4 CSR 240-22.030 Appendix B: The MRN-NEEM Model

Overview: Integration of a top-down and a bottom-up model

CRA International uses an integration of two distinct classes of models to simulate the market dynamics of the electricity sector within the broader U.S. economy: (1) a general equilibrium (or top-down) model and (2) an investment and technology decision-based linear programming (or bottom-up) model. These classes of models, in general, are analyzed by employing two distinct modeling paradigms: top-down and bottom-up analysis. The top-down models are the standard economic framework for analyzing economy-wide policies and are the most commonly used tool for assessing macroeconomic impacts. In this modeling framework, an economy, including production sectors, final household demand, and government taxation and spending, is completely represented, so as to capture economy-wide relationships. But most importantly, the model is based on rigorous microeconomic theoretical foundations. Under (carbon) policy scenarios, all agents in the model respond to price changes (including changes in energy prices and products that utilize energy in their manufacture), and the inter-linkages within the model enable it to take into account a complete set of feedbacks within the economy. The top-down models can also be easily expanded to include multiple regions linked by trade. With such flexibilities, top-down models are suitable for simulating a wide variety of policies, such as the impact of energy policies, trade policies, public finance policies, and many other real world policies, to determine who wins and who loses. The MRN model falls under this category.

Bottom-up models, on the other hand, are used to find the choice of least-cost technology that satisfies a portfolio of policy measures. These models involve a detailed characterization of one aspect of the economy. In particular, models of the electricity sector constructed at the unit level with a menu of costs for current and future technologies are often employed to study the impact of environmental policies on this sector. The NEEM model falls under this bottom-up category.

The two approaches are very distinct in both model structure and their representation of the energy-economic system. The top-down model's representation of the economy is complete at a macro-level but lacks detail regarding specific technologies. Specific technologies are best described from an engineering perspective, which general equilibrium models are unable to represent. In the top-down model, an economic system is represented by production sectors where preferences and technologies are represented by smooth functions. All agents in the model interact to capture economy-wide effects, and are forward-looking, rational optimizers. In contrast, the bottom-up model represents only a portion of the economy (*e.g.*, the energy system or the electricity sector). The bottom-up model is incomplete but this weakness is compensated by the richness of its technology representation. In addition, the sectoral detail encompasses each and every generation unit within the electric sector, which adds realism to actual simulation for practical application. However, despite these strengths, bottom-up models do not fully represent the economy and fail to account for macroeconomic feedbacks from the rest of the economy. Thus, bottom-up models cannot be used alone for macroeconomic analysis.

The effects of an economy-wide policy such as the proposed CO_2 branches represented in the probability tree ripple through the entire economy, so serious analysis of such a carbon policy requires macroeconomic analysis. At the same time, carbon policy will pointedly affect the electric sector, so the use of a bottom-up model is desirable. Therefore, top-down and bottom-up models have a complementary role to play in policy analysis. If coupled appropriately, they can generate a wide-range of detailed results that are consistent across the two models. The weakness of the top-down model is well compensated by the strength of the bottom-up model and *vice versa*. Hence, an integrating a top-down and a bottom-up model is ideally provides the best of both frameworks. CRA International integrated its two models, MRN and NEEM, into a single MRN-NEEM model to provide a unique and consistent approach for U.S. economy-wide policy analysis.

An overarching difference between the two models is regional detail and definition. Figure A - 1 and Table A - 1 show the relationship between the NEEM and MRN regions.[1] There are 27 U.S. NEEM regions but only 9 MRN regions.

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[1] MRN regional borders are delineated by the checkered white and black lines, with MRN region names bounded by boxes. NEEM regional borders are delineated by black lines, with NEEM region names in smaller black text.

