The Impacts of Greenhouse Gas Mitigation Policy Options on the Pennsylvania State Economy

by

Adam Rose*, Dan Wei, and Noah Dormady

School of Policy, Planning, and Development, University of Southern California

Abstract

The Pennsylvania Climate Action Plan (CAP) is the culmination of a formal stakeholder process to specify policies and measures to mitigate emissions of greenhouse gases (GHGs). The implementation of technical and behavioral mitigation options will require changes in the way businesses and government operate, and the way households conduct their daily lives. An important question is whether the sum of all of these microeconomic changes and their interactions will be a stimulus to or a drain on the economy as whole. We apply the Regional Economic Models, Inc. Policy Insight Plus (REMI PI+) Model in an innovative manner to analyze the impacts of major GHG mitigation options at the macroeconomic level in Pennsylvania for the policy horizon of 2009-2020. Our results indicate that the net impacts on the State's economy will be significantly positive. We also develop a reduced form econometric model based on the results and subject it to rigorous statistical testing. This is the first time an independent validation of this kind has been applied to the REMI Model in order to verify its simulation results.

INTRODUCTION

The Pennsylvania Climate Change Act (Act 70) was signed into law in 2008. A Climate Change Advisory Committee (CCAC) was established immediately after the passage of the bill to facilitate the development of a plan to mitigate greenhouse gasses (GHGs) in cooperation with the Pennsylvania Department of Environment Protection (PA DEP).[1] The ensuing *Pennsylvania Climate Action Plan* (PA DEP, 2009) specified a broad set of mitigation options, and, in fact, identified several that result in net cost savings. For example, many electricity demand-side management practices translate into less electricity needed to produce a given outcome, such as running an assembly line or cooling a home, i.e., energy efficiency improvements. However, all of the cost estimates of mitigation work plans apply to the site of their application, or what are termed partial equilibrium economic impacts. They do not include broader general equilibrium or macroeconomic impacts. The many types of linkages in the economy and macroeconomic impacts are extensive and cannot be traced by a simple set of calculations. This endeavor requires the use of a sophisticated model that reflects the major structural features of an economy, the workings of its markets, and interactions between them.

The purpose of this paper is to present a methodology for evaluating the macroeconomic impacts of climate policy and to apply it to the evaluation of the *Pennsylvania Climate Action Plan* (CAP) on the State's economy. We use the Regional Economic Models, Inc. (REMI) Policy Insight Plus (PI+) Model (REMI, 2009), the most widely applied state-level econometric modeling software package in the U.S. The application involves the most extensive analysis of the linkages between individual mitigation

*Corresponding author: Research Professor, School of Policy, Planning and Development, University of Southern California. 230 RGL, 650 Childs Way, Los Angeles, CA, 90089. Email: adamzros@sppd.usc.edu

options and the workings of a state economy to date. It is based on mitigation data carefully estimated by an extensive stakeholder process. To validate the simulation results we develop a reduced form version of the macroeconomic analysis and test it using multivariate regression analysis.

Our results indicate that the Pennsylvania CAP will yield positive overall macroeconomic impacts on the State's economy. Greenhouse gas mitigation activities have a wide range of macroeconomic impacts. Whereas some have dampening effects on the economy, others provide significant cost savings through energy efficiency and thereby provide an economic stimulus to households and businesses. Given the range of options available in Pennsylvania, our results show that, at the macro level, the gains to the economy can exceed the losses. This is especially surprising in a state that contains several major energy sectors and an extensive industrial base. While many analysts have focused on potential losses to these sectors, our analysis has uncovered a strong potential for growth in construction and key manufacturing sectors.

This paper also represents a contribution to the literature by assessing the accuracy of one of the major regional economic analysis and forecasting models in use today. The REMI Model has been applied to analyze the total regional economic impacts of climate action plans in more than ten states and regions of the U.S., and has been applied to hundreds of other important regional and national policy issues over the course of its history. However, this paper provides the first rigorous multivariate statistical test of its results with respect to the consistency between the model outputs and the direct policy variable changes. REMI and other various regional macroeconomic models have been rigorously evaluated and validated in the literature. To date, our analysis represents a unique addition to this important research. Rickman and Schwer (1993; 1995a; 1995b) conduct thorough evaluations of the REMI model by comparing its multipliers with those of other benchmark multipliers (IMPLAN and RIMS II) to determine the causes of variance in multipliers. Other scholars have conducted error analysis to evaluate REMI model outputs by comparing them with other input-output/econometric integration methods (Rey, 1997; Rey, 1998). REMI has also been tested for its consistency across regions for equivalent simulations (Cassing and Giarratani, 1993). There are also a number of studies in the literature designed to evaluate the predictive accuracy of the REMI model by testing the prediction errors in post-sample period forecasting (Treyz et al., 1991; Cassing and Giarratani, 1993). Our analysis moves beyond error analysis to validate, through multivariate econometric analysis, both the explanatory power of the REMI model and consistency of its output with regard to policy variables. This validation method can readily be generalized to many future applications of the REMI Model, as well as other regional macro models.

This paper is divided into 6 sections. Section 2 introduces the REMI Model. Section 3 presents an overview of the input data we use in the REMI simulations. Section 4 presents the simulation results and the interpretation of results. Section 5 develops a reduced form model that tests the REMI results using multivariate regression. Section 6 provides a summary of the results.

