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Abstracts

EPA MARKAL MODEL DATABASES: UPDATE AND CURRENT USES

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The EPA currently has two MARKAL databases representing the U.S. energy system available for public use: a 9 region representation based on the U.S. census divisions, the EPAUS9r, and an aggregate national representation, the EPANMD. In this presentation we will give an update on the status of the two databases and show a sample of the number of ways the databases have been utilized at the EPA for in-house research and for modeling in support of regulatory impact assessments.

OPTIMAL STRATEGIES FOR ACHIEVING THE OBJECTIVES OF THE AMERICAN CLEAN ENERGY AND SECURITY ACT

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The American Clean Energy and Security Act (ACES), also referred to as the Waxman-Markey bill, calls for an 80% reduction in US greenhouse gas emissions by 2050 and includes a variety of incentives to help achieve this ambitious objective. IRG investigated cost-effective strategies to achieve the bills objectives for the Natural Resources Defense Council (NRDC) as part of its Cap 2.0 initiative (www.nrdc.org/cap2.0). This paper presents detailed results from that effort.

We used the US National MARKAL model (USNM-50) to identify least-cost technology and policy pathways for attaining these emissions reduction goals. The model was updated and calibrated to the March AEO2009 Published Release and was modified to reflect the Stimulus Bill, including provisions for weatherization, the State Energy Program, investment tax credits for geothermal heat pumps and solar water heaters, and the extension of the renewable energy production tax credit.

The analysis results show that the emissions reductions required under ACES can be met predominately through energy efficiency, cleaner generation of electricity, and offsets.
Primary energy use will decrease under ACES due to energy efficiency improvements in the vehicle fleets in residential and commercial buildings and in industry. Endogenous technology learning for renewables and other advanced technologies such as coal with CCS drive their investment costs down, making them more attractive economically over time.

Cost-effectively achieving the ACES targets will require the adoption of non-traditional light-duty vehicle (LDV) technologies starting with hybrids then plug-ins and after 2030 electric vehicles displacing gasoline vehicles. We implemented aggressive CAFE standards going to 80 mpg in 2050, which help to lower allowance costs, and we assumed that transportation system policies incentivized in the bill will reduce vehicle miles traveled (VMT) by 12% in 2050 relative to the business-as-usual (BAU) scenario.

ACES can improve energy security and reduce dependence on foreign oil through its incentives for CCS technology because its cost-effective to use the captured CO2 for enhanced oil recovery (EOR). The model results indicate that CO2-stimulated EOR opportunities could produce up 4.8 mbd in 2050.

The model results indicate that ACES could lead to ~$850 billion in total discounted savings to society between 2012 and 2050 relative to the BAU – with increased expenditures in new, more efficient appliances and equipment and low-carbon technologies more than offset by savings from decreased expenditures on fuel and electricity.

Sensitivity runs were performed in which the ACES cap was imposed without complementary policies that mandate or provide incentives for energy efficiency, renewables, CCS, transportation mode shifts and vehicle efficiency, etc. Additional sensitivities were run to investigate the impacts of raising the 2020 target to 20% below 2005 levels instead of 17%, incentivizing more energy efficiency, decreasing investment costs for nuclear power plants, lowering the CAFE standards and eliminating or expanding the transit mode shifts.

APPLICATIONS OF MARKAL TO ECONOMIC IMPACT ANALYSES

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Dan Loughlin, U.S. EPA - Office of Research and Development (ORD)

EPA's Office of Air Quality Planning and Standards (OAQPS) and Office of Research and Development (ORD) are exploring the application of MARKAL to EPA's regulatory economic impact assessments. This presentation will include an overview of a selection of these efforts and their future direction being conducted in the Air Benefits and Cost Group of the Health and Environmental Impacts Division of OAQPS. MARKAL provides a powerful and unique analysis tool, given its high level of technological detail, its representation of large sources of criteria and greenhouse gas emissions, and its ability to capture sectoral and cross-sector interactions. Of particular interest in such applications is the ability to conduct multipollutant analyses with MARKAL. Both current and future applications involve the use of MARKAL on its own and MARKAL in conjunction with other models in OAQPS's toolkit. Stand alone applications include using MARKAL scenarios to bound the economic impacts in Regulatory Impact Analyses (RIA) and using MARKAL as a screening tool to identify key influential parameters and assumptions. Further, MARKAL can be used in a complementary fashion with other models. For example, economic outputs of EPA's computable general equilibrium models, Applied Dynamic Analysis of the Global Economy (ADAGE) and the Response Surface Model (RSM) were used with

