OCS Study
BOEM 2023-055

Consumer Surplus and Energy Substitutes for OCS Oil and Gas Production: The 2023 Revised Market Simulation Model (MarketSim)

Model Description

US Department of the Interior
Bureau of Ocean Energy Management
Sterling, VA

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by

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US Department of the Interior
Bureau of Ocean Energy Management
Sterling, VA

DISCLAIMER

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Abbreviations and Acronyms

AEO	Annual Energy Outlook
API	American Petroleum Institute
BOEM	Bureau of Ocean Energy Management
DOE	Department of Energy
DOI	Department of the Interior
E&D	Exploration and Development
EIA	Energy Information Administration
GHG	greenhouse gas
GLEEM	Greenhouse Gas Life Cycle Energy Model
GOM	Gulf of Mexico
IEA	International Energy Agency
IPI	Institute for Policy Integrity
LNG	liquefied natural gas
MarketSim	Market Simulation Model
NAA	No Action Alternative
NETL	National Energy Technology Laboratory
NEMS	National Energy Modeling System
OCS	Outer Continental Shelf
OECM	Offshore Environmental Cost Model
ROW	rest-of-world
SES	substitution effect sensitivity
UNLV	University of Nevada, Las Vegas
U.S. or US	United States

1. Background

The Bureau of Ocean Energy Management (BOEM) is charged with assisting the U.S. Secretary of the Interior in carrying out the mandates of the Outer Continental Shelf (OCS) Lands Act, which calls for expedited exploration and development of the OCS to, among other goals, "reduce dependence on foreign sources and maintain a favorable balance of payments in world trade." The OCS Lands Act also requires that BOEM prepare forward-looking five-year schedules of proposed OCS oil and gas lease sales, the National OCS Oil and Gas Leasing Program (National OCS Program), that define as specifically as possible the size, timing, and location of the OCS area(s) to be offered for lease.

As part of the development of the National OCS Program, BOEM completes an analysis of the energy market's response to production that could result from leases issued under these programs. This document comprises a detailed description of the methodology used by BOEM to measure the energy market response to new production on leases issued in different planning areas under a specific program. The analytical tool that BOEM employs internally to estimate this market response is called the Market Simulation Model (MarketSim). As might be expected, key inputs to the model are the amounts of new annual OCS oil and gas production. The magnitudes of these production estimates are based on assessments of the non-leased, economically recoverable oil and gas resources in each planning area, as well as historical trends in leasing and production.

The timing of these production estimates emerges from stipulated Exploration and Development (E&D) scenarios in each planning area. An E&D scenario defines the incremental level of OCS exploration, development and production activity within planning areas expected to be made available for leasing in the National OCS Program. Elements of an E&D scenario include the number of exploration wells drilled, the number of platforms installed, the number of development wells drilled, miles of new pipeline constructed, aggregate oil and gas production, and the number of platforms removed. MarketSim's use of the E&D scenarios, however, is limited to the OCS oil and gas production included in a given scenario. The other elements of the E&D scenarios support other analyses conducted by BOEM. A crucial output of the model calculations based on the E&D scenario production is the net change in consumer surplus, an important component of the net benefits calculation for the National OCS Program.

A companion document (*Forecasting Environmental and Social Externalities Associated with OCS Oil and Gas Development*) describes the calculations and supporting data for another model BOEM uses to estimate the net environmental and social costs attributable to the program proposal, specifically the net of the environmental and social costs attributable to the No Action Alternative—that is, from energy sources that would substitute for OCS production in the absence of the National OCS Program (Industrial Economics, Inc. 2023). The outputs of this model's calculations represent another important part of the measure of net social benefits from adoption of the National OCS Program.

2. Model Description

What follows is the general framework for MarketSim's economics-based model representation of U.S. energy markets. The model simulates end-use domestic consumption of oil, natural gas, coal, and electricity in four sectors (residential, commercial, industrial, and transportation); primary energy production; and the transformation of primary energy into electricity. The model mostly represents U.S. energy markets, but it also captures interaction with world energy markets as appropriate. As in the previous version, the current MarketSim takes current measures of energy production, consumption, and prices assuming no new OCS leasing as a baseline to which a given scenario of OCS production is added. Accounting for substitution between different sources of energy, the model calculates equilibrating prices for oil, natural gas, coal, and electricity based upon the user-specified increase in OCS production of oil and gas.

MarketSim is calibrated to reproduce a specified baseline projection, such as the reference case in the Energy Information Administration's (EIA) *2023 Annual Energy Outlook* (referred to in this document as AEO 2023) (EIA 2023a) or other output produced by the EIA's National Energy Modeling System (NEMS) for the baseline projection. The user-specified offshore production scenario then is added to the production side of the market equilibration, and the model adjusts prices until all markets converge on a new equilibrium.

3. Baseline Supply and Demand Projections

The baseline supply and demand projections in MarketSim were obtained from a customized model run of EIA's NEMS model.[1] The standard NEMS runs conducted for EIA's AEO series assume the issuance of new leases for OCS oil and natural gas production. Given that the purpose of MarketSim is to assess the market impacts of new leases relative to a scenario without new leasing, these new leases are not included in the MarketSim baseline. Thus, the customized NEMS runs developed for use in MarketSim deviated from the reference case in the AEO by removing new offshore leasing on the OCS off the lower 48 states from the model's calculations.[2] The results of this NEMS run constitute the baseline data incorporated into the model.

The customized NEMS runs (EIA 2023b)—based on EIA's AEO 2023—generated the baseline supply and demand projections incorporated into MarketSim and relied on data from EIA's *International Energy Outlook 2021* (EIA 2021) to inform projections related to energy supply and demand outside of the United States. Within the MarketSim framework, this data includes projections of non-U.S. supply and demand in global oil markets and U.S. exports and imports of natural gas, electricity, and coal. The *International Energy Outlook 2021* was published prior to Russia's invasion of Ukraine and the passage of the Inflation Reduction Act; therefore, the international data included in the customized NEMS runs used in the 2023 version of MarketSim do not reflect these developments.

4. Model Framework

MarketSim's approach to developing an energy model for policy evaluation is to represent market responses as an equilibrating process that moves the market toward a long-run equilibrium, subject to short-run constraints on supply and demand adjustments from one year to the next. This long-run equilibrium is not directly observable but can be inferred from market conditions reflected in the model's baseline forecast and the underlying parameters of the model. The result is a model that moves ever closer toward a long-run equilibrium with each successive year.

To create such a model, it is necessary to provide a set of assumed long-run elasticities and partial adjustment parameters. These are developed by reviewing the appropriate economic research, using technology assessments and by making comparisons across existing runs of NEMS to infer elasticities (see below). The supply and demand equations in the sections that follow show how MarketSim applies these partial adjustment parameters and long-run supply and demand elasticities.

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[1] The MarketSim model extrapolates the baseline data provided in the NEMS projection forecasts to cover the life of leases issued in the National OCS Program.

[2] See supporting documentation accompanying the delivery of prior NEMS output (Gruenspecht 2009). The data incorporated into the current version of MarketSim are consistent with the "Constrained Supply" scenario described in this document.

5. Oil Market

MarketSim represents the world oil market with sector detail for the United States, a single supply equation for non-U.S. production, and a small number of demand equations for non-U.S. consumption. Oil use for electricity generation is represented in the section on electricity below. The equations that follow specify MarketSim's estimation of U.S. oil demand, non-U.S. oil demand, U.S. oil supply, non-U.S. oil supply, oil imports delivered to the U.S. by tanker, U.S. crude oil exports, and U.S. exports of refined petroleum products.

5.1 U.S. Oil Demand

$$Q_{Doi,t} = A_{oi,t} \cdot P_{o,t}^{\eta_{oi}} \cdot \prod_j P_{j,t}^{\eta_{oji}} + (1 - \gamma_{Doi}) Q_{Doi,t-1}$$

for each U.S. end-use sector i; and $j = g$ (gas), c (coal), and e (electricity) where:

$Q_{Doi,t}$ = the quantity of oil demanded in sector i at time t
$A_{oi,t}$ = a constant calibrated to baseline data
$P_{o,t}$ = price of oil at time t
η_{oi} = long-run price elasticity of oil demand in sector i
$P_{j,t}$ = price of energy source j at time t
η_{oji} = long-run elasticity of demand for oil with respect to the price of energy source j in sector i
γ_{Doi} = rate at which demand for oil in sector i adjusts[3]

The four U.S. end-use sectors i are residential, commercial, industrial, and transportation.

5.2 Non-U.S. Oil Demand

$$Q_{Dox,t} = A_{ox,t} \cdot P_{o,t}^{\eta_{ox}} + (1 - \gamma_{Dox}) Q_{Dox,t-1}$$

where

$Q_{Dox,t}$ = quantity of non-U.S. oil demand at time t
$A_{ox,t}$ = a constant calibrated to baseline data
η_{ox} = long-run price elasticity of non-U.S. oil demand
γ_{Dox} = rate at which non-U.S. oil demand adjusts

Non-U.S. oil demand is strictly a function of the oil price and no other prices, domestic or foreign. MarketSim specifies three categories of non-U.S. oil demand: (1) non-U.S. demand for U.S. crude oil, (2) non-U.S. demand for U.S. refined products, and (3) non-U.S. demand for non-U.S. oil. The model assumes that these three categories are mutually exclusive.

5.3 U.S. Oil Supply

$$Q_{Sou,t} = B_{ou,t} \cdot P_{o,t}^{\eta_{ou}} + (1 - \gamma_{Sou}) Q_{Sou,t-1}$$

[3] Note that this deviates from standard notation used in the empirical literature on demand and supply estimation by using gammas to represent adjustment rather than persistence.

for each domestic source u = lower 48 onshore (conventional), lower 48 onshore (tight), lower 48 offshore, Alaska onshore, Alaska offshore, biofuels, other, and rest of world; where

$Q_{Sou,t}$ = quantity of oil supplied from U.S. source u at time t
$B_{ou,t}$ = a constant calibrated to baseline data
η_{ou} = long-run elasticity of oil supply from source u
γ_{Sou} = rate at which U.S. oil supply u adjusts

Consistent with the EIA classification, the term "oil" includes all liquid fuels that are close substitutes for petroleum products (e.g., biofuels).

5.4 Non-U.S. Oil Supply

$$Q_{Soy,t} = B_{oy,t} \cdot P_{o,t}^{\eta_{oy}} + \left(1 - \gamma_{Soy}\right) Q_{Soy,t-1}$$

where

$Q_{Soy,t}$ = quantity of non-U.S. oil supplied at time t
$B_{oy,t}$ = a constant calibrated to baseline data
η_{oy} = long-run elasticity of non-U.S. oil supply
γ_{Soy} = rate at which non-U.S. oil supply adjusts

Non-U.S. oil supply is estimated in MarketSim's equilibrating equations as a separate value that represents tanker imports and pipeline imports combined, consistent with AEO reporting.

5.5 Oil Imports Delivered via Tanker

MarketSim uses the equations outlined above to find changes in oil market consumption, production, and prices under a given E&D scenario. These equilibrating equations do not distinguish between pipeline and tanker imports of oil. To assess the environmental impacts of the No Action Alternative, however, the Offshore Environmental Cost Model (OECM) requires estimates of the change in imports delivered via tanker.[4] MarketSim therefore uses a post-processing approach to estimate the change in oil tanker imports. Under this approach, MarketSim assumes that all pipeline imports of oil are produced in Canada. Based on this assumption, MarketSim estimates the change in tanker imports as the difference between total imports (estimated as U.S. consumption less U.S. production) and imports from Canada. The model's calculation for imports from Canada is similar to the non-U.S. oil supply formula but utilizes its own parameter, elasticity, and adjustment rate.

$$Q_{Soc,t} = B_{oc,t} \cdot P_{o,t}^{\eta_{oc}} + (1 - \gamma_{Soc}) Q_{Soc,t-1}$$

where

$Q_{Soc,t}$ = quantity of Canadian pipeline oil imports supplied at time t
$B_{oc,t}$ = a constant

[4] The No Action Alternative is defined as the scenario in which BOEM holds no OCS oil and gas lease sales during the 5-year period covered by the program or, in other words, in which the No Sale Option is selected for each program area.

η_{oc} = long-run elasticity of Canadian pipeline oil imports
γ_{Soc} = rate at which Canadian pipeline oil import supply adjusts

5.6 U.S. Crude Oil Exports

As described above, MarketSim models oil as a global commodity trading in a global market with supply and demand specified separately for the U.S. and the rest of the world. To estimate changes in oil exports, MarketSim's demand equations specify the three categories of non-U.S. demand identified above: (1) non-U.S. demand for U.S. crude oil, (2) non-U.S. demand for U.S. refined petroleum products, and (3) non-U.S. demand for non-U.S. oil. The first of these items represents U.S. crude oil exports. Therefore, to estimate the impact of a given E&D scenario on U.S. crude oil exports, MarketSim calculates the difference between non-U.S. demand for U.S. crude oil between the E&D scenario and the model's baseline projection.

Although this method for estimating the change in U.S. crude oil exports is incorporated into MarketSim's balancing equations, it does not distinguish between exports of OCS crude oil and exports of crude from other sources. Modeling crude oil exports at this level of detail would require information on the quality of OCS crude relative to other crudes (i.e., API gravity and sulfur content) and various location-specific factors that may influence the relative cost of refining different U.S. crudes domestically versus exporting them to non-U.S. refineries. Incorporating these details into MarketSim's balancing equations is not currently feasible.

Nevertheless, to approximate OCS crude oil exports, MarketSim includes a series of post-processing calculations that parse the model's estimates of the change in crude oil exports into crude oil produced on the OCS and crude oil produced by other sources. These post-processing calculations are based on the assumption that export is most likely for those types of crude oil that are imported in small quantities relative to the total amount (of that oil type) used as feedstock by U.S. refineries. For the purposes of these post-processing calculations, oil type is defined according to API gravity, as this is the only metric of oil quality for which BOEM has data across all OCS crude oils. More specifically, these post-processing calculations distinguish between heavy crude (API gravity less than 27), medium crude (API gravity greater than or equal to 27 but less than 35), and light crude (API gravity greater than or equal to 35).

The specific steps in the post-processing calculations are as follows:

- Based on recent EIA data on crude oil production and crude oil imports by API gravity category (examined as a proxy for U.S. refinery feedstock; see Table 1), MarketSim assumes that light crude produced on the OCS may be exported but not medium or heavy crude. This assumption reflects the fact that U.S. imports for heavy and medium crudes are fairly large (86 and 47 percent, respectively) relative to the total amount used by U.S. refineries. For light crudes, however, imports represent only 10 percent of the total feedstock for U.S. refineries.

Table 1. U.S. Crude Oil Production and Imports by API Gravity Category

API Gravity Type	Total Imports (thousands of barrels) [A]	Production (thousands of barrels) [B]	Total (thousands of barrels) [C=A+B]
Heavy	1,607,176	261,927	1,869,103
Medium	836,060	960,881	1,796,941
Light	244,173	2,181,004	2,425,177
TOTAL	**2,687,409**	**3,403,812**	**6,091,221**

Data Sources: Import data presented here are derived from EIA (2015a). Production data by API gravity category derived from EIA (2015b).

- Due to uncertainty regarding the exact percentage of light OCS crude likely to be exported, MarketSim specifies this percentage as a range, with a low end of 25 percent and a high end of 75 percent. These values are applied to all light crude oil included in the user-specified E&D scenario.
- If either of the resulting values exceeds the total change in crude exports estimated by MarketSim, the estimate is capped at the total change in exports (i.e., so that the change in OCS crude oil exports does not exceed the total change in exports estimated by MarketSim).

5.7 U.S. Exports of Refined Petroleum Products

MarketSim estimates U.S. exports of refined petroleum products based on the specification of non-U.S. demand for refined petroleum products in the model's balancing equations.[5] For a given E&D scenario, the change in U.S. refined product exports is equal to the estimated change in non-U.S. demand for U.S. refined petroleum products. This approach is similar to that outlined above for U.S. exports of crude oil, which MarketSim estimates based on the change in non-U.S. demand for U.S. crude oil.