II. REMI MODEL ANALYSIS

To conduct a macroeconomic analysis of this scope, including both direct (on-site) effects and various types of indirect (off-site) effects, several modeling approaches are available. These include input-output (I-O), computable general equilibrium (CGE), mathematical programming (MP), and macroeconometric (ME) models. Each of these approaches has its own strengths and weaknesses (see, e.g., Rickman and Schwer, 1995; Rose 1995; Partridge and Rickman, 2010). Depending upon the relative importance of various criteria, researchers will choose the approach that provides the best modeling performance, in terms of a balance of various performance criteria, such as accuracy, transparency, manageability and costs. After careful consideration of these criteria, we have selected the

REMI PI^+ Model. The REMI Model is superior to others reviewed in terms of its forecasting strengths,[2] and it is comparable to CGE models in terms of its accuracy and analytical power. Also, it can be made as transparent as any of the other models with careful explanation of the model, its application and its results.

The REMI Model has evolved over the course of 30 years of refinement (see, e.g., Treyz, 1993). It is a (packaged) program, but is built with a combination of national and region-specific data. Government agencies in practically every state in the U.S. have used a REMI Model for a variety of purposes, including evaluating the impacts of the change in tax rates, the exit or entry of major businesses in particular or economic programs in general, and, more recently, the impacts of energy and/or environmental policy actions (see, e.g., Miller et al., 2010).

We simply provide a summary for general readers here. A macroeconometric forecasting model covers the entire economy, typically in a "top-down" manner, based on macroeconomic aggregate relationships such as consumption and investment. REMI differs somewhat in that it includes some key relationships, such as exports, in a bottom-up approach. In fact, it makes use of the finely-grained sectoring detail of an I-O model, i.e., in the version we used it divides the economy into 169 sectors, thereby allowing important differentials between them. This is especially important in a context of analyzing the impacts of GHG mitigation actions, where various options were fine-tuned to a given sector or where they directly affect several sectors somewhat differently.

The macroeconomic character of the model is able to analyze the interactions between sectors (ordinary multiplier effects) but with some refinement for price changes not found in I-O models. The REMI PI^+ Model also brings into play features of labor and capital markets, as well as trade with other states or countries, including changes in competitiveness.

The econometric feature of the model refers to two considerations. The first is that the model is based on inferential statistical estimation of key parameters based on pooled time series and regional (panel) data across all states of the U.S. (the other candidate models use "calibration," based on a single year's data).[3] This gives the REMI PI^+ model an additional capability of being better able to extrapolate[4] the future course of the economy, a capability the other models lack. The major limitation of the REMI PI^+ model versus the others is that it is pre-packaged and not readily adjustable to any unique features of the case in point. The other models, because they are based on less data and a less formal estimation procedure, can more readily accommodate data changes in technology that might be inferred, for example from engineering data. However, our assessment of the REMI PI^+ Model is that these adjustments were not needed for the purpose at hand. This is because all the selections and specifications of the technological parameters of individual mitigation work plans are undertaken in the microeconomic quantification stage (through the stake-holder and consensus-building process). They are embedded in the estimated costs and savings associated with the implementation of these work plans. Our macroeconomic analysis is built on the results of the microeconomic quantifications.

The use of the REMI PI^+ Model involves the generation of a baseline forecast of the economy through 2020. Then simulations are run of the changes brought about through the implementation of the various GHG mitigation options. Again, this includes the direct effects in the sectors in which the options are implemented, and then the combination of multiplier (purely quantitative interactions) general equilibrium (price-quantity interactions) and macroeconomic (aggregate interactions) impacts. The differences between the baseline and the "counter-factual" simulation represent the total regional economic impacts of these policy options.

III. INPUT DATA

A. MITIGATION OPTIONS

Through the development of the *Pennsylvania Climate Change Action Plan*, over 100 GHG mitigation actions covering multiple economic sectors were reviewed by CCAC and PA DEP. Finally, 52 policies and measures, called "work plans" in the Pennsylvania process, were recommended and approved,[5] among which 42 work plans/measures were analyzed in a quantitative manner.[6] Table 1 lists the micro level impacts (GHG reductions and cost-effectiveness) of implementing each quantified work plan. In total, they can generate $8.6 billion net cost savings (NPV in 2007$)[7] and reduce GHG emissions of 570.9 million tons of carbon dioxide equivalent (MMtCO2e) during the 2009-2020 period. The weighted average cost-effectiveness (using GHG reduction potentials as weights) of the work plans is about $5.3 per ton of CO2e emissions removed.

B. MODELING ASSUMPTIONS

The major data sources of the analysis are the Subcommittees' quantification results or their best estimation of the cost/savings of various recommended work plans/policies. However, we supplement these with some additional data and assumptions in the REMI analysis in cases where these costs and some conditions relating to the implementation of the work plans are not specified by the Subcommittees or are not known with certainty. These additional assumptions are necessary since, for example, in the micro-quantification only the total amount of capital investment needed for individual work plans are estimated. In the macroeconomic modeling, we need to specify both the source of the investment (private or public) and the economic sectors that would be directly stimulated by the investment. The additional assumptions used in the macroeconomic analysis were made through discussions with the sectoral experts from the Subcommittees (see Rose et al. (2011) for the list of the major assumptions we adopted in the analysis).

IV. PRESENTATION OF THE RESULTS

The basic results from our REMI Model macroeconomic analysis are presented in Table 2. These include the macroeconomic impacts from individual *Pennsylvania Climate Action Plan* mitigation work plans. Table 2 includes the Gross State Product (GSP) impacts for each work plan for three selected key years, and also provides a net present value (NPV) calculation for the entire period of 2009 to 2020.[8]

The NPV total GSP impact for the period 2009-2020 is about $5.05 billion (constant 2007 dollars) with the impacts being negative in 2010 and increasing steadily over the years to an annual high of $2.14 billion in 2020. In that year, the impacts represent an increase of 0.31% in GSP in the State.