MARKAL for carbon cap scenario representation. Also, there is a potential opportunity to use the MARKAL emissions inventory with the Control Strategy Tool (CoST) and the Economic Model for Environmental Policy Analysis (EMPAX) computable general equilibrium model.

RETHINKING DEMAND TECHNOLOGY REPRESENTATION IN MARKAL

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A key challenge with building a MARKAL database is determining the appropriate level of detail associated with demand technology representation across the commercial, industrial, residential, and transportation sectors. A database containing hundreds or thousands of demand technologies is at best difficult to maintain and cumbersome to run, and at worst may provide too much detail given the underlying uncertainty. In our view, the level of technology detail should be justified in light of uncertainty considerations. We think that identifying the key model outputs—and how the level of technology detail affects those outputs—should drive MARKAL demand technology representation. The resultant representation should be as simple as possible while still maintaining accuracy in key model outputs. The objective of our presentation is to initiate a discussion regarding different approaches to demand technology representation. To this end, we will review the residential and commercial sectors in the EPANMD and present alternative, simplified approaches for consideration.

IMPLICATIONS OF UNILATERAL UNITED STATES CARBON POLICY

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The administration of President Barack Obama has announced targets for US greenhouse gas (GHG) emission reductions, of 80% lower than the present. In addition, a renewable portfolio standard (RPS) of 25% of generation and a low carbon fuel standard (LCFS) of at least 20% relative GHG reduction, both by 2030, have been announced. A simple calculation shows that these targets imply that the United States' rate of per capita emissions would approach that of Europe, as defined by the International Energy Agency. Combined with the doctrine of per capita emissions convergence, as developed by China and India, attaining these rates in the context of RPS and LCFS standards in the US implies dramatic changes in the structure of U.S. electricity generation, but with no impact upon global climate stabilization. MARKAL was used to model the implications of these policy actions.

MARKAL @ 30 - LEGACY & FUTURE

Gary Goldstein, International Resources Group

The MARKAL model has recent surpassed its 30th anniversary. This is a remarkable accomplishment according to any measure in the field. It all began at Brookhaven National Laboratory's National Center for the Analysis of Energy System (NCAES), with the Reference

Energy System (RES) concept was born and the first application of linear programming to energy created, BESOM - the Brookhaven Energy System Optimization Model. BESOM was a static single time period model, but it served to break new ground and set the foundation for MARKAL.

MARKAL was the result of the IEA Energy Technology Systems Analysis Programme (ETSAP) Implementing Agreement, which brought together researchers from 16 countries to conceive and formulate the essence of MARKAL, that is the data and math, build the model generator, and construct national models for each of the participating countries. These efforts took 4years from start till success. Models were (as I remember it) a couple of thousand rows, submitted overnight on the BNL CDC6600/7600 "supercomputers," which ran up bills of $100k/month. And yes, the 1st runs were submitted via punch-cards.

Jump forward 20years. Now there's PCs, the 1st model management "shell" MARKAL User's Support System (MUSS), and the move to GAMS. The methodology began to move beyond a small group of dedicated specialists to the wider energy planning community, and universities. And as PC power continued to explode, and new LP solution algorithms evolved, the models grew as did the sophistication of the model management systems, 1st ANSWER and then VEDA. Now owing to complexity of current energy systems and the issues that need to be examined in their context, multi-regional modeling and extensive sensitivity analysis dominate. And the models (TIMES), computers (multi-CPU and clusters), and shells (VEDA and ANSWER) continue to rise to the occasion. This presentation will provide a brief look at what has brought the MARKAL/TIMES community to where it is today, while focusing on the tools and techniques being employed by the leading MARKAL/TIMES modelers around the world today. The goal is to pay tribute to where we've come from, but more importantly motivate the next generation of modelers and analysts to rise to the current challenges facing policy makers by continuing to extend the limits of what can be done with the MARKAL/TIMES.