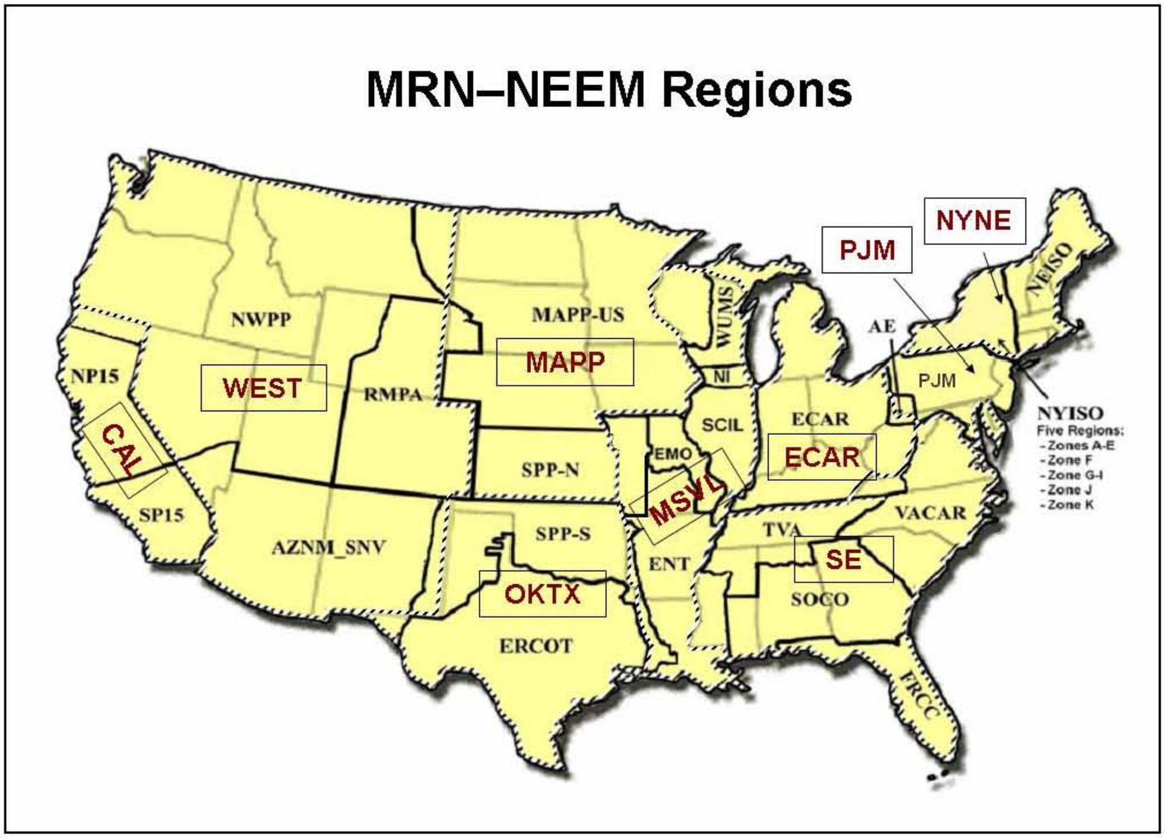

Figure A - 1: Map of MRN and NEEM Regions.

Table A - 1: Mapping of MRN Regions to NEEM Regions.

MRN Region	States	NEEM Region
ECRR	MI, IN, OH, KY, WV	ECAR
NYNE	MA, ME, NH, NY, RI, VT, CT	NEISO, 5 NYISO Regions (Upstate, Downstate, Capital, NYC, LIPA)
MAPP	ND, SD, NE, KS, MN, IA	MAPP-US, SPP-N
PJME	PA, MD, DC, NJ, DE	AE, PJM
CALI	CA	NP15, SP15
WEST	WA, OR, AK, HI, ID, MT, NV, UT, CO, WY, AZ, NM	NWPP, RMPA, AZNM_SNV
SEST	MS, AL, TN, GA, SC, VA, NC, FL	SOCO, FRCC, TVA, VACAR
OKTX	TX, OK	SPP-S, ERCOT
MSVL	IL, MO, AR, LA, WI	WUMS, NI, SCIL, EMO, ENT

1. Multi-Region National (MRN) Model

MRN is a top-down, computable general equilibrium (CGE) model of region-specific impacts and regional interaction in the U.S. economy. The CGE tracks every dollar that is spent through the economy (to reduce carbon emissions, for instance), accounting for the economic gains in those sectors that provide the goods and services that result in emissions reductions, as well as the economic costs to those that incur added expenditures. In addition, the negative impacts associated with declining demand under higher, policy-induced prices are captured. The model also accounts for any changes in the distribution of wealth that result from the combined impact of emissions control spending and the disposition of newly created allowances. The results of a model run thus reflect the *net* impact to the U.S. economy after all the impacts on the winners and losers under a proposed policy have been estimated.

