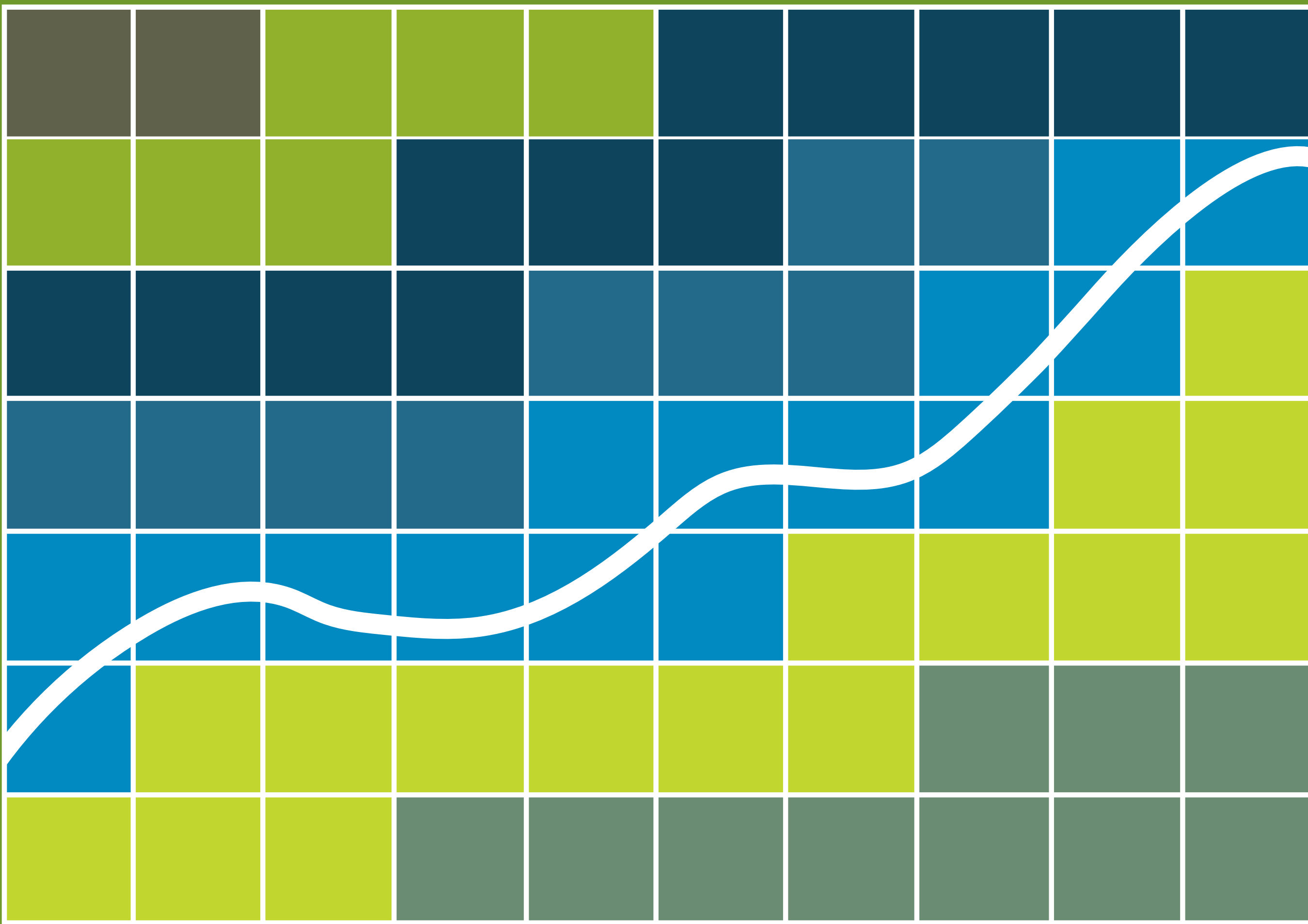

The Bureau of Land Management's Modeling Choice for the Federal Coal Programmatic Review

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Introduction

There are multiple power sector models available to the Department of Interior (DOI)'s Bureau of Land Management (BLM) for analyzing the effect of current and alternative coal regulations and leasing policies during preparation of its programmatic environmental impact statement (PEIS). This document lays out model selection criteria to assist BLM in weighing the benefits and costs of these available models. We first narrow our choice of power sector models for more detailed consideration, focusing on three key models: the Bureau of Ocean Energy Management's MarketSim; the U.S. Energy Information Administration's National Energy Modeling System (NEMS); and ICF International's Integrated Planning Model (IPM). We then develop and apply selection criteria to these models. We conclude with recommendations for model selection, highlighting the tradeoff between model complexity and transparency.

