NCER Assistance Agreement Annual Report Summary

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EPA Agreement Number: R82873101

Title: Implications of Climate Change for Regional Air Pollution, Health Effects and Energy Consumption Behavior

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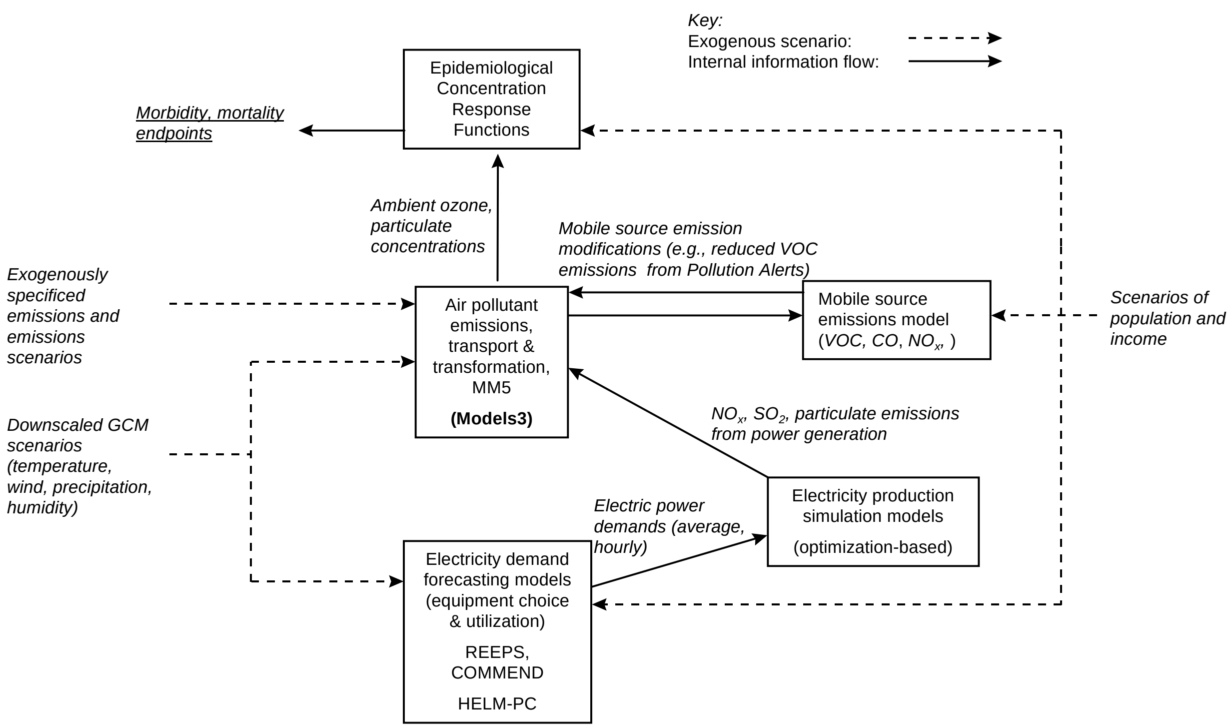
Institution: The Johns Hopkins University

Research Category: Assessing the Consequences of Interactions between Human Activities and a Changing Climate

Project Period: 02/08/2001 – 02/07/2004 (no-cost extension granted through January 2005)

Objective of Research: : This research program has four major modeling elements: climate change and variability, electrical energy demand and production, regional air pollution, and human health effects associated with air pollution exposure. Our overall objective is to develop a scientifically credible modeling facility that will help policy makers and analysts understand the effects of human activities on climate change and variability as well as the possible human responses and adaptations to climate change and variability. The overall connections among the modeling elements listed above are shown schematically below.



Progress Summary/Accomplishments: Progress is described below, divided into three categories, following the three main modeling activities.

Long-Run Electricity Demand Response to Climate Warming (F. Joutz and C. Crowe, George Washington University)

The short-run statistical analyses summarized in the previous year's progress report reflected changes in equipment utilization. Long-run shifts in capital stock that could result from consumers shifting to more energy efficient space conditioning equipment or from greater adoption of air conditioning could not be considered in such analyses. Relative to short-run changes to a given temperature increase, long-run changes could either be larger (if more installations of air conditioning occur) or smaller (if more efficient equipment is substituted for less efficient equipment).