The model also assumes that implementation of a policy such as a carbon emissions cap will occur in a least-cost fashion with fully-functional, competitive product and allowance markets. The only limits imposed on the efficiency of a cap-and-trade market are those that are directly specified in a policy or bill, such as when some sectors are not covered by the proposed cap scheme (even if placed in the offsets category). Leakage of some economic activities outside of the United States is also estimated for sectors that face competitors in other countries that do not have their own emissions caps (or have weaker caps).

The model works with perfect foresight of future prices and policy requirements. This means that the model does not include any costs due to uncertainty and "surprises" that will probably also be associated with compliance with a new policy. It also captures only a long-run equilibrium in all of the markets, and thus does not include any of the costs of an overly rapid shift in markets due to the imposition of a new policy.

The CGE model solves for production levels, trade, relative prices, income, and consumption by accounting for technological as well as behavioral responses to changes in policy. The equilibrium is fully dynamic, meaning that investment decisions determine the future capital stock, which in turn determines future income and consumption. Furthermore, decisions to consume or invest are taken with correct expectations about future policy and opportunities (*i.e.*, with perfect foresight). Investment today requires foregoing consumption of current income. Consumer decisions maximize utility inter-temporally, which implies that an optimal financial trade-off is made between consumption today and consumption in the future. Many of the impacts of policies to reduce carbon emissions indirectly increase the cost of production and consumption, and this has effects on the demand for all commodities. For example, a limit on the quantity of allowable emissions from electric utilities will result in higher electricity prices. Higher electricity prices will then raise production costs throughout the economy, but especially in sectors that use electricity-intensive production processes. As all sectors adjust their production processes to be optimized under post-policy prices, there are changes in demand for labor, materials and commodities, capital, and different types of fuels and primary energy sources.

MRN only explicitly models the economy and energy sector in the United States, but it does also account for foreign imports and exports. Data that characterize the interrelationships of commodity uses within the economy therefore are of primary importance in quantifying the impacts from alternative carbon regulations. As a starting point for characterizing the inputs and outputs of commodities in the U.S. economy, MRN uses a Social Accounting Matrix (SAM) developed for each state by the Minnesota IMPLAN Group, Inc. (MIG). The IMPLAN database represents the activities in 509 sectors for all 50 states and the District of Columbia. CRA adjusts the original SAM data to be consistent with state level energy data from the U.S. Energy Information Administration (EIA), which are more accurate than the corresponding IMPLAN data with respect to energy flows in the U.S. economy. The SAM that results from the combination of IMPLAN and EIA data exactly matches the intensities of commodity use for the modeled production and consumption sectors for any regional aggregation of states. In addition, the SAM completes the circular flow with an account of factor incomes, household savings, trade, and institutional transfers.

Conceptually, the SAM represents a "snapshot" of the economy at the current point along a dynamic growth path. MRN simulates the dynamic growth path into the future in the absence of major changes to policies that are "on the books" today. This initial growth path is known as the "business-as-usual" case, or BAU. In other words, the initial snapshot is for a single year but the BAU case is a forecast over many years. Calibration of the BAU case from the initial snapshot provided by the SAM is completed by incorporating growth forecasts for industries, population, and carbon emissions.