I. Narrowing Model Choice

There are three main types of power-sector models: capacity expansion models, production cost models, and network reliability models. Capacity expansion models simulate or optimize generation and transmission capacity investments over multiple years using a (partial or general) equilibrium model or a cost minimization (often linear programming) model subject to various constraints (e.g., demand, regulations, reliability, etc.). In determining the future mix of generation, these models include representation of the energy resource production sector (oil, natural gas, coal, and renewables). These models are ideal for analyzing medium-run and long-run power generation and energy capacity mixes and the policies that affect them.

Production cost models represent specific power systems at a higher temporal resolution over a shorter-time horizon—a year or less—to determine the (minimum) cost of meeting a particular region's energy needs—down to the hour of each day.

Finally, network reliability models capture the power sector at an even higher temporal resolution to test and ensure the reliability of particular generation and transmission systems for periods of a minute or less (Boyd, 2016; Qi, 2013).

Given BLM's needs, capacity expansion models are clearly preferable. BLM must simulate the impact and costs of energy resource production policies in the medium-run and long-run on the various chains involved in the power sector: energy resource production, transportation, generation, and transmission. Furthermore, capacity expansion models can capture demand, reliability, policy effects, and cost considerations through various model constraints (Qi, 2013). While the choice to consider only capacity

[1] I would like to thank Jayni Hein and Richard Revesz of the Institute for Policy Integrity at New York University School of Law for their valuable contributions to this report.

expansion models narrows our choices to some extent, there are still too many options to discuss in detail.[2]

Therefore, we narrow our discussion to capacity expansion models that are already used by the federal government. It is unlikely – and generally inadvisable – for BLM to adopt a model currently unknown to federal agencies. Thus, we focus on three specific capacity expansion models: the Bureau of Ocean Energy Management (BOEM)'s Revised Market Simulation Model (MarketSim), U.S. Energy Information Administration (EIA)'s National Energy Modeling System (NEMS) model, and ICF International's Integrated Planning Model (IPM).

II. Selection Criteria

We focus on capacity expansion models because BLM is interested in analyzing the impact of proposed coal regulations, leasing policies, and projects in the medium-run and long-run. In order to choose among these three primary models, we need to specify more specific sets of questions (*See* Boyd, 2016).

BLM will primarily use a capacity expansion model to analyze coal production on federal lands. The agency is interested in understanding:

- How does changing lease policies (e.g., increasing minimum bids, increasing royalty rates) affect the energy sector (the price and quantity of coal and other energy sources including natural gas, oil, and renewables), power sector (energy prices and energy reliability), transportation and trade (rail and other transportation industries, imports and exports), and the public (cost of health and environmental externalities, jobs, and government revenue)?
- How does an expansion or contraction of coal capacity (i.e., offering, renewing, or withholding coal leases for bidding) affect the energy, power, transportation, trade, and public sectors? How do the fiscal terms, location, or timing of leases affect outcomes?
- How do the effects of different leasing policies and coal projects differ over time and regionally?
- How do different leasing policies affect overall greenhouse gas emissions? How do they affect global, national, and regional energy and generation portfolios?

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[2] There are many capacity expansion models, including: the Bureau of Ocean Energy Management (BOEM) of the DOI's Revised Market Simulation (MarketSim) model; U.S. Energy Information Administration (EIA) of the Department of Energy (DOE)'s National Energy Modeling System (NEMS) model; ICF International's Integrated Planning Model (IPM); KanORS's Framework for Analysis of Climate-Energy-Technology Systems (FACETS) model; Resources for the Future (RFF)'s Haiku Electricity Market Model; Charles River Associates' North America Electricity and Environment Model (NEEM); NERA's Economic Consulting's N_{ew}ERA Model; Electric Power Research Institute (EPRI)'s U.S. Regional Economy, Greenhouse gas, and Energy model (US-REGEN); National Renewable Energy Laboratory (NREL)'s Regional Energy Deployment System (ReEDS), International Energy Agency (IEA)'s MARKAL (MARKet ALlocation) model, NETPLAN, National Energy Renewable Laboratory's Resource Planning Model, EPIS' Aurora model, ABB's System Optimizer, ABB's Strategist, and Energy Exemplar's PLEXOS® Integrated Energy Model (Beasley and Morris, 2012; Boyd, 2016; Qi, 2013;)..

- How do leasing policies and coal projects affect the division of coal production between private and public (specifically federal) lands? How do they affect the division between underground and surface mine production?
- What would leasing scenarios that aim to meet particular objectives (such as revenue-maximization, U.S. social welfare maximization, or meeting U.S. climate change objectives) look like?

We develop model selection criteria with these questions in mind. We group these criteria by topic.