Table 2 highlights several important points:

- The macroeconomic impacts of 27 of the 42 work plans are positive, which means implementing these work plans will bring about a positive stimulus to the Pennsylvania economy by increasing GSP and creating more jobs.
- Work plans Res/Com-5 (Commission Buildings) and Industry-2 (Industrial Natural Gas and Electricity Best Management Practices) yield the highest positive impacts on the economy—a total NPV of $4.94 billion; work plan Electricity-9 (Combined Heat and Power) results in the highest negative impacts to the economy—an NPV of -$3.24 billion.

TABLE1: Estimated GHG Reductions and Costs/Savings of the 42 Quantified Mitigation/Sequestration Work Plans[9]

Work Plan No.	Work Plan Recommendation	GHG Reductions (MMtCO2e)			Net Present Value 2009-2020 (Million $)	Cost-Effective-ness ($/tCO2e)
		2020	% of 2020 BAU Level	Total 2009-2020		
Ag-3	Management Intensive Grazing	0.6	0.21%	5.5	-$387.37	-$70.43
Ag-4b	Manure Digester Implementation Support--Swine	0.04	0.10%	0.23	$1.13	$4.91
Ag-5a	Regenerative Farming Practices	0.1	0.02%	0.3	$17.86	$59.53
Ag-5b	Carbon Sequestration from Continuous No-Till	0.4	0.15%	2.7	-$32.30	-$11.96
F-1	Forest Protection Initiative – Easement	0.2	0.06%	12.2	$70.92	$5.81
F-3	Forestland Protection and Avoided Conversion – Acquisition	2.1	0.72%	22.6	$620.43	$27.45
F-4	Reforestation, Afforestation, Regeneration	4.0	1.35%	25.9	$597.17	$23.06
F-7	Urban Forestry	3.0	1.01%	19.4	$1,704.55	$87.86
F-8	Wood to Electricity	0.3	0.09%	1.7	$2.95	$1.74
F-9a	Biomass Thermal Energy Initiatives--Combined Heat and Power	0.5	0.16%	3.0	-$159.05	-$53.02
F-9b	Biomass Thermal Energy Initiatives--Fuels for Schools	0.6	0.21%	4.0	$48.28	$12.07
E-3	Stabilized Load Growth	2.8	0.93%	8.2	-$254.68	-$31.06
E-5	Carbon Capture and Sequestration in 2014	5.0	1.70%	12.6	$391.08	$31.04
E-6	Improve Coal-Fired Power Plant Efficiency by 5%	5.4	1.83%	55.4	-$822.53	-$14.85
E-7	Sulfur Hexafluoride (SF6) Emission Reductions from the Electric Power Industry	0.1	0.03%	0.7	$0.29	$0.41
E-9	Promote Combined Heat and Power (CHP)	4.4	1.47%	23.2	$209.20	$9.02
E-10	Nuclear Capacity	14.7	4.96%	31.0	$233.07	$7.52
RC-5	Commission Buildings	1.5	0.51%	9.6	-$70.53	-$7.35
RC-6	Re-Light PA	12.9	4.35%	103.2	-$4,044.07	-$39.19
RC-7	Re-Roof PA	1.4	0.49%	4.3	$1,012.88	$235.55
RC-8	Appliance Standards	1.9	0.64%	12.4	-$290.84	-$23.45
RC-9	Geothermal Heating and Cooling	1.4	0.48%	8.0	$499.75	$62.47
RC-10	DSM - Natural Gas	7.3	2.48%	40.5	-$357.12	-$8.82
RC-11	DSM - Heating Oil and Biofuel for Heat	5.7	1.93%	35.8	$207.57	$5.80
RC-13	DSM - Water	0.1	0.04%	0.8	-$1,011.38	-$1,264.23
Ind-1	Coal Mine Methane (CMM) Recovery	0.6	0.19%	6.4	-$51.80	-$8.09
Ind-2	Industrial NG & Electricity Best Management Practices	5.1	1.74%	25.3	-$972.27	-$38.43
Ind-3	Reduce Lost and Unaccounted for Natural Gas	0.1	0.05%	0.9	-$47.57	-$52.86
W-1	Landfill Methane Displacement of Fossil Fuels	0.1	0.03%	0.6	-$10.26	-$17.10
W-2	Statewide Recycling Initiative	5.4	1.84%	34.4	-$258.38	-$7.51
W-4	Improved Efficiency at Wastewater Treatment Facilities	0.0	0.00%	0.0	-$3.41	-$148.10
W-5	Waste-to-Energy Digesters	0.1	0.03%	0.6	$6.97	$11.62
W-6	Waste-to-Energy MSW	0.2	0.08%	1.4	-$65.79	-$46.99
T-3	Low Rolling Resistance Tires	0.7	0.23%	4.1	-$818.34	-$199.60
T-5a	Eco-Driving 5A PAYD Insurance	0.4	0.15%	1.8	-$665.10	-$369.50
T-5b	Eco-Driving 5B Feebates	0.4	0.14%	2.7	-$532.83	-$197.34
T-5c	Eco-Driving 5C Driver Training	0.6	0.21%	4.5	-$375.74	-$83.50
T-5d	Eco-Driving 5E Tire Inflation	0.1	0.03%	0.6	-$90.22	-$150.37
T-5e	Eco-Driving 5H Speed Limit Reduction	2.0	0.66%	23.0	$6,790.96	$295.26
T-6	Utilizing Existing Public Transportation Systems	0.1	0.02%	0.6	$2,157.51	$3,595.85

Work Plan No.	Work Plan Recommendation	GHG Reductions (MMtCO2e) 2020	% of 2020 BAU Level	Total 2009-2020	Net Present Value 2009-2020 (Million $)	Cost-Effective-ness ($/tCO2e)
T-8	Cutting Emissions from Freight Transportation	1.0	0.34%	6.7	-$956.35	-$142.74
T-9	Increasing Federal Support for Efficient Transit and Freight Transport in PA	1.2	0.40%	12.9	$724.64	$56.17
Total		**94.7**	**32.06%**	**570.9**	**$3,019.28**	**$5.29**

Source: PA DEP (2009).