As a post-processing calculation to MarketSim's specification of the new market equilibrium, the model parses the estimated change in refined product exports between refined products derived from OCS oil and refined products derived from other sources. To make this distinction, MarketSim assumes that the probability that a given barrel of refined product from U.S. refineries is derived from OCS crude oil is proportional to OCS oil's total share of the feedstock used by U.S. refineries (i.e., OCS oil used as feedstock divided by the total feedstock amount). Based on this assumption, the quantity of refined product exports derived from OCS crude is estimated as follows:

$$Q_{R,X,OCS} = F_{OCS} \times Q_{RL,X}$$

where

$Q_{R,X,OCS}$ = change in refined product exports derived from OCS crude oil

F_{OCS} = OCS crude oil's share of total U.S. refinery feedstock

$Q_{RL,X}$ = MarketSim's estimate of the change in U.S. refined product exports

Applying this approach requires information on OCS crude oil as a share of U.S. refinery feedstock (F_{OCS} in the above equation). To derive F_{OCS}, MarketSim ideally would use the projected amount of OCS crude oil used by U.S. refineries and the projected amount of feedstock that these refineries use. These specific projections, however, are not readily available. In the absence of such data, MarketSim approximates OCS crude as a share of total refinery feedstock as follows based on MarketSim projections under the E&D scenario:

$$\boldsymbol{F_{OCS} = \frac{Q_{o,off}}{Q_{o,on} + Q_{o,off} + Q_{o,ni}}}$$

where

F_{OCS} = OCS crude oil's share of total U.S. refinery feedstock

[5] As noted above, this category of non-U.S. demand represents one of three included in the model. The other two categories are non-U.S. demand for U.S. crude oil and non-U.S. demand for non-U.S. oil.

$Q_{o,off}$ = offshore crude oil production in the U.S. projected by MarketSim under the E&D scenario over the model's full analytic time horizon
$Q_{o,on}$ = onshore crude oil production in the U.S. projected by MarketSim under the E&D scenario over the model's full analytic time horizon
$Q_{o,ni}$ = U.S. net imports of oil projected by MarketSim under the E&D scenario over the model's full analytic time horizon

The numerator on the right-hand side of this equation approximates OCS crude used as feedstock at U.S. refineries (because the U.S. exports a relatively small portion of the crude oil it produces), and the denominator represents an approximation of total U.S. refinery feedstock. MarketSim uses projections from the E&D scenario to populate this equation rather than baseline EIA data because onshore and offshore production quantities, as well as net imports, may change significantly under a given E&D scenario relative to the baseline.

MarketSim applies this approach after the model converges on a new market equilibrium and estimates new world oil prices, by year ($P_{o,t}$).

6. Natural Gas Market

MarketSim represents the domestic natural gas market with exports and imports. This stands in contrast to oil, which MarketSim simulates as a global market. Natural gas use for electricity generation is represented in the section on electricity below. The equations that follow specify MarketSim's estimation of U.S. natural gas demand, demand for U.S. natural gas exports, and U.S. natural gas supply.

6.1 U.S. Natural Gas Demand

$$Q_{Dgi,t} = A_{gi,t} \cdot P_{g,t}^{\eta_{gi}} \cdot \prod_{j} P_{j,t}^{\eta_{gji}} + \left(1 - \gamma_{Dgi}\right) Q_{Dgi,t-1}$$

for each U.S. end-use sector i; and $j = o$ (oil), c (coal), and e (electricity) where

$Q_{Dgi,t}$ = quantity of natural gas demanded in sector i at time t
$A_{gi,t}$ = a constant calibrated to baseline data
$P_{g,t}$ = price of natural gas at time t
η_{gi} = long-run price elasticity of natural gas demand in sector i
$P_{j,t}$ = price of energy source j at time t
η_{gji} = long-run elasticity of demand for natural gas with respect to the price of energy source j in sector i
γ_{Dgi} = rate at which demand for natural gas in sector i adjusts

The U.S. natural gas demand sectors represented in MarketSim include the residential, commercial, industrial, and transportation sectors.

6.2 Demand for U.S. Natural Gas Exports

$$Q_{Dgx,t} = A_{gx,t} \cdot P_{g}^{\eta_{gx}} + \left(1 - \gamma_{Dgx}\right) Q_{Dgx,t-1}$$

where

$Q_{Dgx,t}$ = quantity of U.S. natural gas exports at time t
$A_{gx,t}$ = a constant calibrated to baseline data
η_{gx} = long-run price elasticity of export demand for U.S. natural gas
γ_{Dgx} = rate at which export demand for natural gas adjusts

U.S. natural gas exports are dependent only upon the domestic price of natural gas and no other prices, domestic or international.

6.3 U.S. Natural Gas Supply

$$Q_{Sgu,t} = B_{gu,t} \cdot P_{g,t}^{\eta_{gu}} + \left(1 - \gamma_{Sgu}\right) Q_{Sgu,t-1}$$

for each domestic and imported source u, where

$Q_{Sgu,t}$ = quantity of natural gas supplied to the U.S. market from domestic or imported source u at time t
$B_{gu,t}$ = a constant calibrated to baseline data
η_{gu} = long-run elasticity of natural gas supply to the U.S. market from source u
γ_{Sgu} = rate at which natural gas from source u adjusts

Natural gas production categories included in MarketSim are (1) lower 48 conventional, (2) lower 48 unconventional, (3) Alaska, (4) offshore, (5) other, (6) pipeline imports, and (7) tanker imports.

7. Coal Market

MarketSim represents the U.S. coal market with exports and imports. Coal use for electricity generation is represented in the section on electricity below. The equations that follow present the model's estimation of U.S. coal demand, demand for U.S. coal exports, and U.S. coal supply.

7.1 U.S. Coal Demand

$$Q_{Dci,t} = A_{ci,t} \cdot P_{c,t}^{\eta_{ci}} \cdot \prod_{j} P_{j,t}^{\eta_{cji}} + (1 - \gamma_{Dci}) Q_{Dci,t-1}$$

for each U.S. end-use sector i; and $j = g$ (gas), o (oil), and e (electricity) where

$Q_{Dci,t}$ = quantity of coal demanded in sector i at time t
$A_{ci,t}$ = a constant calibrated to baseline data
$P_{c,t}$ = price of coal at time t
η_{ci} = long-run price elasticity of coal demand in sector
$P_{j,t}$ = price of energy source j at time
η_{cji} = long-run elasticity of demand for coal with respect to the price of energy source j in sector i
γ_{Dci} = rate at which demand for coal in sector i adjusts

Other than the electricity sector, whose coal demand is modeled separately, MarketSim's domestic demand sectors for coal include industrial and other.

7.2 Demand for U.S. Coal Exports

$$Q_{Dcx,t} = A_{cx,t} \cdot P_c^{\eta_{cx}} + (1 - \gamma_{Dcx}) Q_{Dcx,t-1}$$

where

$Q_{Dcx,t}$ = quantity of U.S. coal exports at time t
$A_{cx,t}$ = a constant calibrated to baseline data
η_{cx} = long-run price elasticity of export demand for U.S. coal
γ_{Dcx} = rate at which export demand for coal adjusts

Exports are dependent only upon the domestic price of coal. No other energy prices, domestic or international, affect exports of coal.

7.3 U.S. Coal Supply

$$Q_{Scu,t} = B_{cu,t} \cdot P_{c,t}^{\eta_{cu}} + (1 - \gamma_{Scu}) Q_{Scu,t-1}$$

for each domestic and imported source, u where

$Q_{Scu,t}$ = quantity of coal supplied to the U.S. market from domestic or imported source u at time t
$B_{cu,t}$ = a constant calibrated to baseline data
η_{cu} = long-run elasticity of coal supply to the U.S. market from source u
γ_{Scu} = rate at which coal from source u adjusts

8. Electricity Market

MarketSim represents the U.S. electricity market and models U.S. exports and imports of electricity as net imports. The electricity sector in MarketSim also provides additional demand for oil, natural gas, and coal. The equations below present MarketSim's approach for estimating U.S. electricity demand, U.S. electricity supply, and demand for fossil fuels for electricity production.

8.1 U.S. Electricity Demand

$$Q_{Dei,t} = A_{ei,t} \cdot P_{e,t}^{\eta_{ei}} \cdot \prod_j P_{j,t}^{\eta_{eji}} + (1 - \gamma_{Dei}) Q_{Dei,t-1}$$

for each U.S. end-use sector i; and $j = g$ (gas), c (coal), and o (oil) where

$Q_{Dei,t}$ = quantity of electricity demanded in sector i at time t
$A_{ei,t}$ = a constant calibrated to baseline data
$P_{e,t}$ = price of electricity at time t
η_{ei} = long-run price elasticity of electricity demand in sector i
P_j = price of energy source j
η_{eji} = long-run elasticity of demand for electricity with respect to the price of energy source j in sector i
γ_{Dei} = rate at which demand for electricity in sector i adjusts

The U.S. demand sectors for electricity in MarketSim include (1) residential, (2) commercial, (3) industrial, (4) transport, and (5) other.

8.2 U.S. Electricity Supply

MarketSim uses separate approaches for the estimation of electricity derived from fossil fuels and electricity derived from other sources. Although the quantity of electricity generated from fossil fuels is dependent on fossil fuel prices, changes in these prices do not factor into the generation of electricity from non-fossil energy sources. To account for this difference in the economics of electricity generation for different types of power producers, MarketSim specifies electricity supply as follows:

$$Q_{Sej,t} = C_{j,t} \cdot \left(\frac{P_{e,t}}{P_{j,t}}\right)^{\eta_{ej}} + (1 - \gamma_{Sej})Q_{Sej,t-1}$$

for j = oil, natural gas and coal

$$Q_{Sel,t} = C_{l,t} \cdot P_{e,t}^{\eta_{el}} + (1 - \gamma_{Sel})Q_{Sel,t-1}$$

for l = nuclear, hydro, wind, solar, other electric, net imports, where

$Q_{Sej,t}$ = quantity of electricity supplied from fossil fuel energy source j at time t
$Q_{Sel,t}$ = quantity of electricity supplied from source l at time t
$C_{j,t}$ and $C_{l,t}$ = constants calibrated to baseline data
$P_{e,t}$ = price of electricity at time t
$P_{j,t}$ = price of fossil fuel energy source j at time t
η_{ej} = long-run elasticity of electricity supply from fuel j
η_{el} = long-run elasticity of electricity supply from source l
γ_{Sej} = rate at which electric power from fossil energy j adjusts
γ_{Sel} = rate at which electric power from source l adjusts

8.3 Demand for Fossil Fuel Energy to Produce Electricity

$$Q_{Dje,t} = K_{j,t} \cdot Q_{Sej,t}$$

for j = oil, natural gas and coal, where

$Q_{Dje,t}$ = quantity of energy source j used to produce electricity at time t and $K_{j,t}$ is a constant

9. Model Calibration

For a given set of elasticities, adjustment parameters, market quantities, and prices in the baseline projection, MarketSim uses the series of supply and demand equations outlined above to calculate the parameters A, B, C, and K in these equations. These parameters, having been calculated on the baseline projection equilibrium state, calibrate the model formulas directly to the market conditions observed in the baseline projection data. MarketSim then uses these parameters as constants in the simulation supply and demand formulas that equilibrate all four fuel markets under a given E&D scenario.

The model automatically updates the calibration parameters to match new baseline projection data immediately when entered into the baseline projection worksheet tables.

10. Equilibrium

The equilibration calculation of MarketSim selects $P_{o,t}$, $P_{g,t}$, $P_{c,t}$, and $P_{e,t}$ for each period t, such that the quantity of oil, natural gas, coal, and electricity demanded equals the quantity supplied in each period t:

World Oil Market

$$Q_{Doe,t} + Q_{Dox,t} + \sum_i Q_{Doi,t} = Q_{Soy,t} + \sum_u Q_{Sou,t}$$

U.S. Natural Gas Market (with exports and imports)

$$Q_{Dge,t} + \sum_i Q_{Dgi,t} + Q_{Dgx,t} = \sum_u Q_{Sgu,t}$$

U.S. Coal Market (with exports and imports)

$$Q_{Dce,t} + \sum_i Q_{Dci,t} + Q_{Dcx,t} = \sum_u Q_{Scu,t}$$

U.S. Electricity Market (with net imports)

$$\sum_i Q_{Dei,t} = \sum_j Q_{Sej,t} + \sum_l Q_{Sel,t}$$

To initiate the equilibration process for a given E&D scenario, MarketSim first adds the incremental increase in OCS production to the oil and gas supply terms in the above equilibrating equations. Because supply has changed, markets are not in equilibrium under the original baseline prices. Using Excel's solver function, MarketSim then uses reduced gradient methods to iterate through several combinations of the four fuel prices until it can bring all four fuel markets' supply and demand into equilibrium. During this process, all simulated supply and demand values are calculated using the same elasticity, adjustment, and parameter values used to represent the baseline. When zero disparity between supply and demand across all four fuel markets is achieved, MarketSim saves the market-clearing prices and proceeds to the next year to perform the same equilibration.

11. Adjustment Rates and Elasticities

All elasticities and adjustment rates in MarketSim have default values that are obtained from the literature, inferred from NEMS output, or obtained through expert consultation with energy economists in academia. In addition, all values can be edited easily by the user to incorporate the user's best judgment for any given elasticity value or adjustment rate. Further, all default values can be automatically restored after editing to return the values to their original settings. The sections below document the derivation of the default adjustment rates and elasticities included in MarketSim.

11.1 Derivation of Default Adjustment Rates

As described above, MarketSim uses a series of adjustment rates to capture the transition from short-run to long-run market effects. These adjustment rates account for the portion of demand or supply that is allowed to change per time period. In the case of this model, the time period is one year. No data on the adjustment rates for specific energy sources were readily available. In the absence of such data, MarketSim uses expert input from Dr. Stephen Brown of the University of Las Vegas (UNLV) for several adjustment rates. For most values however, MarketSim assumes that the adjustment rate is related to the retirement of energy producing and consuming capital (i.e., equipment that produces energy or consumes energy), as indicated by its lifespan. Based on lifespan values obtained from the literature, adjustment rates are calculated as follows:

$$\gamma_{Dji} = \frac{1}{L_{Dji}} \text{ or } \gamma_{Sju} = \frac{1}{L_{Sju}}$$

where

γ_{Dji} = rate at which the quantity demanded adjusts in each U.S. end-use sector *i* for each fuel *j*

L_{Dji} = lifespan of the main consumption capital in each submarket.

Similarly, γ_{Sju} is the rate at which the quantity supplied adjusts from each production source *u* for each fuel *j*, and L_{Sju} is the lifespan of the main production capital equipment in each submarket.

Tables 2 and 3 present the adjustment rates included in MarketSim, as well as the lifespan values supporting each adjustment rate.

For non-U.S. oil demand, MarketSim assumes an adjustment rate equal to that for the U.S. transport sector, under the assumption that transportation-related uses dominate oil consumption in non-U.S. markets.

Table 2. Adjustment Rates for Energy Demand

Type	Sector	Adjustment Rate	Supporting Lifespan Information
Oil	Residential	0.06	Adjustment rate based on low end of residential oil boiler lifespan range (18 years) presented in EIA (2018b). The low end of the lifespan range from this document was chosen to allow for the possibility of early boiler replacement in response to changes in energy prices.
	Commercial	0.04	Value reflects 25-year service life of oil-fired commercial boilers obtained from EIA (2018b).
	Industrial	0.04	Adjustment rate reflects the low end of the 25- to 40-year life of industrial oil-fired boilers as reported in International Energy Agency (2010). The low end of the lifespan range from this document was chosen to allow for maximum energy substitution.
	Transport	0.09	Value reflects median age of automobiles in operation in the U.S. (11.8 years), as reported in Bureau of Transportation Statistics (2019). Median age is used rather than lifespan to allow for greater demand response to price changes within MarketSim.
	Non-U.S. Demand for U.S. Refined Product Exports	0.09	Assumed to be same as value for U.S. transportation sector, under the assumption that transportation-related uses are dominant in non-U.S. markets.
	Non-U.S. Demand for U.S. Crude Oil Exports	0.09	Assumed to be same as value for U.S. transportation sector, under the assumption that transportation-related uses are dominant in non-U.S. markets.
	Non-U.S. Demand for non-U.S. Oil	0.09	Assumed to be same as value for U.S. transportation sector, under the assumption that transportation-related uses are dominant in non-U.S. markets.
Natural Gas	Residential	0.05	Adjustment rate based on low end of residential gas boiler lifespan range (20 years) presented in EIA (2018b). The low end of the lifespan range from this document was chosen to allow for the possibility of early boiler replacement in response to changes in energy prices.
	Commercial	0.04	Value reflects 25-year service life of gas-fired commercial boilers obtained from EIA (2018b).
	Industrial	0.04	Adjustment rate reflects the low end of the 25- to 40-year life of industrial gas-fired boilers as reported in International Energy Agency (2010). The low end of the lifespan range from this document was chosen to allow for maximum energy substitution.
	Transport	0.08	Value based on 12-year lifespan for gas powered buses obtained from U.S. Department of Transportation, Federal Transit Administration (2007) and the Scott Institute for Energy Innovation (2017).
	Exports	0.04	Assumed same as industrial value.
Electricity	Residential	0.10	Based on expert input of Dr. Stephen Brown (2011).
	Commercial	0.10	Based on expert input of Dr. Stephen Brown (2011).
	Industrial	0.20	Based on expert input of Dr. Stephen Brown (2011).
	Transport	0.10	Assumed value.
	Other	0.10	Assumed value.
Coal	Industrial	0.04	Adjustment rate reflects the low end of the 25- to 40-year life of industrial coal-fired boilers as reported in International Energy Agency (2010). The low end of the lifespan range from this document was chosen to allow for maximum energy substitution.
	Exports	0.04	Assumed same as industrial value.
	Other	0.04	Assumed same as industrial value.