Coal Production Information

Given BLM's focus on coal production on federal lands, it is essential that the chosen model capture the coal industry and its substitutes in sufficient detail. The sub-model or module of coal production should capture (or should be easily modified to capture):

- Details about coal production by region: the type of coal mines (underground, surface, and mountaintop removal) and ownership (federal, state, and private) and substitution effects among them;
- Information about the coal being mined by region and mine type: coal rank (i.e., heat content), grade (i.e., SO_2 content), and quality (i.e., non-SO_2 emissions) and substitution effects;
- Lease fiscal terms (such as royalty rates, minimum bids, rental rates) and simulations of scenarios that change leasing structures; and
- Key regional, basin, or mine information to accurately model regional supply curves, specific production scenarios, and substitution effects.

Substitution

Given the well-documented substitution between coal and natural gas (Ko and Dahl, 2001; EIA, 2012; Gao et al., 2013; Jones, 2014), the model requires sub-model or modules of coal substitutes that capture:

- Key features of the oil, natural gas, and renewable energy sectors to accurately capture substitution among different energy production sectors; and
- Sufficient detail of the renewable energy sector to meet BLM's needs, including temporal and spatial scale, accessibility (connecting sources to load), cost, variability, and uncertainty in generation (Boyd, 2016).

The chosen model should meet all or most of these requirements for the coal and energy resource production sectors, or at least be easily modifiable to do so (Boyd, 2016).

Analysis of Other Key Sectors

The chosen model should also have sub-models or modules of other key sectors, including generation, transmission, transportation, and energy consumption. Specifically, the model should be able to capture:

- Future generation and transmission investment and retirements, ideally endogenously (e.g., determined as part of the model solution rather than specified by the modeler) (Boyd, 2016);
- Constraints on generation and transmission, including minimum capacity, peak load reserve margins, dispatch constraints, and regulatory requirements (including environmental regulations and renewable portfolio standards);
- Industry and consumer demand, and how this behavior changes (e.g., conservation and investment) with changes in energy markets;
- Transportation of coal and other energy resources, including how the transportation network will change over time (due to investment in transportation infrastructure) to impact the future movement of energy resources; and
- Import and export of energy resources – particularly coal – to accurately simulate the effects of different scenarios.

With respect to generation, BLM should also determine whether supply (marginal cost) and total cost (including fixed capital costs) curves for each generating unit, model plant, or region are sufficient for its modeling needs. With respect to transmission, BLM will also need to determine the detail of the transmission model necessary, including whether individual or aggregate transmission lines are sufficient (Boyd, 2016). And given the connections among different sectors, it would also be ideal if the chosen model captured the impacts of policies in the coal sector on the U.S. economy – and each of these sectors – as a whole. It is also necessary for BLM to determine whether the model should capture the U.S. or global economy.

Treatment of Externalities

Given the importance of externalities – particularly greenhouse gas and other air emissions – ideally the model would also explicitly model externalities. The ideal model would capture:

- Upstream and downstream greenhouse gas emissions;
- Other upstream externalities from mining, differentiated by mining type, region, and mine location; and
- Environmental impacts of coal transportation, including greenhouse gas and other emissions.

In modeling these externalities, the model should also be able to account for proposed regulations that are expected to lower these externalities.

Temporal and Spatial Dimensions

The temporal and spatial dimensions of the model are also relevant considerations. Temporally, the model should capture:

- The medium and long-run impacts of a policy – i.e., 30 years or more – given the lifetime of coal mines, generators, and infrastructure and investment; and
- A time step that reflects the planning period of the agency (i.e., five years for BOEM) or less.

Spatially, the model should capture:

- Relevant coal supply regions, ideally basin or mine-specific; and
- Relevant demand regions as is dictated as important by BLM – potentially at the power plant level to capture mine-plant contracts.

Transparency

In line with BLM's newly launched good governance policies, the agency is also interested in doing this analysis in a transparent manner (BLM, 2016). Transparency can be understood in the broader context of public availability, understandability, and robustness. Transparency criteria include:

- The assumptions and inputs of the model are publicly available and clearly documented;
- The model is publicly available;
- The model can be used by the public to test different inputs and scenarios, and does not require special equipment (licenses and large processors) or expertise to run;
- The model is as simple as is required to meet the agency's needs, such that any increased complexity – that increases the difficulty of understanding the drivers of the model and its results – is necessary and improves the predictive power of the model;
- The model allows for sensitivity analysis with respect to key parameters, including the price of coal and natural gas, the availability (and to whom) of technologies (e.g., compliance and generator), and the set of regulations and how they are implemented (Beasley and Morris, 2012; Boyd, 2016); and
- Federal agencies have successfully used the model before to meet similar objectives.