- Mitigation work plans from the Residential and Commercial sector and the Industrial Sector would yield the highest positive impacts on the economy, followed by the work plans from the Agriculture sector and Waste Management sector.

A majority of the work plans generate positive GSP impacts because they are cost-saving. These work plans lower costs throughout all levels of production and increase the purchasing power of consumers in Pennsylvania. Overall, these have a stimulating effect on the macroeconomy. The savings come from direct reductions in fuel and electricity costs, as resources are used in a more efficient manner. The stimulus effects also come from the increased investment in plant and equipment, the associated multiplier effects with the initial investment, and the payback on initial investment in more efficient technologies. The regional economy is also boosted when more indigenous energy resources are utilized to produce alternative energy to replace fossil fuel energy. In other cases, some work plans result in negative GSP impacts. Even though these policies serve to reduce greenhouse gases, they provide insufficient gains in efficiency to cover the costs associated with their initial investment. In a narrow economic sense, they do not pay for themselves. These also raise the cost of production inputs or consumer goods to which they are related.[10] The negative impacts of some work plans also stem from the fact that the potential future benefits are beyond the study period of this analysis, therefore, those benefits are not counted in the macroeconomic modeling. One example is the F-4 Reforestation, Afforestation, Regeneration work plan. Since the potential future benefit from forestry products (e.g., merchantable timber or bioenergy feedstocks) would most likely be realized well beyond the terminal year (i.e., 2020) of this study, they are not considered in the analysis.

Analogous employment impacts were calculated (not shown). Of the 42 work plans in this analysis, 28 yield positive employment impacts overall. We estimate that in the year 2020 nearly 40,000 jobs (full-time equivalent) are added to the Pennsylvania workforce (or 0.52% increase from the baseline level). This is consistent with findings in the literature that investment in energy efficiency and renewable/alternative energy would result in net gains in jobs, largely because the related economic activities (such as building refurbishment and clean/renewable energy technologies) involve more labor-intensive sectors than the conventional fossil fuel supply sectors (Kammen et al., 2004; Global Insight, 2008; Pollin et al., 2009). Because the REMI model presents employment impacts in terms of annual differences from the baseline scenario, these employment impacts are not summed across years, and these results are not cumulative.[11] The simulation results indicate that work plans in the Residential and Commercial, Forestry, and Industrial sectors would create more jobs than the mitigation work plans in other sectors.[12]

A comparison between the GSP and employment impacts in percentage terms also indicates a relatively higher gain in the latter. This is because the climate investment tends to stimulate sectors that are relatively more labor-intensive compared with traditional fossil fuel supply sectors. In addition, a shift from capital to labor is expected when the cost of capital increases stemming from the higher capital costs of clean and renewable energy technologies.[13, 14]

TABLE 2: Gross State Product Impacts of the Pennsylvania Climate Action Plan

(Billions of Fixed 2007$)					
Scenario		**2010**	**2015**	**2020**	**Net Present Value**
	E3	$0.00	$0.00	$0.02	$0.01
	E5	$0.00	-$0.03	-$0.12	-$0.21
	E6	$0.04	$0.10	$0.13	$0.71
	E7	$0.00	$0.00	$0.00	$0.00
	E9	-$0.03	-$0.41	-$0.94	-$3.24
	E10	$0.00	-$0.01	-$0.18	-$0.14
Subtotal - Electricity		$0.00	-$0.35	-$1.10	-$2.88
	I1	$0.01	$0.01	$0.01	$0.06
	I2	$0.00	$0.25	$1.06	$2.47
	I3	$0.00	$0.02	$0.04	$0.12
Subtotal - Industrial		$0.01	$0.28	$1.11	$2.66
	RC5	$0.03	$0.31	$0.75	$2.47
	RC6	-$0.04	$0.28	$0.95	$1.98
	RC7	$0.00	-$0.04	-$0.31	-$0.57
	RC8	$0.00	-$0.02	-$0.02	-$0.10
	RC9	$0.01	$0.07	$0.18	$0.54
	RC10	$0.05	$0.28	$0.35	$1.85
	RC11	$0.13	$0.13	$0.09	$0.98
	RC13	$0.01	$0.05	$0.08	$0.35
Subtotal - Res/Com		$0.17	$1.06	$2.07	$7.50
	F1	-$0.02	$0.00	$0.00	-$0.07
	F3	-$0.01	-$0.02	-$0.03	-$0.16
	F4	-$0.08	-$0.10	-$0.12	-$0.86
	F7	$0.00	-$0.02	-$0.06	-$0.16
	F8	$0.00	$0.00	$0.00	$0.00
	F9a	$0.02	$0.12	$0.25	$0.92
	F9b	$0.00	$0.00	-$0.01	-$0.03
Subtotal - Forestry		-$0.10	-$0.02	$0.03	-$0.37
	Ag3	$0.00	$0.04	$0.07	$0.27
	Ag4b	$0.00	$0.00	$0.00	$0.00
	Ag5a	$0.00	$0.00	$0.00	-$0.01
	Ag5b	$0.00	$0.00	$0.00	$0.02
Subtotal - Ag		$0.00	$0.04	$0.07	$0.27
	W1	$0.00	$0.03	$0.06	$0.22
	W2	$0.00	$0.02	$0.02	$0.13
	W4	$0.00	$0.00	$0.00	$0.00
	W5	$0.00	$0.00	$0.00	$0.01
	W6	$0.00	$0.00	$0.01	$0.02
Subtotal - Waste		$0.01	$0.06	$0.09	$0.39
	T3	$0.00	$0.06	$0.13	$0.43
	T5a	-$0.01	-$0.06	-$0.34	-$0.84
	T5b	-$0.01	$0.00	$0.01	$0.01
	T5c	-$0.10	-$0.10	-$0.09	-$0.77
	T5d	$0.00	$0.00	$0.01	$0.00
	T5e	-$0.58	-$0.11	-$0.11	-$1.91
	T6	-$0.11	-$0.12	-$0.13	-$0.93