RUNNING TIMES IN STOCHASTIC WAY: POLICY ALTERNATIVES UNDER UNCERTAINTY

Oleg Lugovoy, Alexander Golub, Environmental Defense Fund

In this paper we discuss a way to take to account uncertainties in analysis based on TIMES-family models. It is known, that most intertemporal optimisation models, like TIMES, as well as intertemporal CGE models, etc., require perfect foresight assumption. This is scenario-based analysis with goal to answer a “what if” question: what optimal solution would be if we know (or assume) some future exogenous parameters. TIMES as a partial equilibrium model has a number of exogenous parameters including future fuel prices, prices of and efficiency parameters of future technologies, etc. Even current information might be not fully available and uncertain. Because of aggregation, and errors in data, current parameters of technologies might be known with non-zero tolerance. All this parameters might significantly affect “optimal” solution in the “what if” analysis, and might be tested with sensitivity techniques. But even sensitivity analysis doesn't help much in final decision of choosing particular policy, which is on most demand for policy makers. In this paper we discuss a way to apply mean-variance function and real option analysis to TIMES model results and determine "optimal" policy for risk-averse planer.

DEVELOPMENT OF A POST-PROCESSOR FOR EFFICIENT PROCESSING OF MARKAL ANT FILE OUTPUT

Kevin Hunter, Joseph DeCarolis, North Carolina State University

While MARKAL is routinely used to examine energy futures over the next half century, the quantification of large future uncertainties through rigorous sensitivity and uncertainty analysis is made difficult by the desktop design of MARKAL. In order to enable rapid model iteration, we have ported the single-region version of the MARKAL model generator to an 11-node compute cluster running Linux. Running a MARKAL model in batch mode leads to a more than order-of-magnitude increase in the number of model runs that can be performed per unit time. However, this functionality creates the need for a post-processor that can efficiently handle hundreds or thousands of MARKAL runs. The choice of either ANSWER or VEDA engenders certain inherent assumptions: Use of Microsoft Access, Microsoft Excel (and associated workflows), and use of a single processing node (desktop computer). Single-instance user interfaces present workflow inefficiencies. ANSWER on the back-end, for example, only provides basic data viewing capabilities, requiring the researcher to search for data and then copy-and-paste into Excel, where it is analyzed. We have created a post-processor that puts ANT file output into a fully relational database. This allows us to create programmatic definitions of what we intend to analyze (including access to statistical functions), thereby replacing the Access database and removing our analytical dependence on Excel. By removing the Search-Copy-and-Paste paradigm, we are able to enact a dictatorial workflow, allowing us to queue specific data from the database to automatically create tables and figures.

IDENTIFYING IMPORTANT INTERRELATIONSHIPS USING NESTED PARAMETRIC ANALYSIS

Dan Loughlin, U.S. EPA - Office of Research and Development (ORD)

Sensitivity analysis involves investigation of the response of a model's outputs to parametric changes in inputs. In a local sensitivity analysis, a single input is perturbed at a time, with all other inputs held at their baseline values. In contrast, in a global sensitivity analysis, multiple inputs are perturbed simultaneously. Perturbations can be derived stochastically, such as via Monte Carlo sampling, or deterministically, via nested parametric changes or other means. The runs made via a global sensitivity analysis can be analyzed from a local sensitivity perspective, with the benefit of having multiple "baselines." In addition, the results can suggest the relative individual and combined impact of input changes on outputs. In this presentation, ORD will demonstrate the use of a nested parametric analysis to examine how assumptions about the rate of capacity growth for various electricity production technologies can impact the ability to achieve CO2 mitigation goals. Topics that will be covered include: automating hundreds of nested parametric runs, analyzing results via pivot tables and data-mining, and using EPA's MARKAL post-processing tools to visualize and present the results.