These transparency requirements will help ensure that the public understands the analysis and how it would differ with alternative assumptions (Beasley and Morris, 2012; Boyd, 2016).

Finally, there is the question of whether the model meets these requirements or will require some modification to meet them. Specifically:

- The model meets the above criteria; or
- If the model does not meet the criteria, it can meet them at a reasonable cost of adjustment.

If no model meets all criteria, a model should be selected that meets the minimum criteria or that can be modified to meet the minimum criteria. Regardless, after choosing a model, all analysis should be interpreted with these strengths (i.e., met criteria) and weaknesses (i.e., unfulfilled criteria) in mind (Boyd, 2016).

III. Model Comparison: MarketSim, NEMS, and IPM

To select the appropriate model for BLM to analyze coal projects and policies, we apply the above model selection criteria to three models: BOEM's MarketSim, EIA's NEMS, and ICF's IPM. In applying these criteria we identify strengths and weakness of each model. In particular, we find a tradeoff between model complexity and model transparency that BLM should take into careful consideration when selecting a model.

***BOEM's MarketSim*[3]**

BOEM's MarketSim is a relatively simple partial-equilibrium model of U.S. energy markets. Specifically, it models the supply and demand of multiple energy resources (coal, natural gas, oil) and energy by four domestic sectors (residential, commercial, industrial, and transportation) at the national scale. The model captures the rest of the world through the modeling of imports and exports and renewables (nuclear, hydro, wind, solar, other electric, net imports) in its energy supply function, though in less detail. Demand, coal production, and electricity production are modeled at the national scale (with some consideration of imports and exports), while oil and natural gas supply are modeled at fairly aggregate spatial scales (e.g., Alaska, Lower 48, etc.).

The model is run from 2010 to 2084, and BOEM calculates adjustment rates – reflecting the lifespan of "energy producing and consuming capital" – to capture the movement from short-run to long-run equilibrium; this ensures that the model does not move between long-run equilibria instantaneously. Own-price and cross-price demand and supply elasticities are drawn from the literature, though some parameters were derived from NEMS or from the expert input of Dr. Stephen Brown[4] when peer-reviewed estimates were unavailable in the literature. The remaining parameters are calibrated against baseline data given the estimated elasticities and adjustment rates. To simulate new leases, the quantity of oil and gas supplies are increased over the relative time period and equilibria prices are solved.

BOEM developed MarketSim with itself as the sole user of the model. The model meets the majority of our transparency criteria: it is publicly available, there is clear documentation of inputs and assumptions, and it is relatively simple such that it is easy to understand which assumptions drive the results. In particular, the cross-price elasticity assumptions between coal and its substitutes are clear. Additionally, the relatively simple structure of MarketSim is conducive to sensitivity analysis, particularly Monte Carlo simulation. However, in the classic tension between transparency and realism, the model may be overly simple such that it may not capture important nuances of the energy resource market. Specifically, the model is only as accurate as its elasticity and adjustment parameters, which drive the model's results.

[3] This section is based predominately on BOEM (2015).

[4] Dr. Brown is a professor of energy economics at UNLV who is also a visiting fellow at Resources for the Future and is an Associate Editor for *Energy Policy*. For more information, see https://www.unlv.edu/people/stephen-brown.

MarketSim's representation of the coal market currently lacks sufficient detail for BLM's purposes in that it only represents U.S. supply (domestic and imports), U.S. demand (industry and other), and demand for coal exports. Specifically, the model does not capture the differences in type and ownership of coal mines, types of coal, coal lease terms, regional coal supply, and regional demand curves. While it does model substitution effects between energy resources, it cannot capture substitution among federal, state, and private coal mines or among regions. Given the lack of ownership categories, it is unsurprising that it does not explicitly model royalty rates or other leasing policies.

The model also does not explicitly model generation, transmission, transportation (of coal), or regulations. While MarketSim does not explicitly model system constraints, regulations, or key economic sectors, these components are implicitly captured by the underlying parameters of the model. However, given that some parameters are over twenty years old and some are imputed by a sole expert, these parameters may not accurately reflect current demand and supply curves. This is likely to be problematic over time as new regulations are proposed and adopted. Finally, by choosing to model generation, transmission, and transportation implicitly, it is difficult to model the effect of various future scenarios on these sectors and energy resources (including coal) in general.

MarketSim has insufficient model dimensions for BLM's purposes, particularly with respect to spatial dimensions and externalities. While the current version of the model has sufficient temporal dimensions in that it runs until 2084, the model has no regional detail in the coal market and limited regional detail in the natural gas and oil markets. Furthermore, the model does not track upstream or downstream externalities – including greenhouse gases – across temporal or spatial dimensions.[5] It would also be difficult for BLM to modify MarketSim to account for coal transportation externalities, including greenhouse gas emissions.