Table 3. Adjustment Rates for Energy Supply

Type	Sector	Adjustment Rate	Supporting Lifespan Information
Oil	Lower 48 Onshore (Conventional)	0.15	Based on expert input of Dr. Stephen Brown, UNLV (2011).
	Lower 48 Onshore (Tight)	0.15	Based on expert input of Dr. Stephen Brown, UNLV (2011).
	Lower 48 Offshore	0.15	Based on expert input of Dr. Stephen Brown, UNLV (2011).
	Alaska Onshore	0.15	Based on expert input of Dr. Stephen Brown, UNLV (2011).
	Alaska Offshore	0.15	Based on expert input of Dr. Stephen Brown, UNLV (2011).
	Other	0.15	Based on expert input of Dr. Stephen Brown, UNLV (2011).
	Biodiesel	0.15	Based on expert input of Dr. Stephen Brown, UNLV (2011).
	Rest of World	0.15	Based on expert input of Dr. Stephen Brown, UNLV (2011).
	Pipeline Imports	0.15	Assumed to be same as other oil categories.
Natural Gas	Lower 48 Conventional	0.15	Adjustment rate based on lifespan of 5 to 10 years for conventional gas production as reported by Encana in U.S. Department of Interior, National Park Service (2008).
	Lower 48 Unconventional	0.30	Based on expert input of Dr. Stephen Brown, UNLV (2011).
	Lower 48 Offshore	0.15	Assumed to be same as Lower 48 Conventional.
	Alaska Onshore	0.15	Assumed to be same as Lower 48 Conventional.
	Alaska Offshore	0.15	Assumed to be same as Lower 48 Conventional.
	Other	0.15	Assumed to be same as Lower 48 Conventional.
	Imports - Pipeline	0.15	Assumed to be same as Lower 48 Conventional.
	Imports – Liquefied Natural Gas (LNG)	0.15	Assumed to be same as Lower 48 Conventional.
Electricity	Oil	0.03	Adjustment rate based on an assumed 30-year lifespan for oil-fired electricity generation units, consistent with the values below for natural gas and coal units.
	Natural Gas	0.03	Adjustment rate reflects 30-year gas-fired power plant life, as reported in U.S. DOE, National Energy Technology Laboratory (2007, 2019).
	Coal	0.03	Adjustment rate reflects 30-year coal-fired power plant life, as reported in U.S. DOE, National Energy Technology Laboratory (2007, 2019).

Type	Sector	Adjustment Rate	Supporting Lifespan Information
Electricity	Nuclear	0.02	Based on 60-year nuclear power plant life, as reported in U.S. DOE EIA (2010).
	Hydro	0.01	Value reflects assumed 75-year lifespan of hydroelectric facilities, based on the 50- to 100-year range presented in U.S. Geologic Survey (2010).
	Wind (Offshore)	0.05	Value assumes 20-year lifespan for wind power units, based on American Wind Energy Association (2012) and U.S. DOE (2015).
	Wind (Onshore)	0.05	Value assumes 20-year lifespan for wind power units, based on American Wind Energy Association (2012) and U.S. DOE (2015).
	Solar	0.04	Adjustment rate reflects an effective 25-year lifespan for solar systems. This reflects the 30-year operational life of crystalline modules, adjusted for the approximate 20 percent output degradation over a module's lifetime. Lifespan and output degradation estimates from Jordan and Kurtz (2012).
	Other Electric	0.031	Adjustment rate is the average of the values for electricity produced from oil, natural gas, coal, nuclear energy, hydro, solar, and wind.
	Imports	0.026	Adjustment rate is the average of the values for electricity produced from oil, natural gas, coal, nuclear energy, and hydro. Solar and wind were not included in the calculation under the assumption that little solar or wind energy is imported into the United States.
Coal	Domestic	0.10	Based on expert input of Dr. Stephen Brown, UNLV (2011).
	Imports	0.10	Based on expert input of Dr. Stephen Brown, UNLV (2011).

11.2 Selection of Default Elasticity Values

To the extent possible, MarketSim relies upon demand and supply elasticities obtained from peer-reviewed studies in the empirical economics literature. Using peer-reviewed values is central to ensuring that MarketSim's simulation of energy markets reflects the best information available on the demand and supply responses that result from changes in energy prices. As suggested above, in the few cases where peer-reviewed values are not available, elasticity estimates were derived from NEMS outputs or from expert input provided by Dr. Seth Blumsack of Pennsylvania State University, Dr. Charles Mason of the University of Wyoming, and Dr. Gavin Roberts of Weber State University.

11.2.1 Demand Elasticities

To capture the complex interactions between different segments of U.S. energy markets, MarketSim requires own-price and cross-price demand elasticities for every energy source included in the model. For each major energy-consuming sector (e.g., the residential sector), BOEM strove to use own-price and cross-price demand elasticities from the same empirical study to ensure that a sector's simulated responses to energy price changes were based on price sensitivities derived from the same methods and data. The selection of demand elasticities also considered the quality of the estimates produced by each study. BOEM's assessment of quality for individual elasticity estimates considered, among other factors, (1) whether they are statistically significant, (2) methods by which they were derived, and (3) the richness of the data supporting each estimate (e.g., whether they are based on a multi-year panel or reflect energy market data for a single year).

Based on these criteria, MarketSim relies heavily on own-price and cross-price demand elasticities from Serletis *et al.* (2010) for the residential and commercial sectors and Jones (2014) for the industrial sector. Serletis *et al.* (2010) investigate inter-fuel substitution possibilities for energy demand across four fuels (i.e., oil, gas, electricity, and coal) using EIA data for the 1960–2007 period. Based on these data, Serletis *et al.* estimated own-price and cross-price elasticities for the commercial, residential, and industrial sectors, using a flexible translog functional form. Across most sectors, Serletis *et al*. produced statistically significant elasticity values of the expected sign.

Jones (2014) focuses on inter-fuel substitution in the industrial sector, using EIA data for the 1960–2011 period for the same fuels included in Serletis *et al.* (2010), plus biomass. Jones specifies a dynamic linear logit model to estimate own-price and cross-price elasticities and within this framework, estimates both short-run and long-run elasticities. In addition, to assess the role of biomass in industrial sector inter-fuel substitution, Jones develops two sets of models, one set with the four fuels traditionally included in industrial sector energy models (i.e., natural gas, oil, coal, and electricity) and another that includes these energy sources plus biomass. Jones finds that the addition of biomass reduces both the own-price and cross-price elasticities of demand for the four traditionally modeled fuels. The effect is most significant for those values associated with electricity. In both models, the four traditional fuels are found to be substitutes with each other with the exception of electricity and oil; the cross-price elasticities for these energy sources are not statistically significant.

Table 4 presents the default own-price and cross-price demand elasticities included in MarketSim for the residential, commercial, industrial, and transport sectors. The table also shows the default elasticity values for miscellaneous demand sectors included in MarketSim (e.g., natural gas demand in U.S. export markets).

Table 4. MarketSim Default Demand Elasticities

Categories	Elasticity with Respect to Change in Oil Price	Elasticity with Respect to Change in Gas Price	Elasticity with Respect to Change in Electricity Price	Elasticity with Respect to Change in Coal Price
Commercial Sector[1]	-	-	-	-
Oil	-0.939	0.2	1.08	-
Natural Gas	0.07	-0.296	0.419	-
Electric	0.092	0.041	-0.134	-
Coal	-	-	-	-
Residential Sector[1]	-	-	-	-
Oil	-1.002	0.2	1.151	-
Natural Gas	0.07	-0.313	0.507	-
Electric	0.214	0.072	-0.287	-
Coal	-	-	-	-
Industrial Sector[2]				
Oil	-0.264	0.249	0.01	0.090
Natural Gas	0.172	-0.468	0.178	0.050
Electric	0.009	0.118	-0.125	0.061
Coal	0.440	0.351	0.652	-1.468
Miscellaneous Demand Categories	-	-	-	-
Oil – Transport Sector[3]	-0.300	-	-	-
Oil – Rest of World Demand for U.S. Crude[4]	-0.15	-	-	-
Oil – Rest of World Demand for U.S. Refined Products[4]	-0.15			
Oil – Rest of World Demand for non-U.S. oil[4]	-0.15			
Natural Gas – Transport[5]	-	-1.00	-	-
Natural Gas – U.S. Exports[6]	-	-0.89	-	-
Electricity – Transport[5]	-	-	-1.00	-
Electricity – "Other"[7]	-	-	-0.18	-
Coal – Other[8]	-	-	-	-1.468
Coal – U.S. Exports[5]	-	-	-	-1.00

Notes:

1. Commercial and residential sector values are from Serletis *et al.* (2010), except for the cross-price elasticity for gas in response to oil prices and the cross-price elasticity of oil in response to gas prices. For these latter two values, MarketSim uses demand elasticities from Newell and Pizer (2008). Also, Deryugina *et al.* (2020) estimate a range of residential elasticity values for electricity consistent with the value in Serletis *et al.* (2010).
2. For the industrial sector, MarketSim uses demand elasticities from Jones (2014), except for the cross-price elasticity of electricity in response to oil prices and the cross-price elasticity of oil in response to electricity prices. For these values, MarketSim uses demand elasticities from Serletis *et al*. (2010).
3. Dahl (2012)
4. Huntington *et al*. (2019)
5. Assumed to be -1.00
6. Dahl (2010)
7. Assumed to be average of own-price elasticity values for industrial, commercial, and residential sectors
8. Industrial sector value from Jones (2014)

As indicated in the table, MarketSim uses results from Serletis *et al*. (2010) as defaults for the commercial and residential sectors, except for the elasticity of demand for natural gas with respect to the price of oil and the elasticity of demand for oil with respect to the price of natural gas. The estimates for these cross-price elasticities in Serletis *et al.* were of the unexpected sign (negative) and were not statistically significant. Therefore, in lieu of Serletis *et al.*, MarketSim uses results from Newell and Pizer (2008) for these values, for both the commercial and residential sectors. Newell and Pizer (2008) estimate these cross-price relationships for the commercial sector only. Although MarketSim ideally would use default values specific to the residential sector, alternative values for these cross-price elasticities were not readily available for the residential sector. Given the similarities between the commercial and residential sectors, MarketSim uses these two cross-price demand elasticities from Newell and Pizer (2008) as a reasonable approximation of the corresponding residential sector values.

For the industrial sector, MarketSim relies almost exclusively on demand elasticities from Jones (2014) as defaults. Although Serletis *et al.* (2010) estimate elasticity values for the industrial sector, the values in Jones (2014) are based on fuel consumption data that exclude fuel use for purposes other than energy (e.g., petroleum products used as lubricants). As described above, Jones (2014) estimates long-run demand elasticities with two specifications, one including biomass as a substitute and another excluding biomass. Based on the statistical significance of the elasticities with biomass included, MarketSim uses the elasticities from the specification that includes biomass. The two exceptions to this are the cross-price elasticity of demand for oil with respect to the price of electricity and the cross-price elasticity of electricity in response to oil prices, as Jones' estimates for these values are not statistically significant. For these values, MarketSim uses estimates from Serletis *et al.* (2010).

Table 4 also shows MarketSim's default own-price demand elasticities for the transport sector and various miscellaneous demand categories. For these categories, MarketSim relies upon elasticity values from multiple sources. For oil demand in the transportation sector, MarketSim uses a U.S.-specific elasticity value obtained from Dahl's (2012) review of price elasticities estimated for more than 100 countries. This value represents the average of the elasticity values identified in the empirical literature. For non-U.S. oil demand, MarketSim applies the value reported in a Huntington *et al.* (2019) review of crude oil demand elasticities in major industrializing economies. For U.S. natural gas exports, MarketSim uses estimates from Dahl's prior (2010) review of the elasticity literature as defaults.

Two categories for which appropriate demand elasticity values were not identified in the literature are miscellaneous coal demand and demand for U.S. coal exports. MarketSim uses the same industrial sector value obtained from Jones (2014) for the former and assumes a value of -1.00 for the latter.

11.2.2 Supply Elasticities

MarketSim includes default supply elasticities, summarized in Table 5, for every production category modeled for a given fuel (e.g., onshore oil production in the lower 48 states). Consistent with the demand elasticities summarized above, several of MarketSim's supply elasticities were obtained from the economic literature, with data sources varying by fuel type.

Table 5. MarketSim Default Supply Elasticities

Fuel	Source	Supply Elasticity
Oil	Lower 48 Onshore (Conventional)[1]	0.93
	Lower 48 Onshore (Tight)[1]	0.73
	Lower 48 Offshore[2]	0.19
	Alaska Onshore[3]	0.45
	Alaska Offshore[3]	0.70
	Other[2]	0.67
	Biodiesel[4]	0.24
	Rest of World[2]	0.28
	Canadian Pipeline Imports[2]	0.38
Natural Gas	Lower 48 Conventional[5]	0.75
	Lower 48 Unconventional[5]	0.68
	Lower 48 Offshore[6]	0.19
	Alaska Onshore[3]	1.93
	Alaska Offshore[3]	1.93
	Other[7]	0.51
	Pipeline Imports[3]	1.13
	LNG Tanker Imports[8]	1.00
Electricity	Oil[9]	0.22
	Natural Gas[10]	1.50
	Coal[9]	0.27
	Nuclear[10]	0.53
	Other Electric[10]	0.68
	Hydro[10]	0.05
	Wind Onshore[10]	0.65
	Wind Offshore[10]	0.01
	Solar[10]	2.03
	Imports[10]	0.36
Coal	Domestic[11]	4.39
	Imports[3]	1.0

Notes:
1. Newell and Prest (2019)
2. Expert input from C. Mason, G. Roberts, & S. Blumsack, as documented in Price & Ehrnschwender (2021)
3. Derived from specialized NEMS runs of the AEO 2023 provided to the Department of the Interior (DOI) as EIA (2023b)
4. Luchansky and Monks (2009)
5. Newell *et al.* (2019)
6. Assumed to be the same as Oil, Lower 48 Offshore
7. Brown (1998)
8. Assumed value
9. Derived from specialized NEMS runs of the AEO 2018 provided to DOI as EIA (2018a)
10. Derived from EIA (2020)

Derived from NEMS 2019 Reference Case supplemental data provided to DOI as EIA (2019)

For tight oil and other lower 48 onshore oil, MarketSim uses elasticities from a recent study by Newell and Prest (2019). The paper specifically compares the price responses of conventional and unconventional (tight) oil drilling and production. Using micro-data for more than 150,000 oil wells in Texas, North Dakota, California, Oklahoma, and Colorado, Newell and Prest (2019) estimate the elasticity of well drilling and the elasticity of oil production, separately for conventional and unconventional wells. To estimate drilling elasticities, they use multiple model specifications, estimating changes in drilling activity as a function of price in some cases and as a function of revenue in other cases. The production elasticities estimated by Newell and Prest (2019), however, all represent the change in production as a function of the change in revenue, rather than price. To align the supply elasticities in MarketSim with the specification of supply, MarketSim uses the elasticity of well drilling with respect to the oil price from Newell and Prest (2019), which they estimate separately for both conventional and unconventional wells.

Luchansky and Monks (2009) serves as the source for MarketSim's default supply elasticity for domestic biodiesel. This paper uses monthly data for 1997 through 2006 to estimate the market supply and demand for ethanol at the national level. Applying these data to four specifications of supply, Luchansky and Monks (2009) estimate supply elasticities ranging from 0.224 to 0.258. MarketSim uses the midpoint of this range (0.24) as the default supply elasticity for biodiesel.