(Billions of Fixed 2007$)					
Scenario		**2010**	**2015**	**2020**	**Net Present Value**
	T8	$0.00	$0.07	$0.27	$0.65
	T9	$0.10	$0.11	$0.11	$0.84
Subtotal - TLU		-$0.72	-$0.14	-$0.14	-$2.52
Summation Total		**-$0.62**	**$0.92**	**$2.14**	**$5.05**

Note: A positive number in this table indicates a positive stimulus to the Pennsylvania economy, or an increase in GSP; a negative number indicates a negative stimulus, or a decrease in GSP.

The overall results of our analysis are similar to those of some recent regional, national and international studies. Pollin et al. (2009) estimated that the net job creation effect of the American Recovery and Reinvestment Act and American Clean Energy and Security Act can be 1.7 million jobs. In a recent study by Roland-Holst (2009), the impacts of renewable energy deployment and energy efficiency improvements for the California economy, similar to those in the Pennsylvania case, are projected to be a net increase of half a million jobs and an over $100 billion increase in cumulative income by 2050. If we adjust for the relative sizes of the two state economies and the timeline of policy implementation, the results are very similar in percentage terms. Macroeconomic analyses of the climate action plans of Florida and Michigan yield similar positive impacts to the state economies (Rose and Wei, 2011; Miller et al., 2010). However, compared with Florida and Michigan, the Pennsylvania Action Plan yields relatively less favorable impacts to the state economy (0.31% increase in GSP in PA vs. 0.66% and 1.1% increases in GSP in FL and MI in the study terminal year, respectively). One major reason is that Pennsylvania uses in-state produced coal to generate large quantities of electricity. Electricity consumption reduction due to various energy efficiency work plans would result in economic activity reductions in the power generating sector, as well as the coal mining sectors in the state. In contrast, nearly 100% of the coal used in the coal-fired electricity generation in Florida and Michigan is imported. This is the major reason why the demand-side energy efficiency options are much less attractive in Pennsylvania than in the other two states. At the international level, Hanson and Laitner (2006) have found energy efficiency improvements and technological change to have positive general equilibrium impacts.

V. REGRESSION ANALYSIS

We next perform several multivariate analyses to examine the relationship between the microeconomic analysis results in the Pennsylvania Climate Action Plan and the macroeconomic impacts yielded by the REMI model. This is provided as a validation of the results of the macroeconomic analysis in general and the REMI Model in particular.

The dependent variable (Y) to be explained by the statistical analyses is the NPV of GSP impacts of individual mitigation work plans. These impacts are the outputs generated by the macroeconomic analysis of REMI, and are shaped by all of the relevant independent variables and their interactions in the macroeconomic modeling (Rose and Dormady, 2011). The dependent variable has significant variation, and values for individual mitigation options (work plans) in the Pennsylvania CAP range from negative GSP impacts of $3.2B, to positive GSP impacts of $2.4B. Negative values indicate that the REMI Model predicts that the mitigation work plan will incur negative impacts on Pennsylvania GSP, and positive values indicate positive GSP impacts.

The main explanatory variable is the direct net cost of a GHG mitigation work plan. These values are produced from technical working groups (or Subcommittees) represented by sector-specific stakeholders in Pennsylvania. A positive value indicates that the technical working group has concluded that the option will result in a direct net cost and a negative value indicates that the direct effect of the option will be cost-saving. These direct net costs vary widely between work plans. Although the simple average of direct net costs among work plans is positive (cost-incurring), a majority of work plans (55%) have negative direct costs (i.e., cost-saving).

It is important to note that there may be wide variability between macroeconomic outputs (Y) and direct net costs (X). For the 42 mitigation work plans included in this multivariate analysis, there is an overall high (negative) correlation between these two sets of values (Rho = -0.52). That is, for the most part, those work plans that are assessed to be cost-saving by Subcommittees are likely to result in positive GSP impacts from the macroeconomic analysis, while cost-incurring options will typically have the opposite effect on GSP. Also, higher cost-saving work plans are likely to result in higher positive GSP impact, while work plans with larger direct net cost tend to lead to bigger negative GSP impact.

However, this is not always the case. For the exceptions, complicating macroeconomic effects are occurring. For example, the work plan Electricity 9, Combined Heat and Power (CHP), was assessed to have a slightly positive cost (cost-incurring) direct effect of $209M, but its macroeconomic impact was estimated to have the largest overall negative impact on GSP of $3.2B. Residential 6, "Re-Light Pennsylvania," which is aimed at energy efficiency improvements in residential and commercial buildings, was identified by stakeholders to have some of the most significant GHG reduction potentials. This mitigation work plan was estimated to have a direct negative cost (cost-savings) of over $4B, but the results indicated only a smaller positive GSP impact of $1.9B, primarily due to reductions in the production of fossil-based electricity it engenders.