In its current state, the MarketSim model is poorly suited to BLM's coal analysis. Potentially, the model could be modified, but the required changes would be extensive and time-intensive. Furthermore, it is unclear if the data is available to calibrate a more disaggregated version of the model, given that strong assumptions are required to calibrate the current version of MarketSim. For example, BOEM currently assumes an identical elasticity of supply and adjustment parameter for onshore oil production in the lower 48 states, offshore oil production in the lower 48 states, Alaskan oil production, and all other domestic oil production in its MarketSim model, using values provided in Brown (1998)[6] and by Dr. Brown (BOEM, 2015).[7] Even if it could successfully calibrate each of the parameters using estimates

[5] Instead, BOEM uses another model – the 2015 revised Offshore Environmental Cost Model (OECM) – to estimate the value of externalities from exploration and development of oil and nature gas sites in the Outer Continental Shelf. This model accounts for impacts to recreation, air quality, property values, subsidence harvests, commercial fishing, and ecology from oil spills, emissions, and platform and other infrastructure placement (BOEM, 2015b).

[6] Brown (1998) draws elasticity estimates from Chapter 5 of EMF (1991), which is an earlier version of Huntington (1992); he cites both studies.

[7] As it is currently structured with identical elasticities and adjustment parameters for oil parameters, there is potential concern that MarketSim cannot accurately capture substitution between differing types of oil production (offshore versus onshore and lower 48 versus Alaska). If a similar duplication of elasticities were to occur when modifying MarketSim to meet BLM's requirements (i.e., disaggregating the coal sector), concerns would arise about the accuracy of the model's predictions. At a minimum, sensitivity analysis – including Monte Carlos simulation – would be required.

from the literature, it is nearly impossible to keep elasticities and adjustment parameters up-to-date given that many scenario simulations will need to account for proposed or recently enacted regulations for which data is unavailable. However, given the inevitable tradeoff between transparency and complexity, BLM could choose to update the MarketSim model for its use if it strongly values transparency. If the agency chooses to do so, it should always include a sensitivity analysis for key parameters and a Monte Carlo simulation, given some of the aforementioned shortcomings.

U.S. EIA's National Energy Modeling System (NEMS)

EIA's NEMS is a general equilibrium model that solves for the market-clearing level of regional supply and demand in the U.S. energy sector in each period from the current time period to 2040. To solve for this complex equilibrium, NEMS was designed with a complex modular system of energy supply modules (oil and gas supply, natural gas transmission and distribution, coal market,[8] renewable fuels), demand modules (residential, commercial, transportation, industrial), conversion modules (electricity market and liquid fuels market), and non-domestic energy modules (macroeconomic activity and international energy) – some of which are broken down further into sub-modules and all connected together by an integrating module. While NEMS is not an optimization model, there are linear-programming modules and sub-modules within its structure, including: an electrical market module that uses the Capacity Expansion Planning Model to solve for additional generation resources that minimize investment and operation costs subject to constraints (fuel supply, electricity demand, peak load reserve margin, transmission, regulatory (including environmental), renewable portfolio standards); the coal distribution sub-module that solves for the cost minimizing delivery system subject to constraints (demand, regulation including environmental, technical, service and reliability, and contracts between suppliers and generators); and the petroleum market module. Thus, it is a general equilibrium electricity model (electricity, energy inputs, transportation and transmission) set in the context of a macro-economy and global electricity market to capture feedbacks and interactions (Qi, 2013; EIA, 2015).

NEMS' coal module is highly detailed, and meets most of the criteria enumerated above. It consists of two sub-modules: a production submodule and a distribution sub-module. The production sub-module contains approximately 40 econometrically derived supply elasticities in each time period – one for each combination of supply region (14 supply regions), mining type (surface and underground), and coal type (12 coal types).[9] These are balanced against demand curves for 16 demand regions from residential, commercial, industrial, electrical power, and international markets.

The coal distribution sub-module minimizes the transportation costs of distributing coal from mines to generators accounting for a variety of constraints including contracts between suppliers and plants.[10] However, the sub-module does not model the type of transportation and instead uses the average costs of transport; this may make tracking emissions and modeling potential changes in coal transportation

[8] The "Coal Market Module" (CMM) includes two sub-modules: production and distribution.

[9] Supply is a function of "capital utilization of mines, mining capacity, labor productivity, the user cost of capital of mining equipment, the cost of factor inputs (labor and fuel), and other mine supply costs (EIA, 2015)."