For a number of oil supply elasticities, MarketSim relies on expert input provided to BOEM by three energy economists: Dr. Charles Mason of the University of Wyoming, Dr. Seth Blumsack of Penn State University, and Dr. Gavin Roberts of Weber State University. BOEM relies on input provided by these experts for the oil supply elasticities related to lower 48 offshore, rest-of-world oil production, Canadian pipeline imports, and other oil production. The input provided by these experts is documented in Price and Ehrnschwender (2021). For oil production in Alaska, MarketSim uses supply elasticities derived from specialized simulations of NEMS, as described in detail below.

For gas production, MarketSim draws on a variety of sources for elasticities, depending on the production source. For domestic onshore conventional and unconventional shale gas production in the lower 48, MarketSim uses values from Newell *et al.* (2019), who use data from approximately 62,000 gas wells drilled in Texas between 2000–2015 to determine price-responsiveness across the supply process. The study assesses the decision to drill the well, conduct well completion, and produce gas over time and, of these, finds drilling activity to be the most responsive to changes in price. MarketSim makes use of the gas price response values broken out for conventional and unconventional wells, though the study notes that these values may not differ significantly from each other statistically. For offshore production in the lower 48, MarketSim uses the same 0.19 elasticity as for offshore oil production in the lower 48, obtained through the expert input process described in the previous paragraph and documented in Price and Ehrnschwender (2021). For onshore and offshore production in Alaska, MarketSim uses elasticity values derived from specialized simulations of NEMS, as detailed below. For other gas production, MarketSim applies the supply elasticity reported in Brown (1998).

For coal supply, MarketSim uses a supply elasticity derived from annual supply curve data generated by NEMS' Coal Market Module.[6] The annual supply curve data provided by EIA represent 41 distinct coals for a given year for combinations of coal supply region, sulfur content, mining method, and rank. For example, the Central Appalachia coal supply region has five different supply curves for a given year, representing a mix of low- and medium-sulfur coal, underground and surface mines, and premium and bituminous coals. In addition, the annual supply curve for each of the 41 coals is represented as 11 data points, with each data point representing production at a given price point.

Using the EIA data, supply elasticities were estimated for each of the 41 coal types and for every year between 2019 and 2040. To generate elasticity values, the log-transformed quantity was regressed on the log-transformed price, which yielded the elasticity of supply as the coefficient. Each regression was performed over the three central points of the appropriate supply curve. The following equation displays this regression:

$$\ln(Q_{s,t}) = \beta_{s,t}\ln(P_{s,t}) + \beta_0$$

where

$Q_{s,t}$ = quantity supplied on supply curve *s* in year *t*

[6] Though not publicly available, the EIA provided these supply curve data to DOI and provides them to other modelers on a regular basis.

$\beta_{s,t}$ = elasticity of supply for supply curve s in year t[7]
$P_{s,t}$ = price of coal on supply curve s in year t
β_0 = regression constant

Running the above regression for each of the coal supply regions yields regionally specific coal supply elasticity values. The national coal supply elasticity value in MarketSim reflects the weighted average of the regional estimates, using coal production by region as weights.

Where appropriate economic research does not exist or could not be obtained for a specific supply elasticity value, projections from the AEO low-world price, high-world price, and reference cases were used to infer these values. Elasticity estimates may be inferred from the AEO projection for a given year by comparing the differences in energy prices between two scenarios with the differences in energy quantities. For a given energy source and fuel, an annual inferred elasticity value was calculated three times based on the (1) low-price case for oil vs. high-price case for oil, (2) low-price case vs. reference case, and (3) reference case vs. high-price case, for all projection years within the AEO. The formula for this annual inferred elasticity is as follows:

$$\eta_t = \frac{\ln\left(\frac{Q_{A,t}}{Q_{B,t}}\right)}{\ln\left(\frac{P_{A,t}}{P_{B,t}}\right)}$$

where

η_t = inferred elasticity in year t
$Q_{A,t}$ and $Q_{B,t}$ = quantities supplied in year t for cases A and B respectively (each case is compared with both of the other cases)
$P_{A,t}$ and $P_{B,t}$ = prices at time t for cases A and B

The resulting series of inferred elasticities are averaged, excluding extreme outlier results derived from the AEO data.[8]

For a limited number of producing sectors, elasticity values were unavailable from the literature and the data generated by the constrained NEMS run, or recent editions of the AEO yielded elasticity values that appeared unrealistically high or were insufficient to support estimation of a supply elasticity. In such cases, MarketSim uses derived elasticities from previous vintages of the AEO data. If AEO-derived elasticities are not available for those categories, then a default supply elasticity of 1.0 is used.

12. Consumer Surplus in MarketSim

To assess changes in the welfare of U.S. consumers under a given E&D scenario,[9] MarketSim estimates the change in consumer surplus for each of the end-use energy markets included in the model (e.g., residential sector gas, industrial sector oil). For a given energy source, these changes in consumer surplus

[7] Coal supply elasticities are also represented as η_{cr} in Equation 1.
[8] More specifically, elasticities were estimated based on differentials between the low-price case and reference case, reference case and high-price case, and low-price case and high-price case. They then were averaged across these three variants and across years.
[9] MarketSim was designed to estimate changes in consumer surplus for U.S. consumers only. The model results do not include changes in consumer surplus for foreign consumers.

reflect changes in both price and quantity relative to baseline conditions. Under the model structure outlined above, price and quantity may change due to shifts in supply functions driven by the E&D scenario itself or from shifts in demand functions associated with cross-price effects. In addition, changes in quantity and price for a given year (relative to the baseline) reflect the assumption in MarketSim that the amount of energy consumed and produced in a given year depends partially on the quantity consumed and produced in the prior year.

MarketSim's estimation of the change in consumer surplus focuses on welfare changes associated with the consumption of energy within the United States. Although the model accounts for international trade in oil, natural gas, electricity, and coal, it distinguishes between U.S. and non-U.S. consumers of each energy source. This assumption is consistent with the structure of the baseline energy demand projections from EIA that serve as the foundation of MarketSim. These projections reflect U.S. consumption within the residential, commercial, industrial, and transportation sectors. MarketSim's assessment of changes in consumer surplus is limited to these specific demand sectors. None of the model's consumer surplus calculations consider changes in consumption in non-U.S. markets.

12.1 Primary Versus Secondary Markets

With four types of energy included in the model (oil, natural gas, electricity, and coal), MarketSim's calculation of the market equilibrium associated with new OCS oil and gas production accounts for spillover effects to other segments of U.S. energy markets. For example, increased OCS oil production would likely reduce oil prices and lead to a reduction in coal demand due to cross-price effects. Changes in this and other indirectly affected markets may also have feedback effects on oil and natural gas markets. Estimating changes in consumer surplus associated with a given E&D scenario therefore requires careful consideration of surplus changes across multiple markets.

To estimate changes in consumer surplus within the model's multi-market structure, MarketSim draws on the approach outlined in Boardman *et al.* (1996).[10] Recognizing that government interventions in one market (i.e., the primary market) may have spillover effects on other markets (i.e., secondary markets), Boardman *et al.* (1996) present a systematic approach for appropriately estimating welfare changes in general equilibrium. Putting the Boardman *et al.* approach in the context of OCS oil and gas production, the National OCS Program leads to an outward shift in the supply function within one or more primary markets such as oil and/or natural gas. This shift leads to a price reduction in the primary market, as shown by the change from P_{P0} to P_{P1} in Figure 1. Due to cross-price effects, this reduction in price in the primary market causes the demand function for substitutes to shift inward, as shown in Figure 2, reducing the quantity of substitutes demanded from Q_{S0} to Q_{S1}. As explained in Boardman *et al.* (1996), this reduction in quantity demanded for substitutes does not lead to a change in consumer surplus that is not already reflected in the primary market surplus change (described below), because the location of the demand curve within the primary market reflects the existence of substitutes. Due to the budget constraint faced by consumers, willingness to pay at a given quantity along the primary market demand function reflects the incremental utility derived from consuming more in the primary market, net of the utility lost from reducing consumption in the secondary market. Thus, changes in consumer welfare associated with changes in quantity in the primary market reflect not only the quantity changes in the primary market but also the corresponding quantity changes in secondary markets. Put differently, the demand function in the primary market is located further to the left than it would be in the absence of substitutes. Without substitutes, the quantity demanded by consumers in the primary market would be higher at each price point.

[10] This approach is highlighted in Boardman *et al.* (1996), Gramlich (1998), Mohring (1993), Thurman (1991), and Thurman and Wohlgenant (1989).

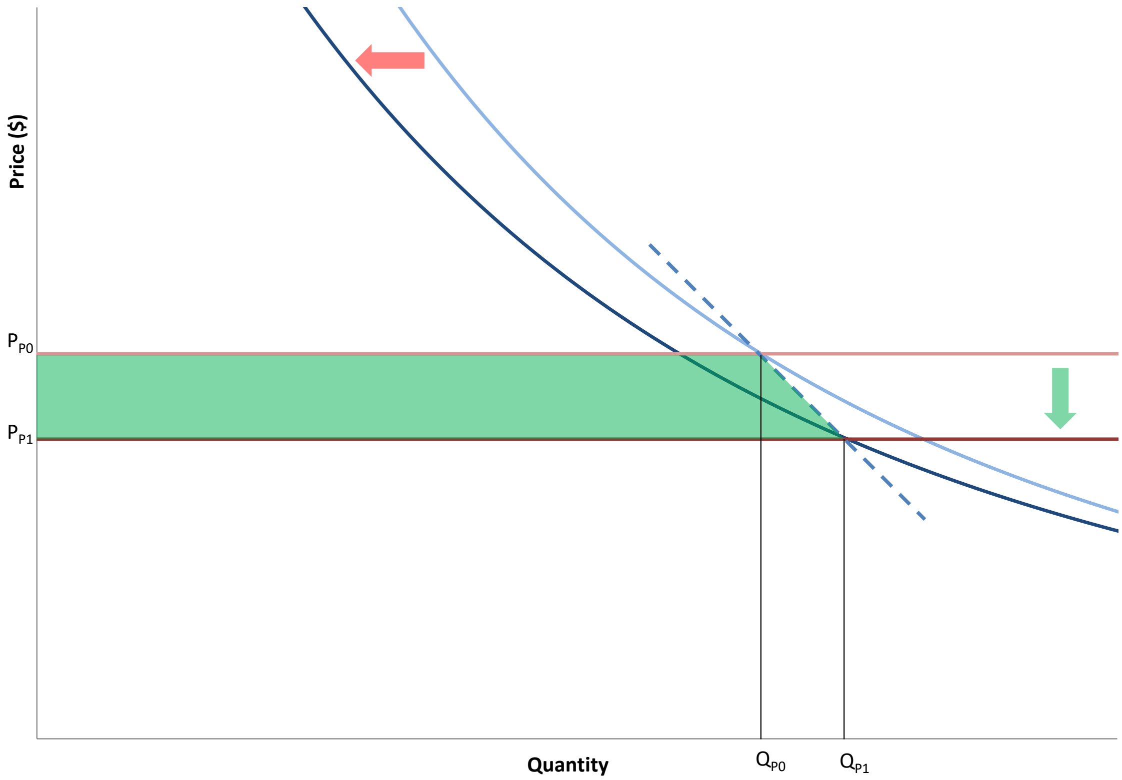

Figure 1. Primary Market Consumer Surplus Change

The shift in demand in the secondary market also leads to a reduction in price within that market, from P_{S0} to P_{S1} in Figure 2. As described in Boardman *et al.* (1996), this reduction in price leads to an increase in consumer surplus represented by area $P_{S0}deP_{S1}$ in Figure 2. This surplus change is not reflected in the primary market. Within MarketSim, this area is estimated as two components. For the rectangle $P_{S0}dfP_{S1}$, this portion of consumer surplus is simply $\Delta P \times Q^*$. To calculate the area of *def*, MarketSim calculates the definite integral of D_{S1} over the range $[Q^*, Q_{S1}]$ and subtracts the area of the rectangle Q^*feQ_{S1}.

Boardman *et al.* (1996) suggest a different approach for estimating consumer surplus changes within the primary market. Returning to the context of the National OCS Program, the program itself causes a shift in supply, which, as described above, causes a reduction in price for substitutes (see Figure 2). As the price of substitutes decreases, demand within the primary market declines, as represented by the inward shift in demand in Figure 1. Equilibrium in the primary market therefore changes from point *a* in the baseline to point *b* following implementation of the National OCS Program. Boardman *et al.* (1996) suggest that the associated change in consumer surplus should be estimated along the equilibrium demand curve represented by the line D* connecting points *a* and *b* in Figure 1. Unlike D_{P0} and D_{P1}, which hold the prices of all other goods constant, the equilibrium demand curve shows demand once prices in other markets have fully adjusted to the change in the primary market.

Using the equilibrium demand curve, the change in the primary market's consumer surplus includes two components. First, the price effect on the baseline quantity is represented by rectangle $P_{P0}acP_{P1}$, calculated as $\Delta P \times Q_{P0}$. Second, the additional consumer surplus associated with the increase in quantity is calculated as triangle *abc*, calculated as $0.5(\Delta Q \times \Delta P)$. In total, the change in consumer surplus for this primary market is the trapezoid $P_{P0}abP_{P1}$.

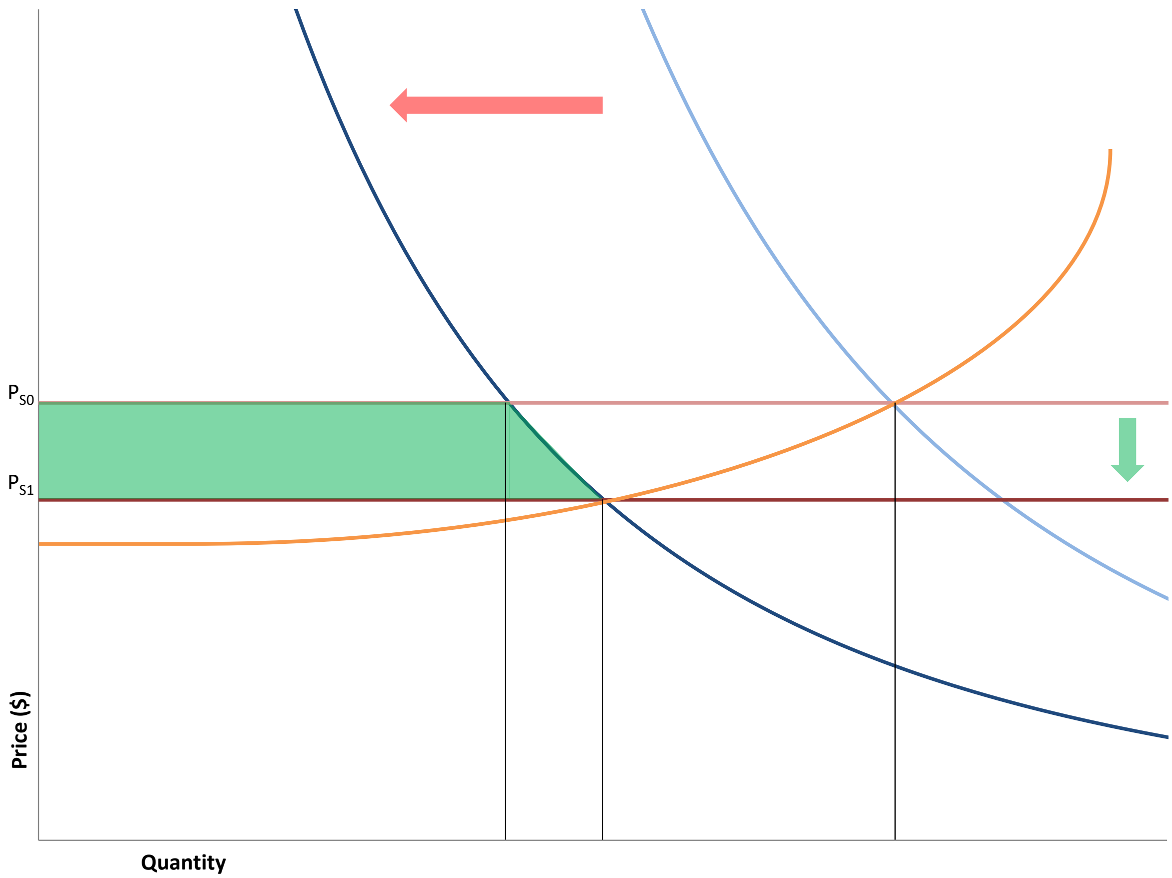

Figure 2. Secondary Market Consumer Surplus Change (reduced quantity and price)

To estimate the changes in consumer surplus associated with the National OCS Program, MarketSim applies the approach from Boardman *et al.* (1996) outlined in Figure 1 and Figure 2. One complicating factor in the application of this approach is that oil and natural gas may be both primary and secondary markets. That is, OCS production of oil may affect natural gas markets, and OCS natural gas production may affect oil markets. Similarly, because electricity may be produced with OCS natural gas and, to a much lesser extent OCS oil, the electricity market may be both a primary and secondary market.[11] A key distinction between primary and secondary markets in Boardman *et al.* (1996), however, is that primary markets see an increase in the equilibrium quantity demanded while secondary markets experience a reduction in quantity.[12] For the purposes of estimating the change in consumer surplus, MarketSim therefore treats oil, natural gas, or electricity as primary markets if the quantity demanded under the E&D scenario increases relative to the baseline. For example, if the equilibrium quantity of oil in the 2020 transportation market is higher in the E&D scenario than the baseline EIA NEMS projection quantity, the 2020 oil transportation market will be treated as a primary market, and its change in consumer surplus will be calculated based on the approach shown in Figure 1. Conversely, if the quantity of oil, natural gas,

[11] To avoid double counting consumer surplus changes associated with oil and natural gas used for electricity production, MarketSim's estimation of the consumer surplus changes for oil and natural gas does not include oil and gas used for electricity generation. Changes in consumer surplus associated with oil and natural gas used for this purpose are reflected in the model's consumer surplus calculations for electricity consumers.
[12] The opposite would be true for policies that reduce supply.

or electricity demanded decreases from the baseline to the E&D scenario, MarketSim calculates the consumer surplus change based on the secondary market approach.[13]

This rule does not apply to coal, which always is treated as a secondary market in MarketSim. Because E&D oil and natural gas production effects on coal markets are only indirect, coal is never considered a primary market for the purposes of MarketSim's consumer surplus change calculations.