To consider long-run cooling electricity demand and technology choice in response to climate change, it is necessary to use a model that allows capital stock to be a variable. Using the residential, commercial, and industrial electricity demand modules of the National Energy Modeling System (USEIA, 2003), we considered the effects of an increase in summer temperatures of 2°F, 3°F and 6°F by 2025. These low, mid-range and high scenarios produced increases in U.S. residential space cooling demand of 10%, 14% and 33%. Overall residential energy demand increased by 1%, 2% and 5% for the three scenarios. There was no corresponding change in commercial or industrial demand.

Under climate warming, the residential energy mix in 2025 included a higher percentage of renewable sources, particularly geothermal heat pumps. The low, mid-range and high scenarios produced increases in energy derived from geothermal heat pumps of 3%, 4% and 10%. Again, there was no corresponding change for the commercial or industrial sectors. This is part because these latter modules assume a 30% discount rate for new appliance technology adoption, reflecting the historically high payback requirements for energy efficiency investments. However, education and "market transformation" initiatives such as USEPA's "Energy Star" program might shift the required paybacks downward. Reducing this discount rate may produce an increase in renewable energy demand outside the residential module. We are investigating several other specification parameters, seeking to identify elements of the residential and commercial energy consumption models that are "hard-wired" into NEMS, or are otherwise not free to adjust with the forecast.

We are developing disaggregated responses by NERC/Electric region. This requires an additional procedure beyond the NEMS forecasts, as the U.S. census regions used in NEMS differ somewhat from the NERC/Electric regions. It will also be necessary to disaggregate the demand responses by load demand period for use in the electricity market simulation models.

Short-Run Electricity Market Response to Changed Temperatures and Demands (B.F. Hobbs and Y. Chen, The Johns Hopkins University)

The objective of this analysis is to update the analysis of temperature sensitivity on electric sector pollution emission based on the load temperature sensitivities provided by the research group from George Washington University and assumed changes in electric generator efficiency as a result of temperature increases. The focus is on the short-run (fixed generation installations) response of the Pennsylvania-Jersey-Maryland system.

Procedures of Analysis. The assumed sensitivities of generator characteristics (MW(e) capacity and MBTU/kWh heat rate) to temperature changes are the same as in previous progress reports. we perform episode analysis by the following steps:

1. Including the regional NO_x trading cap in our model, our analysis focuses on the ozone season of May 1 to Sep. 30, 2000, a total of 3,672 hours. Excluding for the 3-day ozone episode period considered in the 2nd step, the load distribution of remaining 3,600 hours is approximated by five load periods. The PJM market operation is determined separately within each of those periods in a later step. The peak period has 60 hours, while the other periods have 885 hours each. Together with the 72 periods (one for each hour) for the episode days, our model includes 77 periods. These loads are assigned to each of 14 nodes in an aggregated PJM network.
2. We assessed candidates for ozone episodes by looking at 3-day moving averages of temperature in Philadelphia and Washington DC during July and August of 2000. With a moving average of 82˚ F, we select Aug. 7 to Aug. 9, 2003, a span of 72 hours, as our episode period.
3. The year 2000 loads obtained from PJM website serve as the base case loads. To construct a load scenario under climate warming, we increase the base-case load by hourly-and-node specific factors calculated by George Washington University group (see previous progress reports). The resulting loads represent our climate-sensitive load.
4. We then apply a least-cost production costing linear programming model, constructed in years 1 and 2 of this project, to simulate the PJM market response to the assumed loads. This assumes that the market is reasonably competitive, which the PJM Market Monitoring Unit confirms was the case for that year. As a check, we also simulated oligopolistic (Cournot) outcomes for that period, and found that the actual prices in 2000 were most consistent with competitive conditions.[1] The outputs of the market simulation model include generator output by source and time period (MW), and each generator's NO_x and SO_2 emissions by time period (tons).

Summary of Results. We summarize the impact of a 2 ˚ F increase in ambient temperature on pollution emission for ozone season in next sections. In particular, we look at the overall impact on entire ozone season as well as the hourly emission change during the hypothesized 3-day episode.