PROJECTIONS OF CO2 EMISSIONS TRENDS AND REDUCTION POTENTIALS IN RUSSIA: ANALYSIS ON REFERENCE ENERGY SYSTEM RU-TIMES MODEL

Oleg Lugovoy, Alexander Golub, Environmental Defense Fund

The purpose of the paper is to estimate CO2 emissions trends, potentials and costs of CO2 mitigations in Russia. The analysis consist of the next steps: 1) developing a bottom-up TIMES model of Russian economy with extensive representation of energy consuming and producing technologies; 2) reviewing official and alternative scenarios of economic development and demand for energy; 3) comparison of energy and climate policy scenarios; 4) analysis of policy selection under uncertainty. On the current stage of the analysis we consider pathways of CO2 emissions in the power and heat production sector up to 2030. We analyze official and alternative projections of socio-economic development of the Russian economy, and apply RU-TIMES model for policy scenarios comparison and emissions projection. We consider 30 alternative scenarios that combine various economic development trends, energy demand, carbon tax and cap and trade policy, and estimate 'optimal' technology set, fuel mix structure and emissions pathways for each scenario. According to our estimates, Russia has huge potential for emissions reduction; in spite of many experts estimates, in realization of the most optimistic projections of economic growth and electricity and heat demand, CO2 emission from fuel combustion in Russia in power and heat sector won't reach 90% of 1990 level by 2020.

REMI-E3: THE REMI PI+ MACROECONOMIC POLICY ANALYSIS MODEL LINKED WITH MARKAL/TIMES

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This paper describes the conceptual framework of REMI-E3 using the application of the REMI PI^+ macroeconomic model conjoined with the MARKAL/TIMES energy system model. The REMI-E3 model framework has a two-way linkage between REMI PI^+ and MARKAL/TIMES. In the REMI-to-MARKAL linkage the REMI model provides economic forecast parameters for the MARKAL/TIMES reference scenario. Users then simulate policy scenarios with MARKAL/TIMES, generating microeconomic data such as demand changes by industry, changes in fuel use, and costs of fuel operations, maintenance and investments. In the MARKAL-to-REMI linkage the relevant MARKAL/TIMES outputs are converted into policy variable inputs in REMI PI^+. Using these policy variable inputs, the user runs REMI PI^+ to show employment, output, and other macroeconomic changes that result from the scenario.

The REMI PI^+ model is a structural macroeconomic policy analysis model that has been calibrated for hundreds of economies at the national, state, regional and local level.

MARKAL/TIMES is an energy system model. Due to the differing model frameworks, output variables from MARKAL/TIMES need to be mapped and/or translated into economic variables to simulate policy changes in PI^+, and outputs from REMI PI^+ need to be mapped to MARKAL demands. We present the REMI PI^+ to MARKAL/TIMES mapping approach and the MARKAL/TIMES results to REMI PI^+ mapping framework.

MULTI-POLLUTANT PLANNING IN THE NORTHEAST: A SENSITIVITY ANALYSIS OF NORTHEASTERN TRANSPORTATION POLICY

Jason Rudokas, NESCAUM

Traditionally air quality planning and climate planning have progressed largely independently. Northeastern states are beginning to explore the ways and implications of bringing these planning processes together. Currently there are two pilot multi pollutant studies which use MARKAL to weigh the tradeoffs between and synergies arising from state specific climate and air quality goals.

A basic sensitivity analysis can easily show that multi-pollutant tradeoffs are highly sensitive to fuel price assumptions, technology costs and other input assumptions. This analysis first examines the multi pollutant implications of policy scenarios being considered in the northeast such as LDV efficiency standards, technology mandates and incentives and second performs a robust sensitivity analysis where 500 to 1000 model runs were preformed. The key input parameters varied in each run were fuel prices and vehicle cost. The sensitivity analysis reveals a fuller range of multi-pollutant tradeoffs by providing a framework to understand the relationship between input assumptions and modeled results.