The regional detail of MRN can be specified at any level of disaggregation down to the state level, depending on the needs of the analysis.[2] Since carbon emissions are highly correlated with energy use, all the important energy sectors contained in the detailed SAM are

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[2] In contrast, the NEEM model divides the United States into 27 separate regions. This allows greater specificity in assessing impacts to coal markets and allowance markets. Regional gas price differentials are also captured in the NEEM portion of the analysis, based on changes at the Henry Hub projected by MRN.

represented as individual sectors in MRN.[3] CRA aggregates all of the remaining (non-energy) sectors in the SAM into five groups that capture the diversity in energy-intensity across all economic activities. MRN typically uses the ten production sectors in Table A - 2.[4] MRN also accounts for household energy uses, as well as all the productive sectors of the economy, so that MRN can correctly account for individuals' responses to higher fuel costs caused by carbon abatement policies. Importantly, personal transportation (*i.e.*, automobile use) is included in the household energy uses, not in the transportation sector listed in Table A - 2.

Table A - 2: Sectoral Representation in MRN.

Energy Sectors	Non-Energy Sectors
Coal extraction	Agriculture
Oil and gas extraction	Energy-intensive sectors
Oil refining/distribution	Manufacturing
Gas distribution	Transportation services
Electricity generation	Services

MRN tracks CO_2 emissions from fossil fuel combustion and assumes that the costs of reducing other greenhouse gases are comparable to the cost of reducing carbon dioxide emissions. To incorporate carbon emissions in the model, an emissions permit is tracked for each of the three fossil fuel inputs (refined oil, natural gas, and coal). When there is a carbon cap, a fixed number of emissions allowances is assumed to be available in each modeled year. If that limit is less than the BAU emissions level, a scarcity of allowances (*i.e.*, when demand for allowances exceeds their supply) will exist. This scarcity increases the price on carbon (starting from zero) up to the point where demand for the allowances is reduced to the limit of their supply. Limiting the number of allowances available imposes an emissions constraint, and the permit price reflects the marginal cost of abatement.

[3] Non-CO_2 greenhouse gas emissions from coal extraction and oil and gas extraction are not modeled explicitly. An (exogenous or user-defined) offset supply curve based on emissions reductions in these and other natural resource-based sectors (*e.g.*, agriculture) is used to represent the cost of supplying offsets.

[4] Coal extraction and oil and gas extraction are assumed to consume zero fossil fuels.

2. North American Electricity & Environment Model (NEEM)

CRA's stand-alone North American Electricity & Environment Model (NEEM) is a linear programming model that simulates a competitive electricity market for the continental United States. NEEM minimizes the present value of incremental costs to the electric sector while meeting electricity demand and complying with relevant environmental limits. NEEM was designed specifically to be able to simultaneously model least-cost compliance with all state, regional and national, and seasonal and annual emissions caps for SO_2, NO_X, Hg, and CO_2. The least-cost outcome is the expected result in a competitive wholesale electricity market. As part of the cost minimization solution, NEEM produces forecasts of short-term and long-term decisions such as coal choices, investments in pollution control equipment, and new capacity additions in a manner that minimizes the total costs to the electric sector.

The model employs detailed unit-level information on all of the generating units in the United States and portions of Canada. All coal units larger than 200 MW in summer capacity are represented individually in the model, and other units are aggregated.[5] NEEM models the evolution of the North American power system, taking into account demand growth, available generation, environmental technologies, and both present and future environmental regulations. The North American interconnected power system is modeled as a set of regions (generally NERC regions and NERC sub-regions) that are connected by a network of transmission paths.

Environmental regulations affect decisions about: (1) the mix and timing of new capacity, (2) retirement of existing units, (3) the mix and timing of environmental retrofits at existing facilities, (4) fuel choice, primarily by coal units, (5) dispatch of all units, (6) maintenance scheduling for all units, and (7) the flow of power among regions. NEEM captures all of these impacts in the process of optimizing unit responses to environmental policies. For cap-and-trade policies, NEEM also determines permit banking decisions.

In order to be integrated with MRN, NEEM has been formulated as a quadratic program instead of the linear program structure used in the stand-alone model. It solves for the optimal decisions by maximizing the present value of consumer and producer surplus subject to economic, technical, and policy constraints. The economic constraint is that the supply and

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[5] The two AmerenUE coal units under 200 MW in summer capacity, Meramec 1 and Meramec 2, were removed from their aggregates and modeled separately.

demand for electricity is balanced in each region. Technical constraints include operational limits, maintenance requirements, and maximum output. Policy constraints include the required reserve margin and also state and Federal environmental constraints (*i.e.,* emission caps, efficiency standards, and RPS standards).