The updated load sensitivity shows that the overall impact on ozone season is an average of 4.3% increase of load over 2000 ozone season as a result of a 2 °F increase in ambient temperature. This increase of demand leads to no change of total NO_x emissions—by definition—since emissions are capped. However, substantial impacts on fuel cost are observed among scenarios. The increase in fuel cost compared with the base scenario is 21%, 0.4% and 22% as a result of load increase alone,

[1] Or, equivalently, were closest to prices assuming that generators in PJM were heavily forward contracted, which dampens incentives to restrict output and raise prices in the forward market. This was indeed the case with PJM generators in 2000, which accounts for the relative competitiveness of that market relative to California in that year. Chen and Hobbs (2004) describe the competitive and oligopoly simulations of PJM under the NO_x cap for the year 2000 ozone season.

deterioration in generator efficiency due to temperature, and both effects together, respectively for the entire ozone season.

Turning to the three day assumed ozone episode, Figure 1 shows the sum over nodes of loads for the 3-day episode period. Table 1 summarizes the emissions and fuel cost impacts. The impacts due to load changes are orders of magnitude greater than the impacts due to changes in generator efficiency. Note that for this three day period, NOx emission impacts are not zero, because emissions are capped only for the entire ozone season, and not for particular days. NO_x emissions have increased during this time, implying that emissions at other times are lower in order to meet the overall cap.

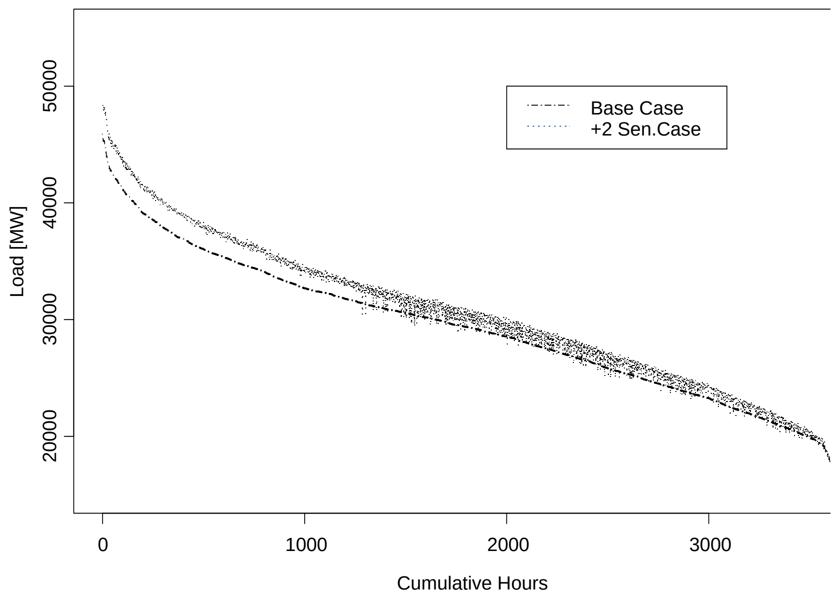


Figure 1. Load Profile over 3-Day Episode Period (Aug 7 – 9)

Table 1. Electricity Demand and Generators Performance Impact Relative to Base Case for Three Day Ozone Episode, Assuming 2 ^{o}F Temperature Increase

Impact\Category	NO_x Emission	SO_2 Emission	Fuel Cost
Demand Impact	5%	5.5%	19.9%
Generators Performance Impact	0.076%	-0.001%	0.25%
Joint Impact	4.9%	5.4%	20.3%

Figure 2 illustrates the hourly emissions impact during our three-day episode period, where the left graph represents the NO_x emission and right one is for SO_2 emission. The climate change scenario is the joint impact of load increase and generators' efficiency deterioration due to the ambient temperature increase. The average impact is 4.9% and 5.4% for NO_x and SO_2, respectively. While most NO_x emission increases occur during peakload hours, i.e., day time, the increase of SO_2 emission tends to occurs during both day and night time.