[10] In other words, the sub-module finds the least-costly way of moving coal between U.S. (demand and supply) regions to equate U.S. demand and supply of coal subject to import and export levels, contracts, and other constraints.

policies difficult. Given the macroeconomic context of NEMS, it also captures imports and exports of coal. In addition to not tracking emissions from coal transportation, NEMS also does not differentiate between mines on private and federal land – a key distinction necessary to capture the impacts of BLM's proposed leasing policies. However, EIA may be willing to modify NEMS to model this distinction.

As can be gleamed from the multitude of modules and sub-modules listed above, NEMS models in detail the consumption of energy (allowing for consumer responses to policies), electricity generation (capturing various regulations and other constraints on the system), and alternative energy resources to coal. The natural gas module simulates production, transport (transmission and distribution), and storage of natural gas over two seasons using three sub-modules. The pipeline tariff, distributor tariff, and interstate transmission sub-modules estimate tariff curves and distribution in order to simulate the natural gas price and the expansion of pipeline and storage capacity. The petroleum module includes sub-modules for domestic refineries and the marketing of liquid fuels. NEMS also has an extensive renewable energy module that captures multiple technologies, capacities, and sites. However, while this model captures various coal substitutes in detail, its complexity makes it difficult to understand the actual level of substitution among coal and these substitutes.

In general, NEMS has sufficient model dimensions, though it fails to track emissions over these dimensions and the various sectors discussed above. The current version runs until 2040 solving for greater than a twenty-year time horizon, although thirty years would be preferable given the lifespan of coal mines and capital. The model also has sufficient regional detail. However, NEMS only captures CO_2 and other emissions from fuel combustion, and not from upstream (production and transport) emissions.

NEMS is mostly transparent; it is publicly available and has extensive documentation. However, NEMS suffers from the tradeoff between realism and transparency in that the level of regional, sector, and regulation detail in the model makes it difficult to disentangle what is driving the results. This is highlighted by its module and sub-module structure that allows for a highly complex modeling environment in which the impact of a single module assumption is difficult to tease out.

EIA developed NEMS to develop its Annual Energy Outlook projects. Other branches and agencies of the U.S. government have used NEMS to complete analytical studies, including U.S. Congress, the Executive Office of the President, other Department of Energy offices including the Office of Policy and International Affairs, and other federal agencies, including the Surface Transportation Board. The model is also used by several non-governmental organizations, including the Electric Power Research Institute (EPRI), Duke University, Georgia Institute of Technology, and NERA Economic Consulting (EIA, 2015).

Overall, the NEMS model is advantageous in several regards. It is a publicly available model that is relatively transparent, though its complexity makes it somewhat opaque. The model appears to meet most of BLM's needs for the coal programmatic review and future assessment of coal scenarios. NEMS is also the sole model to explicitly analyze contracts between coal suppliers and generators as a constraint on transport, and to capture the macro-economic environment in which the U.S. coal market is a part; this latter criterion may significantly impact the model results and allows NEMS to provide valuable information on macro-economic impacts such as employment (EIA, 2014; EIA, 2015).

However, some work may be necessary to enable BLM to model its scenarios of interest. While NEMS's current structure would easily allow BLM to model an expansion or contraction of capacity (using the econometrically estimated supply curves), it cannot model changes to leasing policies – such as royalty rates or minimum bids – because the model does not differentiate between federal and private mines, nor does it model these policies.[11] It would also be difficult to model the impact of coal transport policies given the current lack of explicit modeling of the U.S. rail system (the primary method of coal transport). Potentially, EIA could modify the NEMS model to meet BLM's needs, particularly given that it will likely need to do so if BLM changes its policies.

ICF International's Integrated Planning Model (IPM)

ICF International's Integrated Planning Model (IPM) is a linear programming model that minimizes the cost of meeting national electricity demand (including hourly peak demand) subject to regulatory (emissions) and system (transmission and dispatch) constraints under perfect competition and perfect foresight. In doing so, IPM finds the optimal path over a large set of decision variables – including coal rank, grade, and quality (emissions) – that minimizes the present value of cost streams to expand capacity and control emissions to meet demand, regulatory and system requirements.[12] IPM was recently used by Vulcan (2016) to analyze royalty rate increase and production limit scenarios for coal mines on federal lands (with and without the Clean Power Plan). Unlike NEMS, IPM does not account for sectors outside of the energy sector, with the exception of the transportation sector (Beasley and Morris, 2012; EPA, 2013; Qi, 2013).