The total surplus is equal to the area between the demand and supply curve for electricity. NEEM employs a linear demand curve that is benchmarked to the exogenous forecast of demand and the resulting marginal cost of providing electricity to meet this demand. The electricity supply curve represents the cost of supplying electricity, which includes (1) fixed and variable operating costs for all units, (2) fuel costs, (3) capital investments in new plants and retrofits at new and existing facilities, and (4) the cost of moving power between regions (wheeling charges). To (3) above, because of the long life-span of generating units, capital decisions affect decisions for several years. Therefore, NEEM's model horizon extends past the IRP horizon through 2050, while setting an economic lifetime for all new capacity to 30 years.

On the demand side of the economic constraint, NEEM dispatches to a load duration curve. The load shapes used in NEEM are based upon 2002 actual load profiles from EIA Form 411, and three separate load shapes corresponding to each regional interconnect (Eastern Interconnect, ERCOT, and Western Interconnect) are used. For the eastern interconnect particularly, in which AmerenUE falls, the load shape is based upon the load profile for the ECAR region. Comparison of power prices in ECAR and Eastern Missouri, or EMO, (the NEEM region where AmerenUE is located) confirms a high correlation between the load profile for the ECAR region and that for the EMO region.

From this point, a load duration curve is created and ultimately inputted into the NEEM data file. The load duration curve first breaks up hourly demand into three seasons: summer, winter, and shoulder. The summer is defined as May through September; the winter as January, February, and December; and the shoulder period as March, April, October and November. Hourly demand in ECAR within each season is then sorted from highest to lowest and placed into load blocks. For example, as shown in Table A - 3 below, the 25 hours in load block B11 represent the 25 hours with the highest load in ECAR within the shoulder months. It should be noted that the load blocks have been created to best represent the relative peakiness of energy demand, and, as such, there are fewer hours included in peak demand load blocks and more hours in off-peak demand load blocks. Given this demand structure, NEEM estimates annual regional power prices *by load block.*

Table A - 3: Constitution of NEEM Load Blocks.

Load Block	Season	Number of Hours
B1	Summer	10
B2	Summer	25
B3	Summer	75
B4	Summer	100
B5	Summer	200
B6	Summer	300
B7	Summer	400
B8	Summer	500
B9	Summer	800
B10	Summer	1,262
B11	Shoulder	25
B12	Shoulder	200
B13	Shoulder	600
B14	Shoulder	900
B15	Shoulder	1,203
B16	Winter	25
B17	Winter	100
B18	Winter	400
B19	Winter	700
B20	Winter	935

Coal units (and other units of interest) are represented in detail as these are most affected by environmental regulation. All but small coal units are modeled at a unit level. All non-coal generating units in the United States are also represented in the model, with some level of unit aggregation. In addition to coal units, NEEM represents the following generation technologies - natural gas combined cycle (CC), natural gas combustion turbine (CT), nuclear (NUC), integrated gasification combined cycle (IGCC, also available with carbon capture and sequestration), hydroelectric (H), pumped storage hydro (PS), and a range of renewable technologies. Renewable technologies include: wind (WT), solar photovoltaic (PV), solar thermal (ST), landfill gas (LG), biomass (BM), and geothermal (GEO).

To analyze an environmental policy, NEEM must first be solved for a BAU case in which the policy is not in force. In addition, the BAU case must be consistent in that the exogenously specified demand (*i.e.*, the demand input by the user) matches the demand expected under the set of policies and market conditions assumed in BAU. *From the BAU-case solution, the equilibrium prices that are associated with exogenously specified demands are extracted. These prices along with the exogenously specified demand comprise the benchmark price and quantity points for the electricity demand curve.* These electricity demand curves are defined for each region modeled.

To solve for the carbon policy, or scenario case, the environmental policy of interest is applied, and the NEEM model is resolved. In the scenario case, electricity demand is no longer fixed and therefore demand is responsive to the environmental policy of interest. The model solves for the optimal set of decisions under the policy.