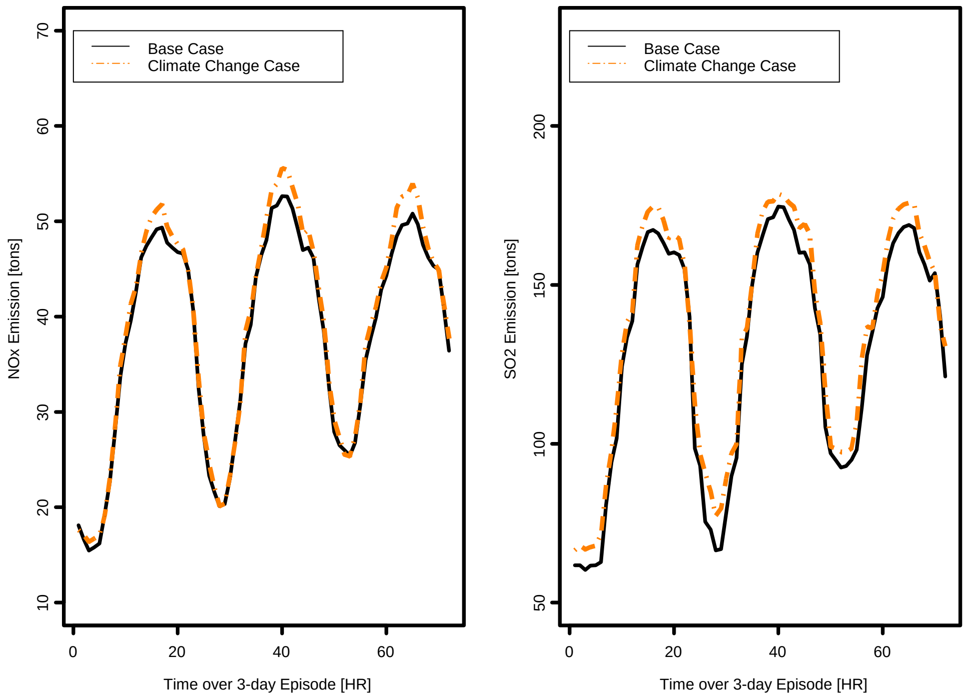


Figure 2. NO_x and SO_2 Emissions Impact during Three-Day Episode Period, PJM

Figure 3 further decomposes the aggregate emissions impact of the three-day episode into state-level results. In terms of NO_x emissions, the greatest tonnage impact occurs in Maryland and Pennsylvania, amounting to 6.3 % and 3.3% increases compared with base case, respectively. The percentage increases for NO_x in Delaware and New Jersey is 10.1% and 3.5%, respectively, but the tonnages involved are much smaller than the other states. Among states, the SO_2 tonnage impact is highest in Pennsylvania and lowest in Maryland.

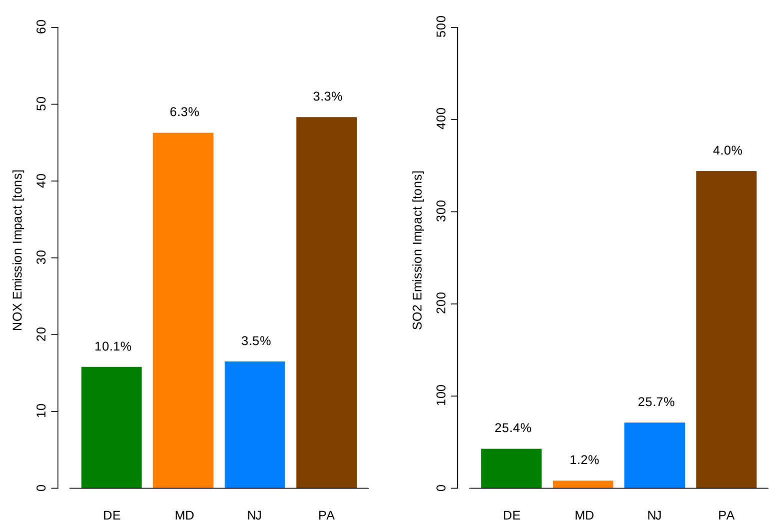


Figure 3. State-Level Impact of 2 ^{o}F Warming during 3-Day Episode

Analysis of Renewable Portfolio, Emissions Cap, and Green Pricing Tradeoffs. There are a range of policies in place to limit the environmental impacts of the electric power sector, and which might act to mitigate the effects of climate warming upon the sector's emissions. An analysis of their interacting effects was conducted using the PJM oligopoly model to better understand how the policies affect costs and emissions, particularly if generators engage in strategic behavior in the various markets.