IPM's coal sector is highly detailed, potentially more so then NEMS. In each time period, the model produces 67 supply curves corresponding to each of the 36 regions, mining type (surface and underground), and 36 coal types (rank, grade, and quality). In assembling these supply curves, the developer quantified the economically recoverable coal reserves and their costs. In considering coal mine types, IPM is more detailed than NEMS in that it accounts for different treatment of overburden for surface mines – dragline versus track and shovels – and different mine design for underground mines – longwall versus continuous room-and-pillar. Unlike NEMS, IPM also models royalties and levies on coal mines – including state and mine type-specific taxes and fees – in additional to other regulations. Like NEMS, IPM also explicitly models the transportation of coal, but in greater detail. Specifically, IPM models the full transportation network such that supply is limited to particular power plants based on available transportation options, and power plants pay different transportation rates based on competition, distances, and location (including a Power River Basin specific price). The model also captures the import and export of coal (EPA, 2013). Finally, ICF modified its model for Vulcan (2016) to account for the private-public division of mines (this modification is not part of the latest EPA version (2013; 2015) of IPM).

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[11] In general, NEMS accounts for most legislation and regulations; see "Appendix A: Handling of federal and selected state legislation and regulations in the AEO" of EIA (2015). However, the sole mention of royalty rates in this documentation is with regards to "The Outer Continental Shelf Deep Water Royalty Relief Act." There is also no mention of royalty rates in the documentation of the "Coal Market Module".

[12] IPM treats the cost of capital as a payment stream, and not an upfront cost.

IPM captures other aspects of the power sector, including generation, transmission, and dispatch. While, like NEMS, it models coal substitutes (natural gas, oil, and renewables), it only models the supply curves of natural gas in significant detail comparable to coal. Similarly, energy demand is modeled relatively simply such that electricity price is only considered endogenously when conducting sensitivity analysis (i.e., not in the base run). Furthermore, the model captures regional supply and demand. While IPM models imports and exports, the model does not capture the connection of the U.S. energy market to the macro-economy. Thus, IPM cannot track the macro-economic effects of energy policies such as employment impacts.

With respect to dimensions, the IPM model fulfills the needs of BLM. IPM models seven discrete time periods out to 2050: 2016, 2018, 2020, 2025, 2030, and 2050. In doing so, the model captures the full lifetime of capital and mines. Like NEMS, IPM models CO_2 and pollutant emissions from combustion, but does not capture upstream (production or transport) emissions (EPA, 2013).

IPM is the least transparent of the three models. The model is *not* publicly available. While there is some documentation on the model—as provided by EPA (2013; 2015) – the model is nearly a black box given its proprietary nature (IPW, 2016). Consultants worked on the coal supply curves (i.e., Wood Mackenzie) and coal transportation networks (specifically Hellerworx and Tetratech), further making reproducibility difficult. Furthermore, given the realism of the model – i.e., it includes regional, sector, regulatory and system constraint detail – IPM is a complex model that requires significant processing power to solve. Thus, like NEMS, it is difficult to disentangle which assumptions are driving the model or to conduct a sensitivity analysis (including a Monte Carlo simulation). Thus, IPM is on the opposite side of the transparency-realism continuum as compared to MarketSim.

IPM uses proprietary software that is licensed by federal agencies (including U.S. EPA, the Surface Transportation Board, and the Federal Energy Regulatory Commission), state agencies (air regulatory agencies and the Regional Greenhouse Gas Initiative (RGGI)), utilities, and public and private sector clients (including the Bipartisan Policy Center and Edison Electric Institute) (Beasley and Morris, 2012; EPA, 2013; RGGI, 2016). Therefore, several federal and state agencies seem to believe that the benefits of detail outweigh reduced transparency.

Given ICF International's model additions to accommodate Vulcan (2016) – such as federal and private coal mine ownership – the IPM model has all of the components necessary to model new lease and royalty rate scenarios (EPA, 2013, p. 9-19). Additionally, it explicitly models the U.S. transportation network. Thus, IPM can model changes in coal reserves, royalty rates, and transport cost and policies, among other changes.

While the pros of the IPM model are clear, its complexity with respect to coal and natural gas markets has some downsides. Most importantly, the IPM model is the most opaque of the three models. Furthermore, IPM lacks detail in some sectors, such as consumer behavior and non-gas substitutes for coal, and the general equilibrium context of NEMS. This latter shortcoming implies that IPM – unlike NEMS – cannot track employment impacts. Last, like NEMS, the complex model structure of IPM makes the elasticity of substitution between coal and natural gas difficult to determine and makes sensitivity analysis – like Monte Carlo simulations – more difficult to run.

IV. Model Selection

Above, we developed model selection criteria and analyzed three viable models currently in use by federal agencies. As expected, no model meets all of the suggested criteria. Rather, BLM will need to weigh the tradeoffs among these models and proceed with one or more models that best meet its needs for coal PEIS and future projects.