12.2 Effects of Persisting Quantity on Consumer Surplus

MarketSim's supply and demand equations include lagged or persisting quantities such that the minimum quantity of fuel demanded or supplied in any given year is a certain percentage of the quantity demanded or supplied, respectively, during the previous year. In cases of large quantities added or removed from the E&D scenario production schedule year-on-year, the lagged structure of the model may result in short-term swings in price in certain markets as the model responds to these changes in OCS production. This sometimes leads to counterintuitive results within the model. For example, in some years, particularly those following a sharp reduction in production associated with the OCS program, the quantity demanded may decline relative to the baseline while price increases. As shown above in Figure 2, however, reductions in demand in secondary markets typically are accompanied by reductions in price instead of an increase—the inward shift in demand reduces both quantity and price.

To estimate the consumer surplus change in secondary markets under these conditions of declining quantity with increasing price, MarketSim follows the approach shown in Figure 3. Similar to the situation depicted in Figure 2 where price declines, the approach shown in Figure 3 limits estimation of the change in consumer surplus to effects associated with the change in price projected by MarketSim for the portion of the quantity demanded that remains unchanged relative to the baseline, as represented by rectangle $P_{S1}ghP_{S0}$ in Figure 3. Surplus changes associated with the reduction in quantity are reflected in the estimated surplus change in primary markets.[14]

The lagged quantities in MarketSim's demand equations also may lead to situations where consumer surplus decreases following sharp reductions in E&D production after the E&D peak. For example, as E&D production peaks, the quantity of energy demanded increases in response to lower energy prices. After the E&D production peak, however, the subsequent reduction in energy consumption for any given year is limited by the lagged quantities in MarketSim's demand equations and cannot drop below a certain threshold defined by $(1-\gamma)Q_{t-1}$. To meet this demand following the sharp reductions in E&D production, supply must increase from other sources, but an increase in price is necessary to achieve such an increase. Thus, price and the quantity demanded may both increase relative to the baseline, leading to a reduction in consumer surplus. These reactions to sudden increases and decreases can be minimized by smoothing E&D production schedules over time, or by setting all of the adjustment rates (γ values) to 1 in the model.

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[13] MarketSim may treat a given market as a primary market one year and as a secondary market in other years. For any given year, MarketSim determines primary/secondary market status based on the change in quantity demanded relative to the baseline.

[14] In primary markets with increasing quantity, increased prices imply a consumer surplus loss. MarketSim estimates such losses using the general approach outlined in Figure 1 but estimates a reduction in consumer surplus for the baseline quantity (Q_{P0}) and over the increase in quantity (Q_{P1}-Q_{P0}).

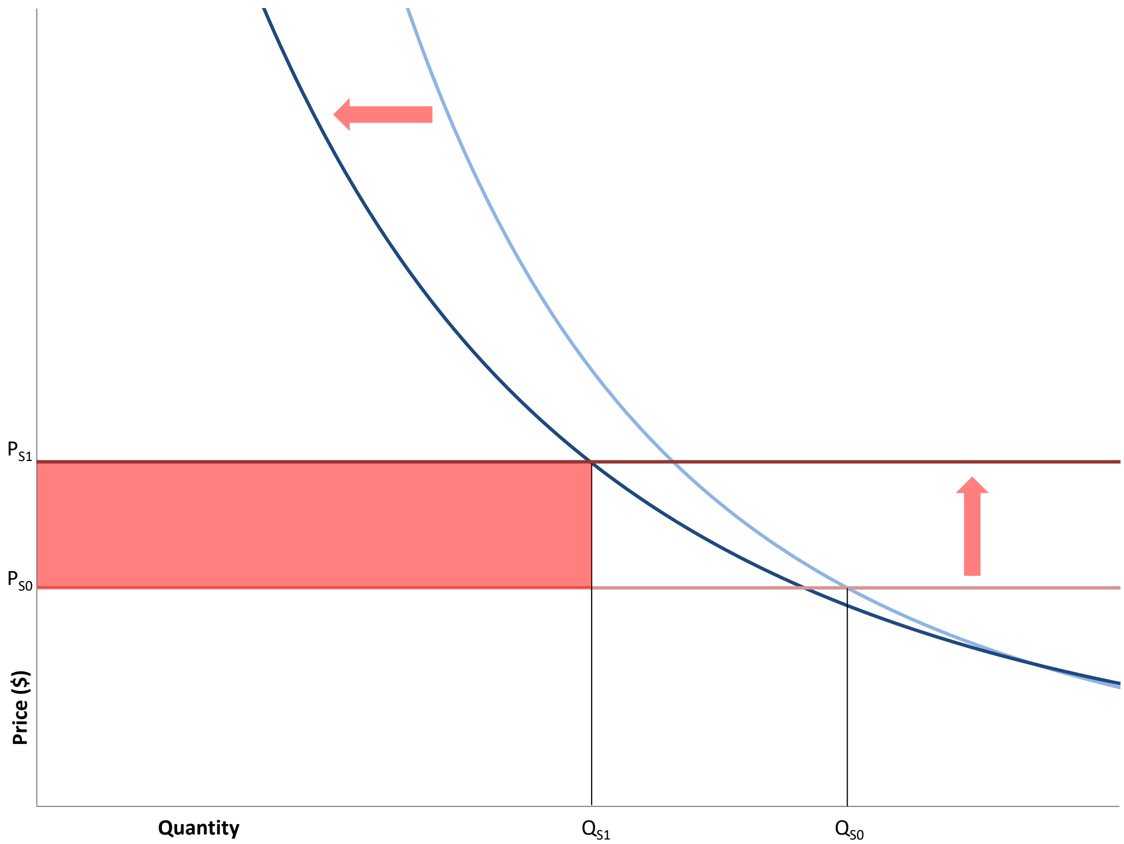

Figure 3. Secondary Market Consumer Surplus Change (reduced quantity, increase in price)

12.3 Exclusion of Domestic Producer Surplus Losses

Following the approach described above, MarketSim estimates the full change in consumer surplus associated with a given E&D scenario. This calculation includes transfers in surplus from (or to) energy producers resulting from changes in energy prices. For example, if the price of energy declines as shown above in Figure 1, the portion of the consumer surplus impact represented by rectangle $P_{P0}acP_{P1}$ in Figure 1 is a transfer of surplus from producers to consumers. To the extent that consumer surplus gains such as those represented by rectangle $P_{P0}acP_{P1}$ are a transfer from *U.S.* producers, they do not represent a welfare gain for the United States, as the gain to U.S. consumers is offset by the loss to U.S. producers. In contrast, transfers from non-U.S. producers to U.S. consumers do represent an increase in U.S. welfare.

To enable model users to estimate changes in U.S. consumer surplus net of transfers from U.S. producers, MarketSim generates an alternative set of consumer surplus estimates that exclude welfare transfers from (or to) U.S. energy producers. To generate these estimates, MarketSim multiplies the portion of the consumer surplus impact that represents a transfer from (or to) producers by the fraction of demand met by non-U.S. sources. In situations where a given energy source is treated as a primary market, the transfer portion of the consumer surplus impact is rectangle $P_{P0}acP_{P1}$ in Figure 1. When MarketSim treats an energy source as a secondary market, the entire change in consumer surplus represents a transfer.

Following this approach, an important step in evaluating consumer surplus net of transfers from domestic producers is estimating the fraction of demand met by non-U.S. sources. Because the specification of supply and demand differs somewhat across oil, gas, electricity, and coal markets in MarketSim (e.g., oil is modeled as a global market, whereas natural gas is modeled for the U.S. market with imports and exports), our approach for estimating the fraction of U.S. demand met by non-U.S. sources varies by energy source, as detailed below.

12.3.1 Oil

MarketSim models the world oil market but distinguishes between supply and demand in the United States and in other countries. Based on this information, MarketSim would ideally estimate the fraction of U.S. oil demand met by non-U.S. sources as follows:

$$L_f = \frac{Gross\ Imports}{Domestic\ Oil\ Demand}$$

where

L_f = fraction of U.S. oil demand met by non-U.S. sources of supply

As currently specified, MarketSim does not directly estimate U.S. gross imports of oil. However, gross imports may be calculated based on other data in MarketSim:

$$Gross\ Imports = (D_{US} - Y_{US}) + Gross\ Exports$$

where

D_{US} = U.S. oil demand
Y_{US} = U.S. oil production

As illustrated in this equation, gross imports are equal to net imports plus gross exports. Within oil markets, each of the three variables on the right-hand side of the above equation are estimated by MarketSim. However, the model includes two separate (mutually exclusive) values for gross exports: gross exports of crude oil and gross exports of refined petroleum products. Gross exports of crude oil clearly represent exports of U.S.-sourced oil. Gross exports of refined products, however, likely include refined products sourced from U.S. crude and refined products sourced from non-U.S. crude. Thus, BOEM must choose whether to include or exclude refined product exports from the calculation of gross imports.

Because some but not all of the refined products exported by the U.S. are sourced from U.S. crude, including or excluding refined product exports from the estimate of gross exports will provide an imperfect estimate of the consumer surplus adjustment. Excluding refined product exports may lead to underestimation of both gross imports and the adjusted consumer surplus rectangle ($P_{P0}acP_{P1}$ in Figure 1). In contrast, including refined product exports treats some exports of refined products as if they were produced from U.S. crude even though they were produced from non-US crude, leading to overestimation of both gross imports and the adjusted consumer surplus rectangle.

To determine whether to include or exclude refined petroleum products from the estimate of gross exports, IEc and BOEM examine (1) the size of U.S. crude exports relative to U.S. exports of refined petroleum products and (2) the extent to which U.S. refineries rely on U.S. crude versus non-U.S. crude. These data are presented below in Figure 4 and Figure 5, respectively. Both series are derived from the customized NEMS run performed by EIA based on the AEO 2023. As shown in Figure 4, U.S. exports of refined petroleum products are projected to be between double and triple crude oil exports through 2050. In addition, Figure 5 shows that U.S. crude is projected to account for approximately 55 to 60 percent of U.S. refinery feedstocks over the same time period. Together, these data suggest that (1) exports of refined products are a significant portion of oil exports, and (2) more than half of these refined product exports represent exports of U.S. crude oil. From these patterns in the data, it appears that the potential for underestimation and overestimation of consumer surplus is similar for the two options.

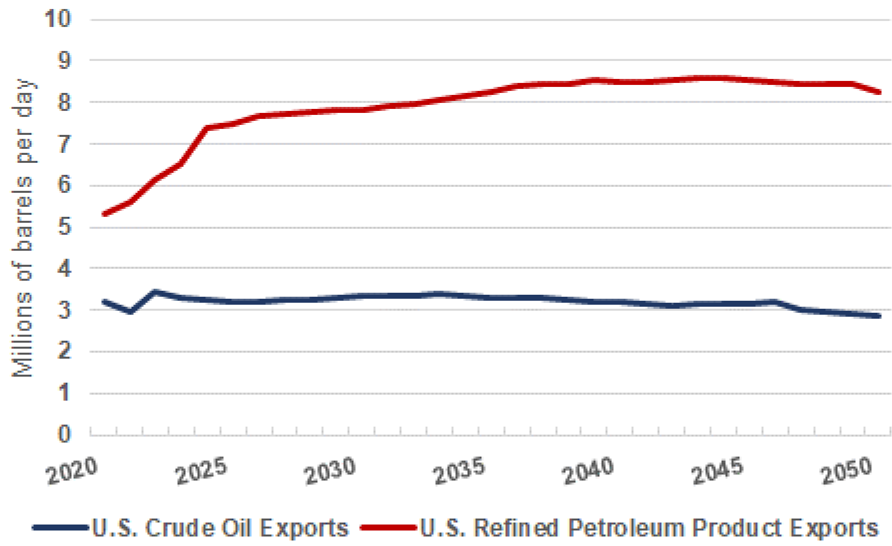

Figure 4. Projections of U.S. Crude Oil and Refined Petroleum Exports
Source: EIA customized NEMS run based on AEO 2023 (EIA 2023b)

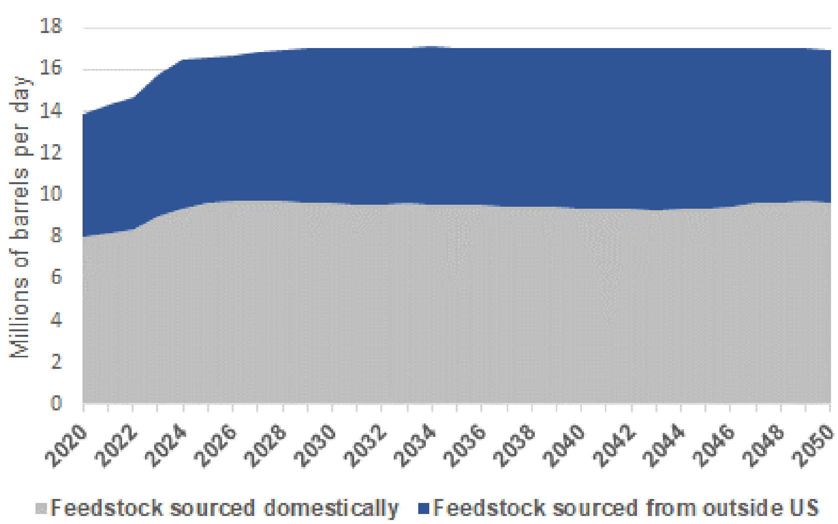

Figure 5. Projections of U.S. Refinery Feedstock Mix
Source: EIA customized NEMS run based on AEO 2023 (EIA 2023b)

To avoid potential overestimation of consumer surplus effects, MarketSim excludes U.S. refined petroleum product exports from the fraction of U.S. oil demand met by non-U.S. sources of supply (L_f in the first oil equation above). Therefore, using variables included in MarketSim, this fraction is as follows:

$$L_f = \frac{(D_{L,W} - D_{L,ROW}) - (S_{L,W} - S_{L,ROW}) + EX_C}{(D_{L,W} - D_{L,ROW})}$$

where

L_f = fraction of U.S. oil demand met by non-U.S. sources of supply
$D_{L,W}$ = global oil demand
$D_{L,ROW}$ = non-U.S. oil demand
$S_{L,W}$ = global oil supply
$S_{L,ROW}$ = non-U.S. oil supply
EX_C = U.S. gross exports of crude oil

The numerator of this formula represents gross imports (U.S. demand less U.S. supply [net imports] plus gross exports), and the denominator represents domestic oil consumption (i.e., U.S. oil demand).