Renewable portfolio standards and green pricing programs are two distinct approaches in power markets for promoting renewable generation. The cost of emissions allowances can also be an incentive to install renewables. The renewable portfolio standard is a mandatory requirement that a fixed percent of power delivered to customers from suppliers (or load service entities, LSE) has to be from renewable sources. In contrast, green pricing programs offer a voluntary opportunity for customers with a higher willingness-to-pay associated with environmental good to pay a premium to procure their power from renewable sources. An emerging issue is the interaction of green pricing programs, renewable portfolio standards and allowances markets. Such interactions can possibly decrease the competiveness of power markets, and induce inefficiencies and welfare loss. An oligopolistic equilibrium model based on a complementarity formulation was applied to investigate such interactions. In the model, renewable generation is modeled as a differentiated product for which consumers have a demand curve, with assumed cross-elasticities relative to the demand for so-called "grey" (nonrenewable) energy. The renewable portfolio standards are formulated as a coupled constraint imposed over the compliance period with tradable credits. Suppliers with a substantial capacity share are designated as strategic players in the respective markets, exercising a Cournot strategy, while the remaining capacity is treated as a competitive fringe.

The application was to the USEPA NO_x Budget Program and PJM market during the 2000 ozone season, using the same input data as used in the climate impact analysis. The results show that total energy consumption is constrained by renewable generation due to renewable portfolio standards. Substantial market power can be introduced if a supplier simultaneously exercises market power in the renewable and conventional power market. In comparison to a scenario in which suppliers only possess market power in the conventional power market, the power prices are higher given Cournot suppliers concurrently exercise market power in both power markets. However, the NO_x allowance price is lower since the market power in renewable market suppresses the demand for allowances.

Regional Air Pollution Modeling and Health Effects Characterization – J.H. Ellis

There have been dramatic changes in the system with which we generate ambient air concentration fields for use in this project. This has had positive and negative effects, with the former far outweighing the latter. First the negative effect – making the new system operational has been very time and labor intensive and has slowed year three progress in this portion of the project considerably. The benefits associated with this development are, however, very large and very wide-ranging.

Prior to this year, we were restricted (both hardware and software-driven) to performing limited duration scenarios (on the order of several days long) and limited (spatial) domain scenarios. We now can successfully generate continental US scenarios for any arbitrary run length. For example, we completed several months ago a suite of scenarios using MM5/MCIP/SMOKE/CMAQ for the entire US and the period May 1 through September 30 for 1990-1999 and 2050-2059 (this latter group of ten years of ozone season simulations used GISS output as input to regridder in MM5). In MM5, these runs were first made for a 108km domain, then nested to 36km, which was subsequently fed to MCIP, SMOKE and CMAQ.

Most recently, we re-ran the MCIP analyses to produce MCIP output files sufficiently small (i..e., daily) that NCO data extraction utilities (e.g., ncks) would function. The issue here was extraction of surface temperature data required in the energy demand and distribution analyses described above.

Specifics regarding the new hardware system follow:

- master node (dual Xeon CPU, 3Gb memory, 800 Gb U320 SCSI internal disk capacity, dual gigabit ethernet, 200/400Gb LTO-2 tape backup)
- 40 compute nodes (each with dual Xeon CPU, 1Gb memory, 150Gb U320 SCSI internal disk capacity, gigabit ethernet)
- 4 network-attached storage devices (each with single P4 CPU, 1Gb memory, 1000Gb fast IDE disk capacity, gigabit ethernet)
- master node-attached 2100Gb U320 SCSI disk array
- 24 port managed gigabit ethernet switch (private, secure network)
- two 16 port unmanaged gigabit ethernet switches
- two 32 port KVM (keyboard-video-mouse) switches
- two 42U rack mount enclosures
- seven 3000VA UPS
- cat5 KVM extenders (allowing multiple displays to control the cluster)
- Portland Group f77, f90 and cc compilers, NCAR Graphics, PAVE Visualization System, MPI
- Linux RedHat9.0 operating system

We recently applied for and were awarded $20K by the Engineering School to create a computer room dedicated to this machine (seven 30A circuits, 60000 BTU/hr cooling capacity - the cluster is noisy and it is hot). This renovation work will commence mid-August 2004 (until now, we have been making do with a large window AC unit in the existing Ellis computing lab).