In an ideal world, BLM would simulate the effect of leasing policy changes using all three models, modifying both NEMS and MarketSim to suit its needs. Using all three models is ideal because each model contains different assumptions that drive its results,[13] many of which are hard to disentangle (particularly for the complex models).

A next-best solution would be for BLM to choose MarketSim – the most simple and transparent model – and one of the complex models, NEMS or IPM. This would minimize the cost of the transparency-complexity tradeoff discussed throughout this document.

If BLM can choose only one model, due to time or resource constraints, BLM must weigh complexity versus transparency. One could argue that MarketSim is too simple and would require significant modification to tailor it to the coal PEIS process. However, the shortcomings of MarketSim are clear to outsiders (because of its transparency and simplicity); this cannot be said of the more complex models. With the ability to conduct sensitivity analysis and Monte Carlo Simulations, MarketSim's simplicity allows us to model this uncertainty more explicitly.

NEMS falls somewhere between MarketSim and IPM in terms of transparency and complexity, though it would require some additional modification for the coal PEIS and future coal analysis. Given the balance between complexity and transparency, NEMS is a strong model choice, especially if EIA is willing to modify the model to meet BLM's needs.

Finally, IPM is highly complex and is the sole model that is already modified to conduct BLM's analysis. Yet, the model lacks transparency and some of the detail about coal substitutes (particularly oil and renewables), consumer behavior, and the macro-economy captured by NEMS. However, if BLM needs a model quickly and lacks the time required to modify models, IPM may best meet BLM's needs. IPM meets key modeling requirements for the coal PEIS: (1) substitution of federal coal with private coal, natural gas, and renewables, (2) multiple regions and types of coal (rank, rank, quality), (3) coal transportation and its costs, (4) leasing policies (coal capacity, royalty rates, and transportation costs), and (5) the establishment and retirement of power plants (preferably endogenously) to capture the change in generation mix over time.

In the end, BLM's choice comes down to weighing transparency and complexity, along with the agency's resource and time constraints. Ideally, more work can and should be done to test the accuracy of these models. In particular, each model should be run against theoretical and known scenarios – including backcasting of power sector models – to test their relative strengths. For example, a simpler and more transparent model may be preferable if it makes accurate predictions.

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[13] Some of the important assumptions are: how regulations are modeled, the technologies available to generators, and the price of natural gas.

Additionally, regardless of which model is chosen, BLM should ask the developers to modify the models to allow for sensitivity analyses over key parameters, such as the price of natural gas. Without the ability to conduct sensitivity analysis, the most complex models, particularly if they are poor predictors, can suffer from false precision.

After choosing a model, resulting analysis should be interpreted with model strengths and weaknesses in mind (Boyd, 2016). In addition to discussing each model's individual limitations, BLM and any other agency using capacity expansion models should also discuss their limitations as a whole. For example, investment decisions in the power sector are often driven by a sector's ability to procure financing, not by the capital costs as modeled in many of these models. While some models like NEMS try to include adjustment factors to account for these financing costs, they are not modeling financial restrictions explicitly (Beasley and Morris, 2012). Additionally, while some capacity expansion models track employment – such as NEMS[14] in our analysis – capacity expansion models are not accurate job estimate predictors, even in the case of CGE models like NEMS (Beasley and Morris, 2012). Finally, as noted above, these models do not track upstream emissions and other externalities, although these models could be adjusted to do so; NEMS and IPM track downstream combustion emissions.

V. Conclusion

This paper is not a comprehensive review of power sector models available to BLM or of capacity-expansion models used by the federal government. Instead, this paper develops selection criteria for BLM to apply when making its model selection for its analysis of coal leases and of proposed leasing policies. BLM can apply these criteria to available capacity-expansion models that may be suitable for the coal PEIS process and beyond.

We apply these criteria to three models, which we identify as the most likely for BLM to consider, demonstrating how to apply these criteria in assessing each model's pros and cons. Our recommendation depends upon on how BLM chooses to weigh model transparency against model complexity (and potential realism). We favor the use of multiple models or NEMS to balance these tradeoffs. However, if BLM is constrained by time or resources (or both), IPM is a sound choice, given its plug-and-play nature. However, IPM is more opaque and requires hiring an outside consultant to run the model and scenarios. Finally, regardless of which model is chosen, BLM should take steps to ensure that the model allows for sensitivity analyses over key parameters, like the price of natural gas, and that the limitations of the model are disclosed.

[14] The Macroeconomic Activity Module (MAM) in NEMS provides estimates of employment by industrial and service sectors and census divisions (EIA, 2014). MarketSim and IPM do not model the impact of policy changes on national employment.

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