12.3.2 Natural Gas

For natural gas, MarketSim simulates the U.S. market (rather than the global market) but estimates U.S. imports and exports of natural gas. Based on this specification of the market, MarketSim estimates the percentage of U.S. natural gas demand met by non-U.S. sources as follows:

$$G_f = \frac{S_{G,I}}{(D_{G,T} - D_{G,X})}$$

where

G_f = fraction of U.S. natural gas demand met by non-U.S. sources of supply
$S_{G,I}$ = U.S. natural gas imports
$D_{G,T}$ = total U.S. natural gas demand, including demand for U.S. natural gas exports
$D_{G,X}$ = demand for U.S. natural gas exports

12.3.3 Electricity

MarketSim models the U.S. electricity market at the national level and includes net imports in its specification of electricity supply. MarketSim therefore estimate the share of U.S. demand satisfied by non-U.S. generation as follows:

$$E_f = \frac{S_{E,NI}}{D_{E,T}}$$

where

E_f = fraction of U.S. electricity demand met by non-U.S. sources of supply
$S_{E,NI}$ = U.S. net imports of electricity
$D_{E,T}$ = total U.S. demand for electricity (including net imports)[15]

[15] Given the structure of MarketSim, the total U.S. demand for electricity is equal to the U.S. electricity supply (including net imports). Thus, the formula for E_f could be re-written with the U.S. supply of electricity in the denominator.

12.3.4 Coal

Similar to its treatment of natural gas markets, MarketSim simulates coal as a national market and estimates imports and exports separately (rather than estimating net imports). Based on this model structure, MarketSim estimates the percentage of U.S. coal demand met by non-U.S. producers as follows:

$$C_f = \frac{S_{C,I}}{(D_{C,T} - D_{C,X})}$$

where

C_f = fraction of U.S. coal demand met by non-U.S. sources of supply
$S_{C,I}$ = U.S. coal imports
$D_{C,T}$ = total U.S. coal demand, including demand for U.S. exports
$D_{C,X}$ = demand for U.S. coal exports

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Appendix A. MarketSim Model Sensitivity Testing

A.1 Overview

The outputs generated by MarketSim for a given E&D scenario depend, in part, on the elasticity parameters included in the model and the model's baseline supply, demand, and pricing data. To better understand the sensitivity of MarketSim's outputs to the value of various elasticity parameters and baseline data included in the model, a range of sensitivity tests was performed in which we varied one or more default model parameters or baseline data series and analyzed the corresponding model output changes. This appendix presents the results of these sensitivity tests, organized into the following sections, each of which is focused on different categories of potential sensitivity scenarios:

1. **Batched elasticity sensitivities,** or the testing of how changes to multiple elasticity parameters affect model outcomes when applied simultaneously.

2. **Discrete elasticity sensitivities,** or the testing of how changes to individual elasticity parameters (or in some cases the concurrent testing of two similar elasticity parameters) affect model outcomes. The specific elasticity parameters examined are defined based on findings from the results of the batched elasticity sensitivities summarized above.

3. **Baseline data sensitivities,** or the assessment of how changes to baseline data affect model outputs, including the use of unmodified baseline projections from the EIA's AEO instead of the special variant of these data typically provided by EIA.

4. **Layered elasticity and baseline data sensitivities related to decarbonization,** or the simultaneous testing of elasticity sensitivities and baseline data changes, centered around decarbonization or "net-zero" scenarios.

Across each of the sensitivity analyses discussed above, IEc has collected results according to multiple output metrics, including the following:

- **Fuel substitution effects.** The sensitivities examine how the composition of substitution changes when alternative model parameters and/or baseline data are entered into the model. Substitution effects results for each set of sensitivity tests are outlined in this appendix.[16]

- **Emissions impact:** Given the heightened interest in the greenhouse gas (GHG) impacts of government decisions related to energy and the environment, this appendix estimates the sensitivity of the GHG impact estimates generated by the OECM based on MarketSim outputs under alternative assumptions, both for an E&D scenario and under the No Action Alternative. Criteria pollutant emissions impacts are also examined.[17] Details on the OECM's methods for estimating emissions are included in the technical documentation for that model (Industrial

[16] All sensitivity tests were conducted using the AEO 2020 baseline version of MarketSim. At the time of the batched elasticity sensitivities, it was the most recent version of MarketSim available and therefore was used for consistency across the rest of the sensitivity tests. In addition, AEO 2020 data is used in the Princeton Net-Zero modeling, and this version of MarketSim allowed for consistency in the implementation of the adapted net-zero baseline data into the analysis.

[17] The batched elasticity sensitivities and discrete elasticity sensitivities examine emissions impacts using the 2018 version of the OECM, which was the most recent version at the time those analyses were conducted. However, the emissions impacts for the baseline data sensitivities and decarbonization sensitivities, which were conducted later, are based on the updated 2023 version of the OECM.

Economics, Inc. 2023). The OECM was designed to capture a large portion of E&D emissions and emissions associated with the No Action Alternative. BOEM's Greenhouse Gas Life Cycle Energy Emissions Model (GLEEM) can capture additional GHG emissions impacts, though GLEEM was not used for the purposes of the sensitivity analyses presented here.

The sensitivity analyses are based on a representative E&D scenario for the Gulf of Mexico that includes a cumulative 322 million barrels of oil production and 416 billion cubic feet of natural gas production over 32 years, with years 1 through 3 including no production. As described in the sections below, the baseline and decarbonization sensitivities use this full scenario while the batched elasticity sensitivities and discrete elasticity sensitivities limit the scenario to 15 years of production.

A.2 Batched Elasticity Sensitivities

Methods – Batched Elasticity Sensitivities

For the first set of sensitivities, IEc and BOEM defined sensitivity scenarios around multiple concurrent adjustments to MarketSim's elasticity values. The goal of this exercise was to assess sensitivity under scenarios where certain classes of elasticity parameters (e.g., all own price elasticities of demand for oil) are systematically higher or lower than the default. **Table A-1** outlines the batched elasticity scenarios tested. The batches test doubling and halving all own-price elasticities falling within oil supply, oil demand, gas supply, gas demand, electricity supply, and electricity demand. The analysis also includes a set of demand elasticity batches for cross-price elasticities.

Table A-1. Specification of Batched Sensitivity Scenarios

Batch	Energy Source	Own-Price or Cross-Price Elasticities	Elasticity Changes	Change in Production Scenario
1	Oil Supply	Own price	Doubled and halved	First 15 years of ***oil*** production from representative E&D scenario for the Gulf of Mexico (GOM)
2	Gas Supply	Own price	Doubled and halved	First 15 years of ***natural gas*** production from representative E&D scenario for the GOM
3	Electricity Supply	Own price	Doubled and halved	First 15 years of ***natural gas*** production from representative E&D scenario for the GOM
4	Oil Demand	Own price	Doubled and halved	First 15 years of ***oil*** production from representative E&D scenario for the GOM
5	Gas Demand	Own price	Doubled and halved	First 15 years of ***natural gas*** production from representative E&D scenario for the GOM
6	Electricity Demand	Own price	Doubled and halved	First 15 years of ***natural gas*** production from representative E&D scenario for the GOM
7	Oil Demand	Own price and cross price	Doubled and halved	First 15 years of ***oil and natural gas*** production from representative E&D scenario for the GOM
8	Gas Demand	Own price and cross price	Doubled and halved	First 15 years of ***oil and natural gas*** production from representative E&D scenario for the GOM
9	Electricity Demand	Own price and cross price	Doubled and halved	First 15 years of ***oil and natural gas*** production from representative E&D scenario for the GOM

Note: For each energy source listed, all categories of production/consumption were included in the sensitivity testing (e.g., all sources of supply for oil).

The E&D scenarios used for all of the batch sensitivities represented in Table A-1 include the first 15 years of production from a longer representative E&D scenario for the Gulf of Mexico. Rather than using all 32 years of OCS production from this scenario, the batch sensitivities are limited to the first 15 years of production, starting with the first year of production (with cumulative oil production of 186 million barrels and cumulative gas production of 285 billion cubic feet), to minimize model run time. Additional details on the specific data to be used from this E&D scenario are presented above in Table A-1.

Results – Batched Elasticity Sensitivities

Tables A-2 to A-10, and Figures A-1 to A-9 display substitution effects results across the nine elasticity batch scenario tests. Based on these substitution effects, key conclusions from the batch sensitivities include the following:

- For the oil supply and oil demand batch sensitivities (batches 1, 4, and 7), there are small shifts between domestic onshore oil production and reduced demand (conservation). The change in substitution patterns for these batches is noticeable but not significant.
- For the gas supply and demand batch sensitivities (batches 2, 5, and 8), there is a more pronounced shift in the substitution pattern, particularly for domestic onshore gas production and reduced demand. This shift in substitution is more substantial than the shifts observed for the sensitivities related to MarketSim's oil elasticities.
- The changes in substitution patterns for the electricity batches (batches 3, 6, and 9) are fairly insignificant.

The findings from the batch tests were also used to identify discrete elasticity parameters for testing. Accordingly, further discussion of the batch elasticity tests is included in the discussion of discrete elasticity sensitivity testing methods in the following section.

The results of the sensitivity tests with respect to the emissions impacts estimated by the OECM are presented in Tables A-11 through A-14 below, separated by batch, for the E&D scenario and No Action Alternative. Tables A-11 and A-12 present these outputs in physical units for the E&D scenario and No Action Alternative, respectively. Tables A-13 and A-14 present these results as the percentage change relative to the appropriate baseline results, respectively, under the E&D scenario and No Action Alternative.[18]

[18] Note that for the E&D emissions for scenarios involving gas production but not oil production, the results do not reflect emissions associated with oil exports. In a scenario involving OCS gas production but not oil, such emissions would likely be minimal. After completing these sensitivities, BOEM modified MarketSim and the OECM to capture these emissions impacts.

Table A-2. Percent of Total Substitution—Elasticity Batch 1: Oil Supply, Own Price

Supply Category	MarketSim Default	Doubled Own Price Elasticities Only	Halved Own Price Elasticities
Domestic Onshore Oil Production	16.34%	18.88%	12.88%
Domestic Offshore Oil Production	0.76%	0.87%	0.60%
Domestic Onshore Gas Production	1.80%	1.03%	2.83%
Domestic Offshore Gas Production	0.01%	0.00%	0.01%
Domestic Coal Production	0.24%	0.14%	0.38%
Oil Imports	66.01%	64.86%	67.56%
Gas Imports	0.05%	0.03%	0.08%
Coal Imports	0.00%	0.00%	0.00%
Electricity	0.39%	0.22%	0.62%
Reduced Demand	4.64%	2.67%	7.33%
Other Liquids	9.77%	11.29%	7.70%
Other Gas	0.00%	0.00%	0.00%

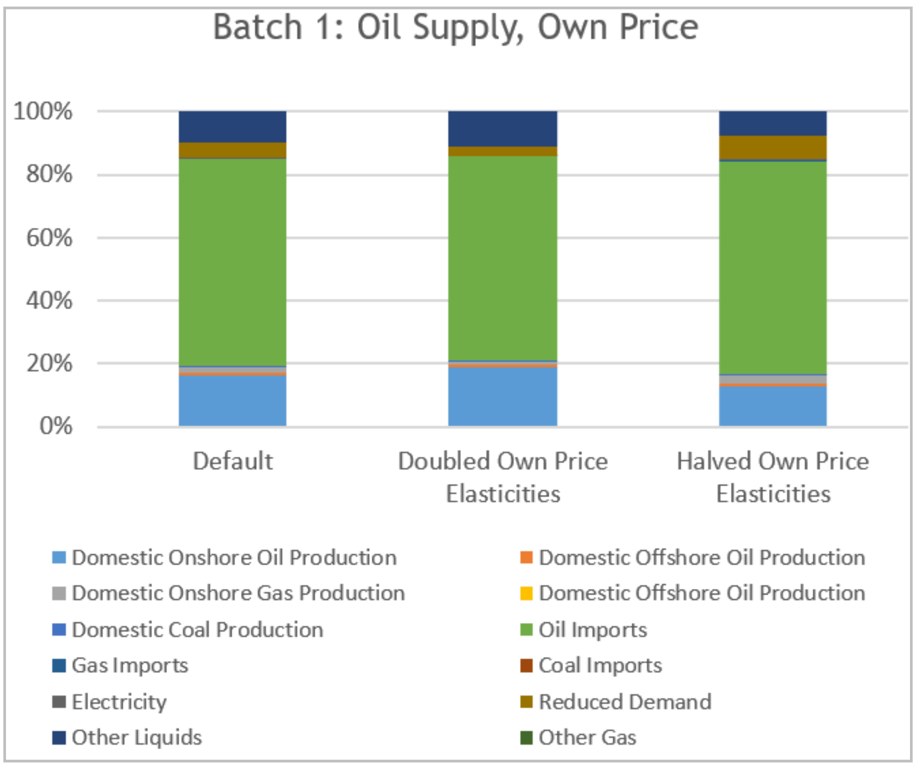

Figure A-1. Substitution Effect Results—Elasticity Batch 1: Oil Supply, Own Price

Table A-3. Percent of Total Substitution—Elasticity Batch 2: Gas Supply, Own Price

Supply Category	MarketSim Default	Doubled Own Price Elasticities Only	Halved Own Price Elasticities
Domestic Onshore Oil Production	0.69%	0.29%	1.23%
Domestic Offshore Oil Production	0.03%	0.01%	0.05%
Domestic Onshore Gas Production	75.54%	84.94%	61.42%
Domestic Offshore Gas Production	0.34%	0.37%	0.28%
Domestic Coal Production	1.08%	0.60%	1.81%
Oil Imports	3.52%	2.15%	5.70%
Gas Imports	2.29%	2.56%	1.88%
Coal Imports	0.00%	0.00%	0.00%
Electricity	2.78%	1.54%	4.60%
Reduced Demand	13.24%	7.29%	22.22%
Other Liquids	0.42%	0.17%	0.74%
Other Gas	0.07%	0.08%	0.06%

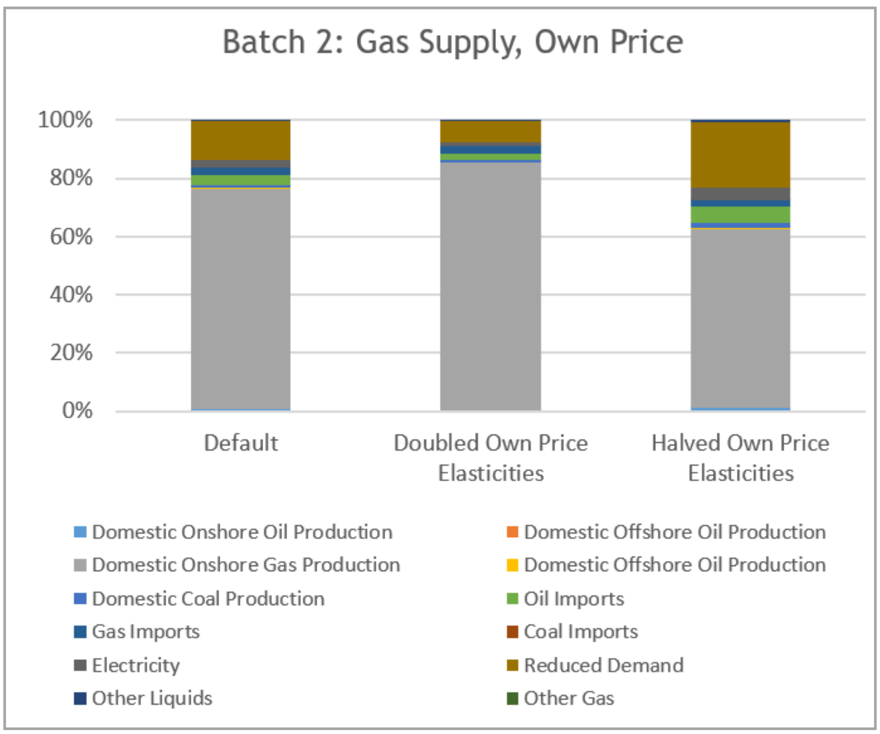

Figure A-2. Substitution Effect Results—Elasticity Batch 2: Gas Supply, Own Price