Between these two work plans, the variability of outcomes arises from various macroeconomic relationships that are picked up by the REMI model. Macroeconomic effects, which ripple throughout the state economy, take place as price changes, input substitutions, investment requirements, and demand shifts in one sector of the economy affect prices and output in directly and indirectly related sectors of the economy. Combined heat and power systems require significant upfront capital expenditures, which increase the capital cost of the commercial and industrial sectors that install the CHP systems. However, these investments in turn stimulate demand in other production sectors. Likewise, cost savings from energy efficiency improvements increase demand in other sectors, as the upfront capital costs of efficiency improvements are quickly recouped by decreases in consumer expenditures on electricity. Also, a related tradeoff occurs from these efficiency improvements, as they lead to decreased demand from the utilities sector.

The remaining sets of explanatory variables are included mainly for statistical control and also help explain sector-specific impacts. "ES" indicates that the work plan is from the Energy Supply sector, "RCI" from the Residential, Commercial and Industrial sector, "TLU" from the Transportation and Land Use Sector, and “AFW” from the Agriculture, Forestry and Waste Management sector. These variables are all binary (dummy) variables.

Four additional explanatory variables are also included in this analysis in binary form. The first two relate to the capital investment associated with the work plan. "CONST" indicates that the work plan involves a capital investment in construction (e.g. building a new power plant). "MFG" indicates that the work plan represents a capital investment in equipment or appliances manufacturing. "GS" indicates that the work plan receives a state government subsidy.[15] And finally, "CR" indicates that the work plan results in consumer consumption reallocation, such as reducing spending on electricity, gas, and other fuels, and increasing consumption in energy-efficient appliances and other consumption categories.

Because of the significant variance in both Y and X, some of the key assumptions of the classic linear regression model are more closely achieved through a minor transformation of the data, specifically a cubic root transformation of both of these terms. This enables us to retain Gaussian parameterization across our dependent variable, lessen any statistically-significant heteroskedastic error variance,[16] retain the full range of estimation across both positive and negative values (which is not possible with logarithmic transformation), and add four interaction terms. The cubic root of direct net costs (X) is placed in a multiplicative interaction term with each of the four aggregate sectors of the climate action plan (ES, RCI, TLU, and AFW). This allows us to assess the marginal impact of direct costs associated with each subgroup's GHG mitigation work plans. The functional form of our preferred estimating equation is:

$$\sqrt[3]{Y} = \beta_1 \sqrt[3]{X} * ES + \beta_2 \sqrt[3]{X} * RCI + \beta_3 \sqrt[3]{X} * TLU + \beta_4 \sqrt[3]{X} * AFW + \beta_5 ES + \beta_6 RCI + \beta_7 TLU + \beta_8 AFW + \beta_9 CONST + \beta_{10} MFG + \beta_{11} GS + \beta_{12} CR$$

where

Y:	NPV of the GSP impacts of a work plan
X:	NPV of the direct net cost of a work plan
ES:	Energy Supply work plan
RCI:	Residential, Commercial, Industrial work plan
TLU:	Transportation and Land Use work plan
AFW:	Agriculture, Forestry, and Waste Management work plan
CONST:	Capital investment on building constructions, which has stimulus impacts to the local construction sector
MFG:	Capital investment on equipment, which has stimulus impacts to the machinery and equipment manufacturing sectors
GS:	Work plan that receives state government subsidy (assuming government spending decreases by the same amount elsewhere)
CR:	Work plan that results in consumer consumption reallocation

Table 3 provides the results of our multivariate statistical analysis. We ran both a reduced form model (Model 1) and an extended model (Model 2), which includes interaction terms to evaluate the individual sectoral impacts of the direct net costs associated with GHG mitigation work plans. Furthermore, our assumption that the regression coefficient for each sector is statistically distinct from the sectors in the aggregate is affirmed. Comparing across these interaction terms, one can see that the energy supply sector has the largest absolute impact on the macroeconomic impacts compared to the other sectors and the aggregate. Cost-saving (cost-incurring) work plans associated with the energy supply sector result in larger positive (negative) GSP impacts because of the nature of electricity supply policy options. These options result in either large costs or cost savings to both the energy sector and related manufacturing and construction sectors, which have large multiplier effects on the Pennsylvania economy.

Overall, Model 2 has strong summary and fitness measures, as indicated by large R-squared and F-statistic values. The model explains over 70 percent of the variance in the dependent variable. Of note is the exclusion of an intercept term in both OLS models. Exclusion of an intercept term for these models is warranted, because the dependent variable is the rate of change in GSP given policy changes within the state. We assume that, prior to any GHG mitigation/sequestration policies, the state economy is in equilibrium, and there would be no change in the trajectory of GSP overall, except from exogenous and stochastic events beyond the scope of this analysis[17].

TABLE 3: Regression Analysis

	Model 1 OLS	Model 2 OLS
$\sqrt[3]{X}$	-0.53*** [-4.45]	
$\sqrt[3]{X} \times TLU$		-0.44*** [-3.69]
$\sqrt[3]{X} \times ES$		-1.54*** [-6.00]
$\sqrt[3]{X} \times RCI$		-0.58* [-2.11]
$\sqrt[3]{X} \times AFW$		-0.22 [-0.98]
ES	-4.35 [-1.33]	-5.52* [-2.23]
RCI	3.54 [1.50]	1.61 [0.57]
TLU	1.41 [0.54]	1.32 [0.64]
AFW	1.23 [1.02]	0.34 [0.30]
CONST	2.89 [1.32]	5.60* [2.53]
MFG	1.47 [0.77]	2.43 [1.37]
GS	-4.74* [-2.39]	-5.01* [-2.41]
CR	-1.96 [-1.09]	-2.43 [-1.46]
R^2	0.62	0.72
F	21.25***	16.84***
N	42	42

* <0.05, **<0.01, ***<0.001. T values in brackets. OLS Model t-values based on White's robust standard errors.

