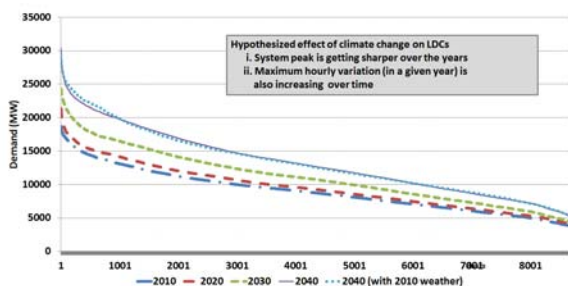
Supply trends for the Northeast region under different scenarios
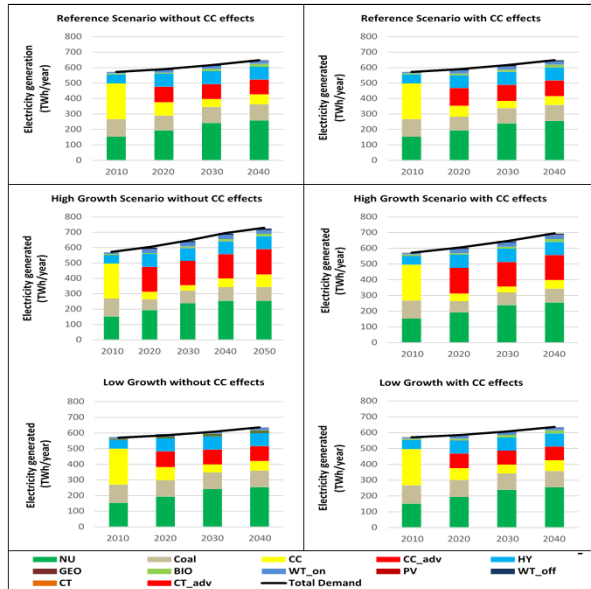
Price trends for New Jersey under different scenarios

Abatement cost curves for CO_2 emissions reduction and renewables generation from the power sector in the U.S Northeast

Key findings

- Scenarios with climate change effects and high economic growth have consistently resulted in *higher* capacity additions (in MW), supply costs, prices and ratepayers' costs.

- Interestingly, the compound average growth rate (CAGR) for wholesale price projections under all scenario themes more or less corresponds to the fuel cost escalation rate for natural gas (at 2.1% a year).Hence the future wholesale electricity prices are expected to be strongly *correlated* with natural gas prices.

- RPS instruments are cost-effective, when compared to emissions cap-type instruments, in encouraging renewables generation. Likewise emissions cap instruments are cost-effective, when compared to RPS type instruments, in reducing CO_2 emissions from the power sector.

- A policy mix designed to achieve a cumulative CO_2 emissions target of *7601 MTCO₂* and *4693 TWh* of renewable generation is likely to yield the least supply cost for the Northeast power sector (2010-50)