Table A-4. Percent of Total Substitution—Elasticity Batch 3: Electricity Supply, Own Price

Supply Category	MarketSim Default	Doubled Own Price Elasticities Only	Halved Own Price Elasticities
Domestic Onshore Oil Production	0.69%	0.65%	0.70%
Domestic Offshore Oil Production	0.03%	0.03%	0.03%
Domestic Onshore Gas Production	75.54%	72.75%	76.98%
Domestic Offshore Gas Production	0.34%	0.33%	0.34%
Domestic Coal Production	1.08%	1.69%	0.76%
Oil Imports	3.52%	3.51%	3.54%
Gas Imports	2.29%	2.22%	2.33%
Coal Imports	0.00%	0.00%	0.00%
Electricity	2.78%	5.52%	1.36%
Reduced Demand	13.24%	12.85%	13.47%
Other Liquids	0.42%	0.39%	0.42%
Other Gas	0.07%	0.07%	0.07%

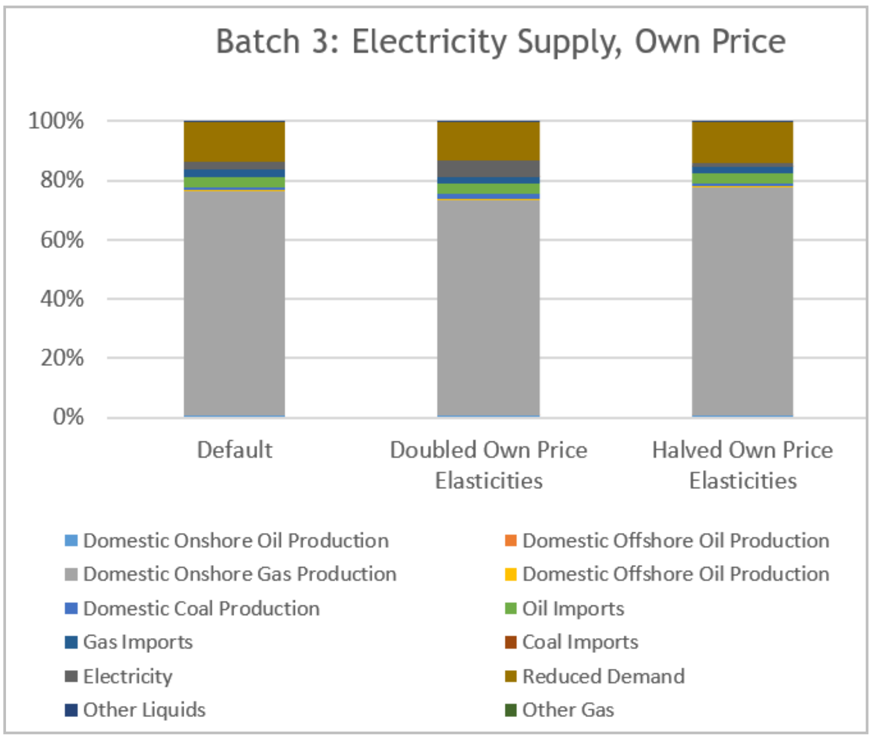

Figure A-3. Substitution Effect Results—Elasticity Batch 3: Electricity Supply, Own Price

Table A-5. Percent of Total Substitution—Elasticity Batch 4: Oil Demand, Own Price

Supply Category	MarketSim Default	Doubled Own Price Elasticities Only	Halved Own Price Elasticities
Domestic Onshore Oil Production	16.34%	12.91%	18.85%
Domestic Offshore Oil Production	0.76%	0.60%	0.87%
Domestic Onshore Gas Production	1.80%	1.42%	2.07%
Domestic Offshore Gas Production	0.01%	0.01%	0.01%
Domestic Coal Production	0.24%	0.19%	0.27%
Oil Imports	66.01%	67.69%	64.76%
Gas Imports	0.05%	0.04%	0.06%
Coal Imports	0.00%	0.00%	0.00%
Electricity	0.39%	0.31%	0.45%
Reduced Demand	4.64%	9.12%	1.38%
Other Liquids	9.77%	7.72%	11.28%
Other Gas	0.00%	0.00%	0.00%

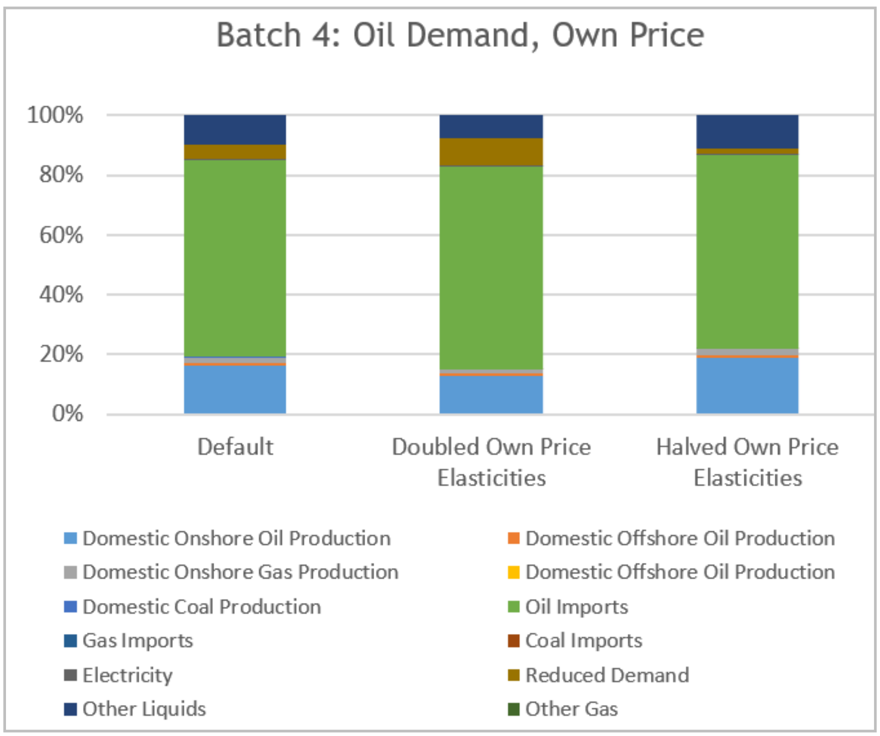

Figure A-4. Substitution Effect Results—Elasticity Batch 4: Oil Demand, Own Price

Table A-6. Percent of Total Substitution—Elasticity Batch 5: Gas Demand, Own Price

Supply Category	MarketSim Default	Doubled Own Price Elasticities Only	Halved Own Price Elasticities
Domestic Onshore Oil Production	0.69%	0.56%	0.78%
Domestic Offshore Oil Production	0.03%	0.02%	0.03%
Domestic Onshore Gas Production	75.54%	62.11%	84.39%
Domestic Offshore Gas Production	0.34%	0.28%	0.37%
Domestic Coal Production	1.08%	0.91%	1.20%
Oil Imports	3.52%	2.99%	3.87%
Gas Imports	2.29%	1.90%	2.55%
Coal Imports	0.00%	0.00%	0.00%
Electricity	2.78%	2.32%	3.08%
Reduced Demand	13.24%	28.51%	3.19%
Other Liquids	0.42%	0.34%	0.47%
Other Gas	0.07%	0.06%	0.07%

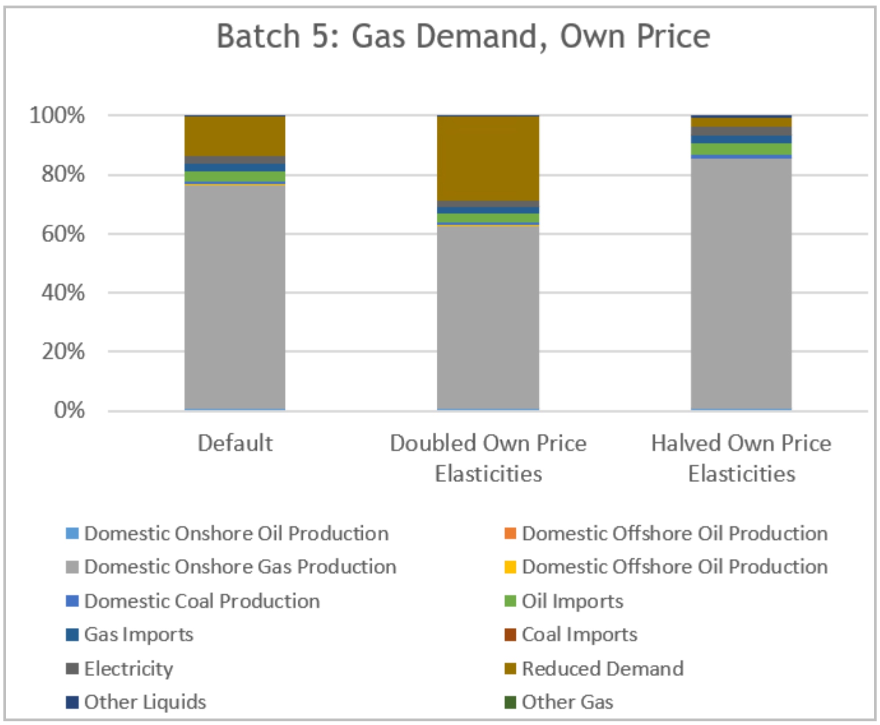

Figure A-5. Substitution Effect Results—Elasticity Batch 5: Gas Demand, Own Price

Table A-7. Percent of Total Substitution—Elasticity Batch 6: Electricity Demand, Own Price

Supply Category	MarketSim Default	Doubled Own Price Elasticities Only	Halved Own Price Elasticities
Domestic Onshore Oil Production	0.69%	0.66%	0.71%
Domestic Offshore Oil Production	0.03%	0.03%	0.03%
Domestic Onshore Gas Production	75.54%	74.49%	76.35%
Domestic Offshore Gas Production	0.34%	0.33%	0.34%
Domestic Coal Production	1.08%	0.87%	1.25%
Oil Imports	3.52%	3.30%	3.72%
Gas Imports	2.29%	2.26%	2.32%
Coal Imports	0.00%	0.00%	0.00%
Electricity	2.78%	2.11%	3.30%
Reduced Demand	13.24%	15.49%	11.49%
Other Liquids	0.42%	0.40%	0.43%
Other Gas	0.07%	0.07%	0.07%

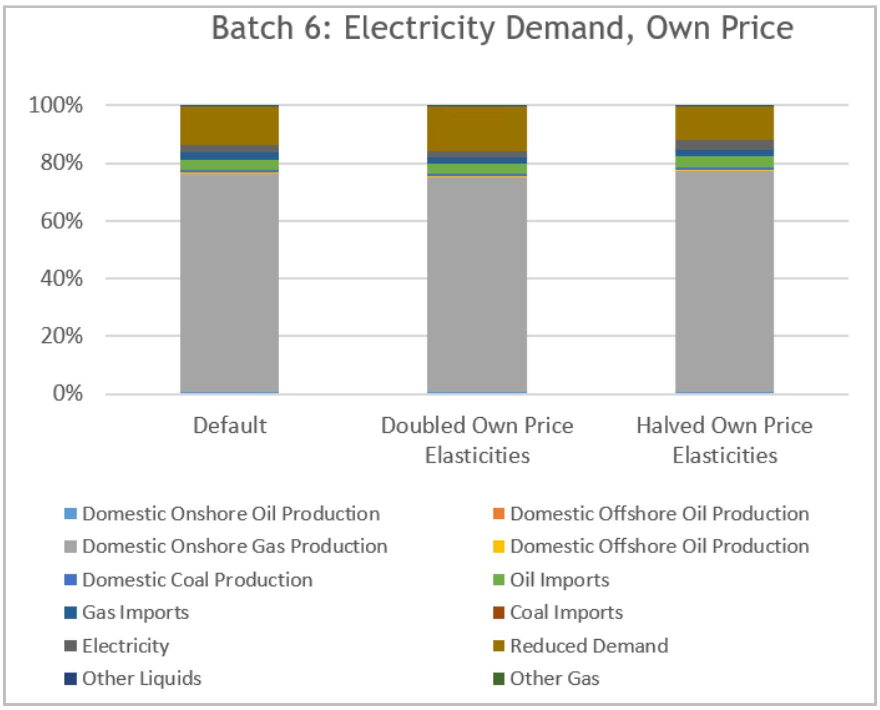

Figure A-6. Substitution Effect Results—Elasticity Batch 6: Electricity Demand, Own Price

Table A-8. Percent of Total Substitution—Elasticity Batch 7: Oil Demand, Own Price & Cross Price

Supply Category	MarketSim Default	Doubled Own Price Elasticities Only	Halved Own Price Elasticities
Domestic Onshore Oil Production	13.12%	10.51%	15.02%
Domestic Offshore Oil Production	0.61%	0.49%	0.69%
Domestic Onshore Gas Production	17.10%	16.83%	17.30%
Domestic Offshore Gas Production	0.07%	0.07%	0.08%
Domestic Coal Production	0.41%	0.38%	0.44%
Oil Imports	52.99%	55.13%	51.59%
Gas Imports	0.52%	0.51%	0.52%
Coal Imports	0.00%	0.00%	0.00%
Electricity	0.89%	0.83%	0.93%
Reduced Demand	6.43%	8.96%	4.42%
Other Liquids	7.85%	6.28%	8.98%
Other Gas	0.02%	0.01%	0.02%

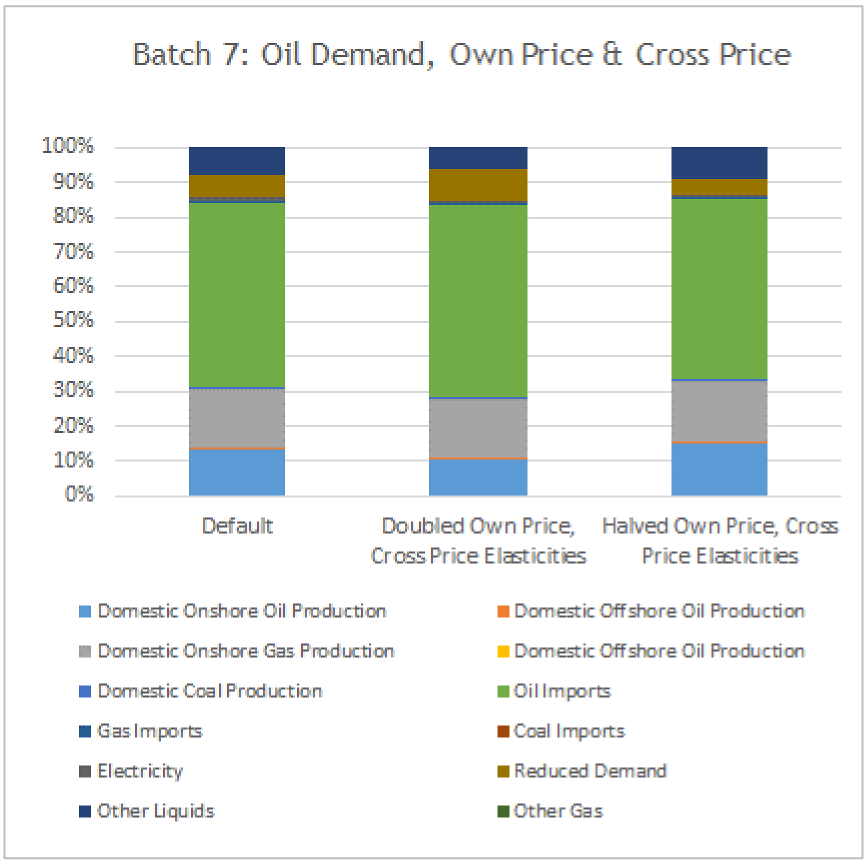

Figure A-7. Substitution Effect Results—Elasticity Batch 7: Oil Demand, Own Price & Cross Price

Table A-9. Percent of Total Substitution—Elasticity Batch 7: Gas Demand, Own Price & Cross Price

Supply Category	MarketSim Default	Doubled Own Price Elasticities Only	Halved Own Price Elasticities
Domestic Onshore Oil Production	13.12%	13.09%	13.14%
Domestic Offshore Oil Production	0.61%	0.61%	0.61%
Domestic Onshore Gas Production	17.10%	15.28%	18.26%
Domestic Offshore Gas Production	0.07%	0.07%	0.08%
Domestic Coal Production	0.41%	0.39%	0.43%
Oil Imports	52.99%	52.87%	53.06%
Gas Imports	0.52%	0.46%	0.55%
Coal Imports	0.00%	0.00%	0.00%
Electricity	0.89%	0.82%	0.93%
Reduced Demand	6.43%	8.57%	5.08%
Other Liquids	7.85%	7.83%	7.86%
Other Gas	0.02%	0.01%	0.02%