The visual basic language was used to develop a routine that wrote the appropriate files required by GAMS such as the .GEN and .DD files for each run. After the runs input files were written GAMS was initiated. After completing a run the routine would read the specified output from .ANT files and collect key data in an excel spreadsheet.

LARGE-SCALE BOTTOM-UP DEMAND DRIVEN COMPUTATIONAL MODEL OF THE US ENERGY GRID

Russell Winans, Cornell University

There is a growing need for a hierarchical integration of the entire energy supply and demand network as populations increase and new technologies are integrated into the energy system. New models need to focus on providing more realism in the simulation of the demand market to address new technology and policy issues, which focus on making the energy system more efficient, reliable, and resilient.

A MARKet ALlocation (MARKAL) model is constructed using a bottom-up demand model from preexisting New York City Best Practice Model house hold data to simulate travel demand and energy consumption at a micro level. This approach creates a fine resolution dynamic demand market to drive a supply chain model which co-optimizes supply resources and load-reducing demand resources to maximize reliability and minimize costs in real-time. This allows for an accurate assessment of market penetrating "smart" technologies, advanced electric storage, and peak-shaving technologies, which includes: plug-in hybrid electric vehicles (PHEVs), electric vehicles (EVs), distributed resources and generation, and variable-output renewable resources. As well this model provides insight to key policy issues such as the effectiveness of free competitive retail markets, incentives to provide customers with real-time rates, pollution impacts and strategies, energy efficiency and reliability standards, and incentives for the development and deployment of "smart" technologies.

MODELING OPTIMAL TRANSITION PATHWAYS TO A LOW CARBON ECONOMY IN CALIFORNIA: IMPACTS OF ADVANCED VEHICLES AND FUELS ON THE ENERGY SYSTEM

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Our project goal is to develop an integrated system model that will identify optimized scenarios for meeting 2050 climate policy goals and evaluate the resource and economic impacts to the state of California. We hope to provide insights on how economic drivers, such as cost considerations and a cap-and-trade program, will affect future decisions on the investment of future energy technologies and utilization of resources under various scenarios. In particular, we will investigate how the adoption of advanced vehicles for meeting statewide greenhouse gas emission goals could impact the structure and operation of the energy system and resource use. We focus on assessing low-carbon transportation energy futures for California to: 1) understand the potential interactions between the future transport and electricity sectors, 2) identify optimal (i.e. cost-effective) technology strategies for reducing greenhouse gas emission targets in 2020 and in 2050, and 3) understand the impacts of energy and greenhouse gas policies on the evolution of the transport and electricity sectors.

EFFECTIVENESS OF CARBON MITIGATION STRATEGIES AT THE MUNICIPAL LEVEL: APPLICATION AND EXTENSION OF MARKAL MODELS

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The MARKAL-family of models were originally developed to model the energy systems at the macro-level (e.g., WORLD, GMM, NEMS), and this work has both extended the model library and enriched our understanding of the energy system behavior at the (aggregated) macro-levels. Recently, a few researchers have attempted to apply the modeling framework to the local level either as a sub-model (e.g., MARKAL-Lite in Europe) or to model city-systems that are larger than many countries (Bhatt, et al., 2008 & Linky, Bhatt & Lee, 2008 for New York; Motoki & Kosaka, 2007 for Tokyo). Realizing the value of quantitative modeling as a decision-aid at the municipal level, we focus our attention on modeling the energy (and material) systems so elected officials and administrators can better understand the behavior and responsiveness of the whole system to different policy scenarios. In this paper, we describe our efforts to develop and apply MARKAL-family of models at two municipalities in Western Pennsylvania, and examine the responsiveness of the two energy and material systems to different policy instruments enacted at the state level and implemented at the municipal level. The legal framework at the state level, specifically, PA Act 129 and Act 213, provided the ex ante basis for modeling different scenarios, and the model outcomes provided clues on the effectiveness of existing measures to mitigate GHG emissions.