On the software side of the ledger, all of the SMOKE and CMAQ analyses are now performed one day at a time (MM5 is still run as a single large job – a five month, US-wide run produces an MM5 output filesize of about 70GB). I have benefited greatly from the generous assistance of Christian Hogrefe in making this software operational (it was he who originally provided me the various daily scripts that I subsequently modified for this work). As well, my colleagues at Columbia University/NASA have been extremely helpful in providing and making operational the GISS output used for future year runs (thanks to Cynthia Rosenzweig, Barry Lynn, Rick Healy and Richie Goldberg).

The coming months look to be very productive. We are now interfacing the energy demand modeling and distribution results with the regional air pollution system and will be positioned come

September to perform an extensive series of experiments that we think will represent a definitive statement regarding climate change effects on energy demand, energy distribution, ambient air quality and resulting health effects.

References

Y.H. Chen and B.F. Hobbs, “An Oligopolistic Power Market Model with Tradable NO_x Permits,” *IEEE Transactions on Power Systems*, revision in process.

US Energy Information Agency, National Energy Modeling System, documentation available at www.eia.doe.gov.

Journal Publications

M. L. Bell and J. H. Ellis, Sensitivity analysis of tropospheric ozone to modified biogenic emissions for the Mid-Atlantic Region, Atmospheric Environment, 38(13), pp1879-1889, 2004.

M.L. Bell and J. H. Ellis, Comparison of the 1-Hour and 8-Hour National Ambient Air Quality Standards for Ozone Using an Air Pollution Modeling System, Journal of Air and Waste Management, Volume 53, December 2003, pp1531-1540.

M.L. Bell, B.F. Hobbs and J.H. Ellis, Metrics Matter: Conflicting Air Quality Rankings from Different Indices of Air Pollution, Journal of the Air and Waste Management Association, accepted, June 2004.

Y.H. Chen and B.F. Hobbs, “An Oligopolistic Power Market Model with Tradable NO_x Permits,” *IEEE Transactions on Power Systems*, revision in process.

Y.H. Chen, B.F. Hobbs, T. Munson, and S. Leyffer, “A Large Scale MPEC Model of Stackelberg Leader Behavior in the Electricity, Transmission, and Allowances Market,” *Computational Management Science*, to be submitted.

C. Crowley and F.L. Joutz ,“Hourly Electricity Loads: Temperature Elasticities and Climate Change.” (2003) in Proceedings: IAEE 23rd North American Conference, Mexico City, October 2003

C. Crowley and F.L. Joutz , “Hourly Electricity Loads: Temperature Elasticities and Climate Change.” (updated version, 2004) submitted to Energy Studies Review, returned for revisions, July 2004

Presentations

Y.H. Chen and B.F. Hobbs, “Interaction of Oligopolistic Transmission Portfolio Standards, Green Gricing Programs, & Emission Allowances”, 24th Annual North American Conference of the US Association for Energy Economics and International Association for Energy Economics, July 8 - 10, 2004, Washington, DC

C. Crowley and F.L. Joutz, “Residential Energy Consumption: Longer Term Response to Climate Change,” 24th Annual North American Conference of the US Association for Energy Economics and International Association for Energy Economics, July 8 - 10, 2004, Washington, DC

C. Crowley and F.L. Joutz, “Hourly Electricity Loads: Temperature Elasticities and Climate Change,” 23rd International Association for Energy Economics, North American Conference / VI Congreso Anual de la AMEE, October 19-21 2003, Mexico City

Y.H. Chen and B.F. Hobbs, “An Oligopolistic Electricity Market Model with Tradable NOx Permits,” 23rd International Association for Energy Economics, North American Conference / VI Congreso Anual de la AMEE, October 19-21 2003, Mexico City

Y.H. Chen, B.F. Hobbs, and F.A.M. Rijkers, “US NO_x Permits and BE-NL Market Integration: Applications of Complementarity Oligopoly Power Models,” Annual Meeting, Institute for Operations Research and Management Science, Atlanta, GA, Oct. 19-23, 2003.