MRN-NEEM Integration methodology

As discussed previously, MRN accounts for all sectors except for the electric utility and coal supply sectors. The level of electric sector demand for natural gas, the supply of electricity, and the demand for electricity (all exogenous to MRN) are provided by the NEEM model. The MRN model is then solved for a new equilibrium and provides NEEM with the supply and price of natural gas, a new electricity demand level and price of electricity, and the non-utility demand and price for coal. If allowing for emissions trading between utility and non-utility sectors, then the MRN model further provides the non-utility carbon allowance demand and price. In a nutshell, MRN supplies functions for electricity demand, non-utility coal demand, non-utility carbon allowance demand, and the supply of natural gas. NEEM accepts MRN's outputs as inputs and *vice versa*, as shown in Figure A - 2. This iterative process continues until convergence in the NEEM and MRN equilibrium price of electricity is achieved.

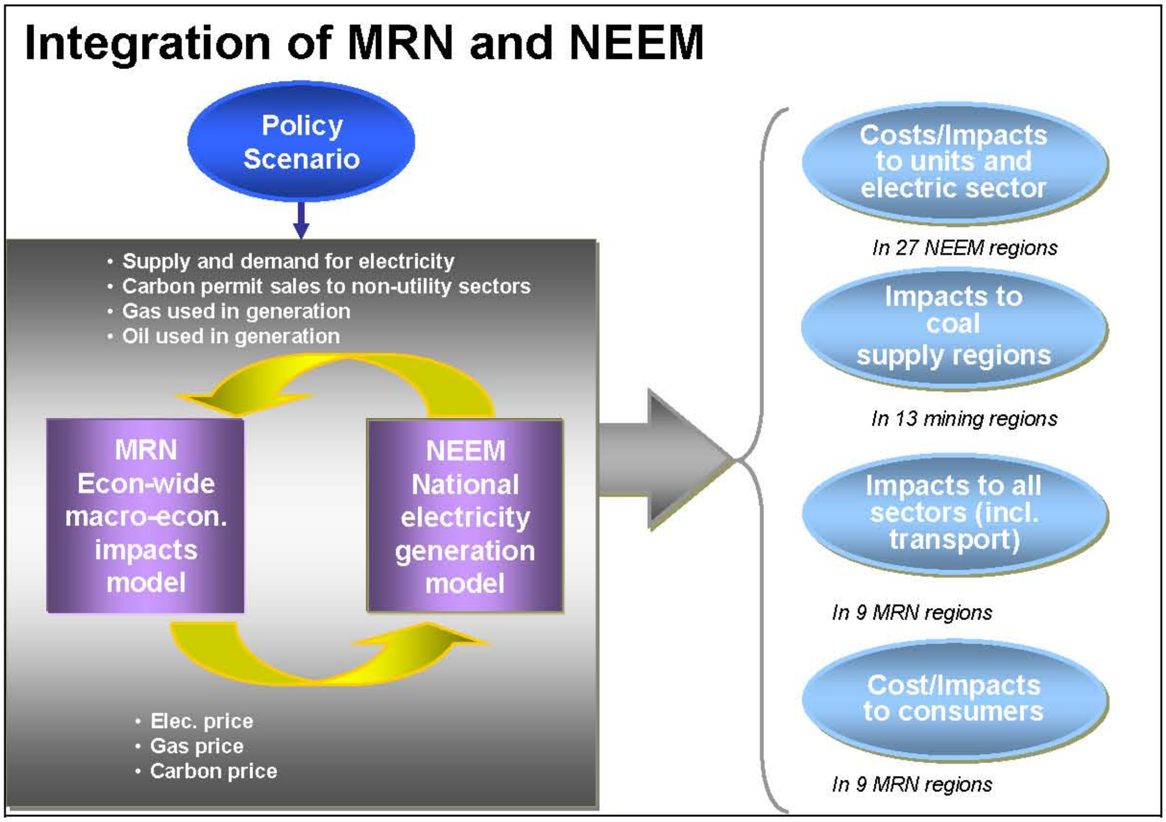

Figure A - 2: The Integration of MRN and NEEM.