Our results show clear limits to GHG reductions at the local level without changing the source of energy (mostly coal-fired power plants in PA). Responsiveness of the two municipalities greatly depended on the asset-stock characteristics (both buildings and appliances), confirming our a priori expectation that the same policy instrument may have different effects in different regions/localities due to the nature (and quality) of existing stock. Our results also suggest that the easiest and cheapest way to reduce emissions is to change behavior – reducing demand for energy had almost the same effect as phasing out older appliances and replacing them with newer ones, and with no associated costs. Policy options that promote and incent such behavioral changes are likely to be more effective than options that attempt to change the characteristic of the energy system.

RENEWABLE ENERGY DEVELOPMENT INFRASTRUCTURE PROJECT COLORADO CLIMATE ACTION PLAN SCENARIO ANALYSIS FOR COLORADO POWER SECTOR

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A state-specific MARKAL model is developed to assess the state's renewable energy development potential for the Renewable Energy Development Infrastructure (REDI) project. The objective of the REDI project, funded by the DOE's Office of Electricity Delivery and Energy Reliability, is to investigate and produce a report with recommendations that will lead to the expansion of a minimum of 1 GW of new renewable energy in Colorado.

The study concentrates on the electric power system of Colorado and presents the development of an energy system incorporating Renewable Energy Standards, Demand-Side Management and Energy Efficiency (DSM/EE) measures. The focus of the study is to demonstrate the current status of power sector in Colorado and quantify the pathways for sustainable future energy system development meeting Colorado Climate Action Plan (CAP) goals by 2020. The model integrates existing installed generation capacity; future advanced technologies; power grid constraints for power import, DSM/EE programs under various policy scenarios, and provides total system cost of carbon policy scenarios as well as emissions profile. Natural gas price volatility and load forecast sensitivities are explicitly addressed. The study show 1 GW of Concentrated Solar Power and about 3.9 GW of additional wind generation is needed by 2020 to meet the CAP goals. The study also show higher DSM/EE measures by

Investor Owned Utilities and Non-IOUs could reduce the renewable needs therefore, less costs and lower rates and more savings to the ratepayers.

AN INTEGRATED ANALYTICAL TOOL FOR LOCAL ENERGY PLANNING, SOLID WASTE MANAGEMENT, WASTE WATER TREATMENT, AND GREENHOUSE GAS EMISSION MITIGATION

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The EPA Regional Office in New York City has formed a diverse partnership with Brookhaven National Laboratory, academic institutions and regional transportation and land use planning organizations to develop a suite of analytic system models to provide a quantitative vision of technology and management strategy options for reducing the carbon footprint at the local level. In this paper we describe our initial results of the construction of integrated urban energy-water-solid waste systems analysis frameworks (Urban MARKAL) for New York City and Long Island based on the MARKAL modeling platform. New York City is a representative large urban center with rapid growth in energy needs, amount of waste water to be treated, and in the quantity of solid waste managed. From a geographic perspective Long Island faces infrastructure constraints despite its location within the New York metropolitan area. The capability to import electricity from outside Long Island is constrained and treatment of waste-water and management of solid wastes need to be handled locally. Base case studies on the two urban areas using this framework have demonstrated its capability to analyze intertwined issues between energy planning, solid waste management programs, and wastewater treatment schemes, separately or jointly, in a single framework through source reduction, efficiency improvements, and enhanced management strategies.

Combined with local stakeholder participation, extension of this approach by linking the urban MARKAL with analytical tools such as EnergyPlus, MM5, and MOVES hold the promise of influencing the current environmental regulatory regime, including multi-media aspects of carbon control, at the Regional or National level. The stakeholder collaboration using the Urban MARKAL framework will help cast studies that meet all future validation criteria for greenhouse gases under regional Protocols, such as the Regional Greenhouse Gas Initiative, Energy Star, Landfill Methane Outreach Program (LMOP), Transportation and Air Quality Program, Green Power Partnerships and a possible federal cap and trade regime.