Among sectoral coefficients, the strongest and most statistically significant impacts come from the energy sector itself. Its coefficient indicates that its macroeconomic impacts are nearly five hundred percent larger than other sectors. This sector also has the largest marginal impact of direct costs, and by comparison between Model 1 and Model 2, it is approximately three times larger than the expected direct net cost impact of all sectors combined. The AFW and TLU sectors have the smallest macroeconomic impacts overall, and the direct net cost of TLU sector work plans is highly statistically significant.

The coefficient estimates of the two capital investment variables, investment for construction and investment in machinery and equipment, are both positive, and construction investment is statistically significant. Simulating capital investment change in REMI involves two aspects: the increase of the capital cost of the sectors that take the mitigation actions and the increase of the final demand in the construction and machinery and equipment manufacturing sectors. In general, the former yields negative impacts to the economy, and the latter yields positive impacts. The positive signs of the two capital investment dummy variables indicate that the positive effects are expected to exceed the negative effects in PA.

The estimated coefficient of GS is -5.01. The negative sign indicates that, holding all the other variables fixed, if a mitigation work plan involves state government subsidies, its overall impact on GSP is expected to decrease by -$125.8M, or -5.01[3]. In REMI, the state government subsidy is simulated in two aspects. The stimulus effects are due to the sectors that receive the government subsidy and the dampening effects due to the decrease of the same amount of government spending elsewhere. The negative sign of this variable indicates that in PA, it is expected that the stimulus effects of directing government subsidy to the mitigation work plans cannot in general offset the dampening effects associated with the decreased government spending in other areas.

VI. CONCLUSION

This paper summarizes a detailed analysis of the impacts of the *Pennsylvania Climate Action Plan* on the state's economy. Our results are based on the REMI PI$^+$ model, a state of the art macroeconometric model, and data derived from in-depth and consensus-based technical stakeholder assessment. These results indicate that the majority of greenhouse gas mitigation or sequestration work plans have positive impacts on the State's economy. The total net results from the 42 individual work plans indicates that in the Year 2020, 38,800 full-time equivalent jobs will be added to the State's economy and the net present value of gross state product will increase by $5.05 billion.

Among these work plans, the largest gains to the State's economy come from Commissioning and Retro-Commissioning buildings and Industrial Natural Gas and Electricity Best Management Practices. Combined, these account for about 33 percent of the total gains. The largest employment gains come from Urban Forestry and Re-light PA. Combined, these account for about 45 percent of the total job creation.

Positive macroeconomic gains stem mainly from the ability of mitigation and sequestration work plans to lower the costs of production. Decreased production costs come principally from energy efficiency improvements, which enable greater production capabilities from fewer or less costly resources. Decreased spending costs on energy have positive impacts on consumer purchasing power, which has positive economy-wide impacts as those efficiency savings ripple throughout the macroeconomy. Positive economic gains also come from stimulus effects of increased investment in plant and equipment.

A further verification of our results is provided through statistical analyses. Multivariate regression analysis is used to confirm the close proximity between the combination of direct and indirect macroeconomic impacts and the direct impact assessments of stakeholders. The results of these analyses indicate that the macroeconomic impacts from the REMI model are highly robust when one controls for investment and consumption characteristics. The results represent a strong validation of the application of the REMI Model to the analysis in this paper.

Finally, it should be noted that the estimates of economic benefits from this analysis of the *Pennsylvania Climate Action Plan* represent a lower bound from a broader perspective. They do not include the avoidance of damage from the climate change that continued baseline GHG emissions would bring forth, reduction in damage from the associated decrease in ordinary co-pollutants, reduction in the use of natural resources, or reduction in traffic congestion, among others.

ENDNOTES

[1] Five Subcommittees: Energy Generation, Transmission, and Distribution; Residential and Commercial; Industry and Waste; Land Use and Transportation; and Agriculture and Forestry, were assigned by CCAC. The tasks of each subcommittee were to identify and provide technical analysis of potential GHG mitigation, sequestration, and offsetting policy actions in its respective sector.

[2] Statistically estimated time series models are best suited to forecasting, but were not among the candidates considered here because our emphasis was on policy analysis. Other widely used policy analysis models include I-O and CGE models. IMPLAN (MIG, 2011), the major provider of input-output tables generates static models, which therefore do not have a forecasting capability. Only dynamic CGE models have a projection, but not necessarily a forecasting, ability, and empirical versions at the state level are very rare. In addition, there are very few examples in the literature evaluating the predictive accuracy of the dynamic CGE models. Statistical techniques are extensively used in the equation parameters and response estimations in the REMI model. There are a number of studies in the literature designed to validate the predictive accuracy of the REMI Model (Treyz et al., 1991; Cassing and Giarratani, 1992). In these studies, post-sample period forecasts are computed. The predicted values are then compared with the actual values with the prediction error measured by the mean absolute percentage error (MAPE). The evaluations indicated that the REMI model produces very good forecasts over a short period of time beyond the historical data sample. As expected for all forecasting models, prediction accuracy deteriorates as the forecasting period lengthens. Studies also indicate REMI can predict major changes in the direction of economic activity for larger industries in short-term forecasting (Cassing and Giarratani, 1992).

[3] REMI is the best of the models reviewed in terms of addressing the fact that many impacts take time to materialize and that the size of impacts changes over time as prices and wages adjust. In short, it better incorporates the actual dynamics of the economy.

[4] The model can be used alone for forecasting with some caveats, or used in conjunction with other forecast "drivers".

[5] Among the 52 work plans, 28 were approved by CCAC unanimously, 11 with only three or less objections, and 13 with eight or fewer objections or abstentions (PA DEP, 2009).

[6] The selection, design, and analysis of the GHG mitigation work plans were performed through an in-depth and consensus-based stakeholder assessment process. This process was fostered by the Center for Climate Strategies, who worked closely with government officials, institutional experts, and members of the stakeholder community. The process combines the traditional facilitated conflict resolution model with expert technical assistance and analysis. A two-level analytical framework is adopted for the development and analysis of mitigation work plans. The first is the "council" or "commission" comprised of governor-appointed representatives of groups, interests and parties that have a direct stake in the effects of climate change or efforts to mitigate them. The second level is the multi-sector subcommittees made up of members of the commission plus other individuals with particular expertise in the topic area of the focused economic sectors (see, e.g., Rose et al., 2009).

[7] There is an extensive literature on market failure in decision regarding energy use, especially why people do not take advantage of cost-saving energy efficiency opportunities. Major reasons include: myopia, inability to process technical information, split incentives (principal-agent issues), and lack of access to capital markets (Sathaye and Murtishaw, 2004; Schleich and Gruber, 2008; National Commission on Energy Policy, 2004).

[8] In contrast to the entries presented in Table 1, a positive number in Table 2 represents a positive stimulus to the state economy (i.e., an increase in GSP). A negative number means negative impacts on the state economy (i.e., a decrease in the GSP).

[9] Some modifications and updates were made to the original quantifications of some work plans before we undertook the macroeconomic analysis. For example, the original analysis of F-7 Urban Forestry included not only energy savings, but also benefits from esthetic, air quality, storm water, etc. into the estimation of the direct savings. In the REMI analysis, we only modeled the energy savings. For another instance, we updated the original

quantification of ES-6 "Improve Coal-fired Power Plant Efficiency by 5%" by adding the estimation of fuel cost savings yielded by this work plan, which was omitted in the first place.

[10] The results for Electricity-9 (cogeneration), for example, can be decomposed into negative and positive stimuli, with the net effects being negative. The negative economic stimuli of this work plan include the increased cost (including annualized capital costs, operating and maintenance costs, and fuel costs) to the commercial and industrial sectors due to the installation of the CHP systems; reduced final demand from the conventional electricity generation (which equals the sum of electricity output from the CHP plus avoided electricity use in boilers/space heaters/water heaters). The positive stimuli include various fuel cost savings (e.g., electricity, natural gas, oil, and other fuel cost savings) to the commercial and industrial sectors from displaced heating fuels for all kinds of CHP systems; increase in final demand to the Construction and Engine, Turbine, and Power Transmission Equipment Manufacturing sectors; and increase in final demand in Farm (biomass) and Natural Gas Distribution sectors due to the increased demand of fuels and feedstocks to supply the CHP facilities.

[11] For example, a new business opens its doors in 2009 and creates 100 new jobs. As long as the business is open, that area will have 100 more jobs than it would have had without the business. In other words, it will have 100 more jobs in 2009, 2010, 2011, etc. We cannot say that the total number of jobs created is 100 + 100 + 100 +… Every year it is the *same* 100 jobs that persist over time not an additional 100 jobs.

[12] The total GSP and employment impacts presented above represent simple sums of impacts of individual work plans. The REMI Model yields slightly higher overall impact results when a simultaneous simulation is performed (in which all the 42 work plans are simulated in one single run). The simultaneous simulation indicates a GSP impact of $3.33 billion and an employment increase of 53 thousand full-time equivalent jobs in Year 2020. The difference in results between the simultaneous simulation and the ordinary sum can be explained by the non-linearity in the REMI Model and synergies in economic actions it captures.

[13] Nominal wages should increase with overall expansion in the economy. However, the net expansionary effect induced by the 42 PA mitigation work plans we analyzed in the study in terms of GSP is less than 0.5%. While the relative capital cost increase caused by the mitigation work plans is about 1%. As capital becomes more costly, the overall substitution effect is from capital to labor.

[14] Analysis on sectoral impacts shows that the impacts of the various mitigation work plans vary significantly by sector of the Pennsylvania Economy. One would expect producers of energy efficient equipment to benefit from increased demand for their products, as will most consumer goods and trade sectors because of increased demand stemming from increased purchasing power. The top five positively impacted sectors in terms of the NPV of GSP are, in descending order, Real Estate, Transit and Ground Passenger Transportation, Waste Collection; Waste Treatment and Disposal and Waste Management, Offices of Health Practitioners, and Monetary Authorities, Credit Intermediation.

One would expect Electric Utilities related to fossil fuels, to witness a decline. In fact, the Electric Power Generation, Transmission, and Distribution sector is expected to have the largest negative impact by far -- $7.38 billion (NPV). Other negatively affected sectors in descending order of impacts are Petroleum and Coal Products Manufacturing, Natural Gas Distribution, Coal Mining, Water, Sewage, and Other Systems, and Pipeline Transportation. However, none of these sectors is expected to have a decline of more than $0.4 billion.

[15] A key assumption of our REMI analysis is that state government spending is assumed fixed and exogenous. This means that if a policy option receives a government subsidy, government expenditure is offset elsewhere.

[16] The critical value for a Breusch-Pagan/Cook-Weisberg test of our transformed model (Model 2) is 0.41 (P>0.52).

[17] Exclusion of the intercept term allows us to easily interpret coefficients because we can include all sectors of the economy, rather than exclude one as the reference category as we do in Model 3. We test for any potential coefficient bias due to intercept suppression, and find it to have very minor impacts that do not outweigh the benefits of easily interpreting the reference category.

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