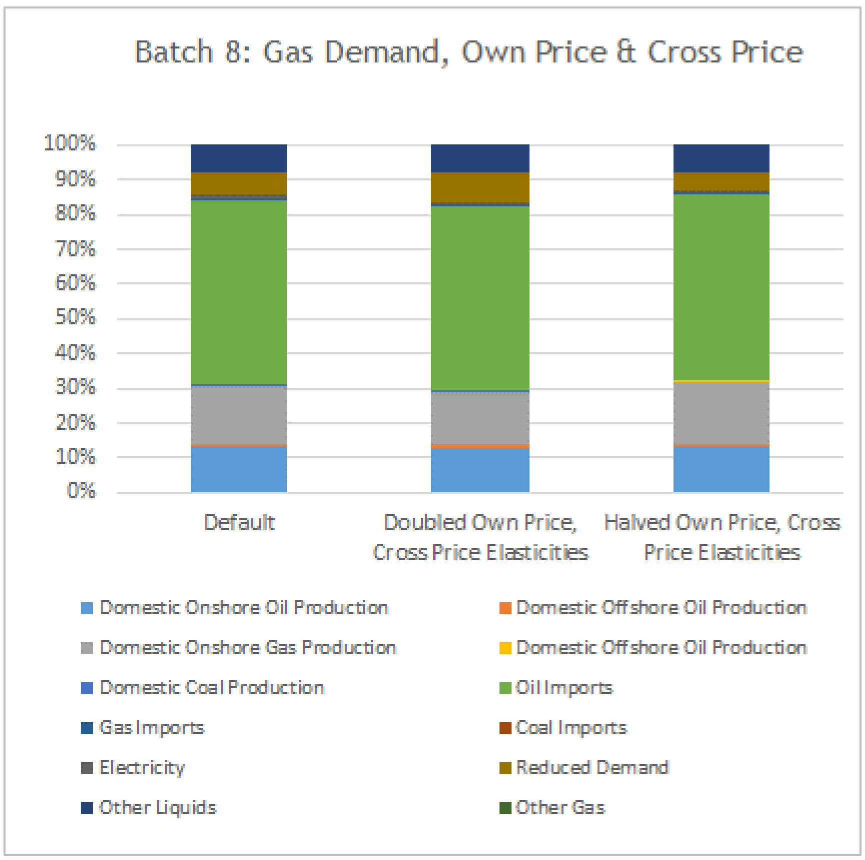

Figure A-8. Substitution Effect Results—Elasticity Batch 8: Gas Demand, Own Price & Cross Price

Table A-10. Percent of Total Substitution—Elasticity Batch 9: Electricity Demand, Own Price & Cross Price

Supply Category	MarketSim Default	Doubled Own Price Elasticities Only	Halved Own Price Elasticities
Domestic Onshore Oil Production	13.12%	13.11%	13.13%
Domestic Offshore Oil Production	0.61%	0.61%	0.61%
Domestic Onshore Gas Production	17.10%	17.41%	16.87%
Domestic Offshore Gas Production	0.07%	0.08%	0.07%
Domestic Coal Production	0.41%	0.45%	0.38%
Oil Imports	52.99%	52.92%	53.02%
Gas Imports	0.52%	0.53%	0.51%
Coal Imports	0.00%	0.00%	0.00%
Electricity	0.89%	1.02%	0.79%
Reduced Demand	6.43%	6.02%	6.74%
Other Liquids	7.85%	7.84%	7.85%
Other Gas	0.02%	0.02%	0.01%

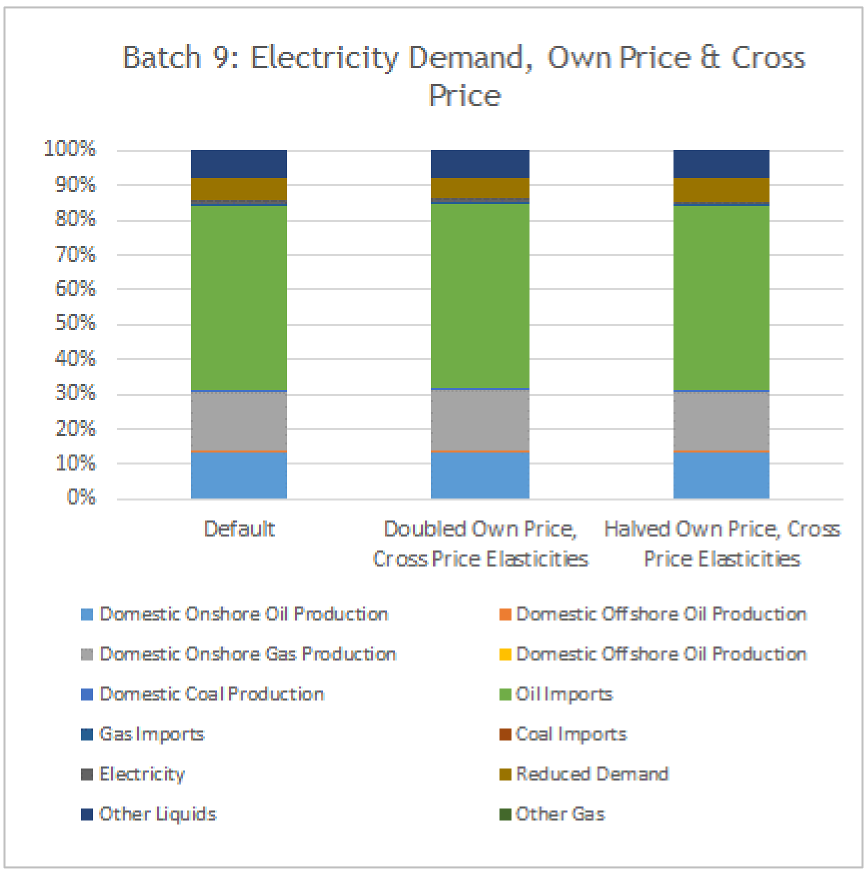

Figure A-9. Substitution Effect Results—Elasticity Batch 9: Electricity Demand, Own Price & Cross Price

Table A-11. Batch Elasticity Sensitivities OECM Air Emissions Impacts—E&D Scenario (1,000s of tons)

Batch	Scenario	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
Baseline	Oil Supply-Doubled Own Price	23.23	1.93	0.64	0.61	6.59	4.22	2,497.72	14.44	0.08
Baseline	Oil Supply-Halved Own Price	22.94	1.89	0.63	0.60	6.56	3.95	2,438.37	14.26	0.07
Baseline	Gas Supply-Doubled Own Price	23.23	1.93	0.64	0.61	6.59	4.23	2,498.34	14.44	0.08
1	Gas Supply-Halved Own Price	23.19	1.93	0.64	0.61	6.58	4.18	2,477.11	14.38	0.08
	Electricity Supply-Doubled Own Price	23.27	1.93	0.64	0.61	6.59	4.29	2,526.11	14.53	0.08
2	Electricity Supply-Halved Own Price	22.94	1.89	0.63	0.60	6.56	3.95	2,438.37	14.26	0.07
	Oil Demand-Doubled Own Price	22.94	1.89	0.63	0.60	6.56	3.95	2,438.37	14.26	0.07
3	Oil Demand-Halved Own Price	22.94	1.89	0.63	0.60	6.56	3.95	2,438.37	14.26	0.07
	Gas Demand-Doubled Own Price	22.94	1.89	0.63	0.60	6.56	3.95	2,438.37	14.26	0.07
4	Gas Demand-Halved Own Price	23.27	1.93	0.64	0.61	6.59	4.29	2,525.96	14.53	0.08
	Electricity Demand-Doubled Own Price	23.19	1.93	0.64	0.61	6.58	4.18	2,477.14	14.38	0.08
5	Electricity Demand-Halved Own Price	22.94	1.89	0.63	0.60	6.56	3.95	2,438.37	14.26	0.07
	Oil Demand-Doubled Own Price & Cross Price	22.94	1.89	0.63	0.60	6.56	3.95	2,438.37	14.26	0.07
6	Oil Demand-Halved Own Price & Cross Price	22.94	1.89	0.63	0.60	6.56	3.95	2,438.37	14.26	0.07
	Gas Demand-Doubled Own Price & Cross Price	22.94	1.89	0.63	0.60	6.56	3.95	2,438.37	14.26	0.07
7	Gas Demand-Halved Own Price & Cross Price	23.27	1.93	0.64	0.61	6.59	4.29	2,528.08	14.54	0.08
	Electricity Demand-Doubled Own Price & Cross Price	23.19	1.93	0.64	0.61	6.58	4.18	2,477.29	14.38	0.08
8	Electricity Demand-Halved Own Price & Cross Price	23.23	1.93	0.64	0.61	6.59	4.23	2,498.28	14.44	0.08
	Oil Supply-Doubled Own Price	23.23	1.93	0.64	0.61	6.59	4.23	2,498.38	14.44	0.08
9	Oil Supply-Halved Own Price	23.23	1.93	0.64	0.61	6.59	4.23	2,498.40	14.44	0.08
	Gas Supply-Doubled Own Price	23.23	1.93	0.64	0.61	6.59	4.23	2,498.32	14.44	0.08

Table A-12. Batch Elasticity Sensitivities OECM Air Emissions Impacts—No Action Alternative (1,000s of tons)

Batch	Scenario	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
Baseline	Oil Supply-Doubled Own Price	3.29	0.68	0.06	0.04	0.42	9.48	6,904.43	55.44	0.08
Baseline	Oil Supply-Halved Own Price	16.52	0.19	0.19	0.16	1.54	13.80	868.98	75.05	0.03
Baseline	Gas Supply-Doubled Own Price	19.84	0.87	0.25	0.21	1.97	23.32	7,769.04	130.60	0.11
1	Gas Supply-Halved Own Price	2.64	0.73	0.05	0.04	0.38	9.87	6,885.47	58.94	0.08
	Electricity Supply-Doubled Own Price	4.18	0.61	0.09	0.06	0.49	8.93	6,928.59	50.62	0.09
2	Electricity Supply-Halved Own Price	18.86	0.20	0.20	0.19	1.75	15.70	940.36	85.11	0.03
	Oil Demand-Doubled Own Price	13.17	0.18	0.17	0.14	1.24	11.05	769.56	60.53	0.02
3	Oil Demand-Halved Own Price	15.48	0.19	0.19	0.16	1.45	12.92	819.08	70.47	0.02
	Gas Demand-Doubled Own Price	17.11	0.19	0.19	0.17	1.59	14.29	897.50	77.63	0.03
4	Gas Demand-Halved Own Price	2.95	0.58	0.06	0.04	0.37	7.91	6,857.51	44.90	0.08
	Electricity Demand-Doubled Own Price	3.54	0.75	0.07	0.05	0.47	10.62	6,937.76	63.13	0.08
5	Electricity Demand-Halved Own Price	13.67	0.16	0.16	0.14	1.28	11.42	722.07	62.12	0.02
	Oil Demand-Doubled Own Price & Cross Price	18.39	0.21	0.21	0.18	1.71	15.35	965.09	83.52	0.03
6	Oil Demand-Halved Own Price & Cross Price	16.14	0.18	0.18	0.16	1.50	13.48	843.86	73.26	0.02
	Gas Demand-Doubled Own Price & Cross Price	16.83	0.20	0.20	0.17	1.57	14.05	889.82	76.49	0.03
7	Gas Demand-Halved Own Price & Cross Price	19.54	0.78	0.25	0.21	1.92	21.85	7,823.59	120.58	0.11
	Electricity Demand-Doubled Own Price & Cross Price	20.07	0.94	0.26	0.21	2.01	24.39	7,747.81	137.91	0.11
8	Electricity Demand-Halved Own Price & Cross Price	17.93	0.85	0.23	0.19	1.79	21.72	7,670.24	121.94	0.11
	Oil Supply-Doubled Own Price	21.05	0.89	0.27	0.22	2.08	24.32	7,831.19	136.07	0.11
9	Oil Supply-Halved Own Price	20.21	0.88	0.26	0.21	2.00	23.62	7,790.77	132.33	0.11
	Gas Supply-Doubled Own Price	19.57	0.87	0.25	0.21	1.94	23.09	7,750.88	129.32	0.11

Table A-13. Batch Elasticity Sensitivities OECM Air Emissions Percentage Change from Baseline—E&D Scenario (1,000s of tons)

Batch	Scenario	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
Baseline	Oil Supply-Doubled Own Price	-0.1%	-0.2%	-0.1%	-0.1%	0.0%	-1.1%	-0.8%	-0.4%	-1.3%
Baseline	Oil Supply-Halved Own Price	0.2%	0.3%	0.1%	0.1%	0.1%	1.5%	1.1%	0.6%	1.7%
Baseline	Gas Supply-Doubled Own Price	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1	Gas Supply-Halved Own Price	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Electricity Supply-Doubled Own Price	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	Electricity Supply-Halved Own Price	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Oil Demand-Doubled Own Price	0.2%	0.3%	0.1%	0.1%	0.1%	1.5%	1.1%	0.6%	1.7%
3	Oil Demand-Halved Own Price	-0.1%	-0.2%	-0.1%	-0.1%	0.0%	-1.1%	-0.8%	-0.4%	-1.3%
	Gas Demand-Doubled Own Price	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	Gas Demand-Halved Own Price	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Electricity Demand-Doubled Own Price	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	Electricity Demand-Halved Own Price	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Oil Demand-Doubled Own Price & Cross Price	0.2%	0.3%	0.1%	0.1%	0.1%	1.6%	1.2%	0.6%	1.8%
6	Oil Demand-Halved Own Price & Cross Price	-0.1%	-0.2%	-0.1%	-0.1%	0.0%	-1.1%	-0.8%	-0.5%	-1.3%
	Gas Demand-Doubled Own Price & Cross Price	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7	Gas Demand-Halved Own Price & Cross Price	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Electricity Demand-Doubled Own Price & Cross Price	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8	Electricity Demand-Halved Own Price & Cross Price	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Oil Supply-Doubled Own Price	-0.1%	-0.2%	-0.1%	-0.1%	0.0%	-1.1%	-0.8%	-0.4%	-1.3%
9	Oil Supply-Halved Own Price	0.2%	0.3%	0.1%	0.1%	0.1%	1.5%	1.1%	0.6%	1.7%
	Gas Supply-Doubled Own Price	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table A-14. Batch Elasticity Sensitivities OECM Air Emissions Percentage Change from Baseline—No Action Alternative (1,000s of tons)

Batch	Scenario	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
Baseline	Oil Supply-Doubled Own Price	-19.7%	7.6%	-25.8%	-18.3%	-10.4%	4.2%	-0.3%	6.3%	-2.1%
Baseline	Oil Supply-Halved Own Price	26.9%	-10.5%	35.7%	25.2%	14.3%	-5.8%	0.3%	-8.7%	2.9%
Baseline	Gas Supply-Doubled Own Price	-5.0%	-77.0%	-21.7%	-11.7%	-11.0%	-32.7%	-87.9%	-34.8%	-73.8%
1	Gas Supply-Halved Own Price	-33.6%	-79.9%	-31.5%	-35.6%	-37.2%	-52.6%	-90.1%	-53.7%	-80.5%
	Electricity Supply-Doubled Own Price	-22.0%	-78.1%	-23.9%	-25.2%	-26.4%	-44.6%	-89.5%	-46.0%	-78.0%
2	Electricity Supply-Halved Own Price	-13.8%	-78.2%	-26.6%	-19.4%	-19.1%	-38.7%	-88.4%	-40.6%	-75.7%
	Oil Demand-Doubled Own Price	-10.2%	-14.6%	-11.8%	-8.1%	-13.6%	-16.5%	-0.7%	-19.0%	0.5%
3	Oil Demand-Halved Own Price	7.5%	10.7%	8.8%	5.9%	9.9%	12.0%	0.5%	13.9%	-0.4%
	Gas Demand-Doubled Own Price	-31.1%	-81.9%	-38.3%	-35.0%	-35.2%	-51.0%	-90.7%	-52.4%	-80.6%
4	Gas Demand-Halved Own Price	-7.3%	-75.7%	-17.4%	-12.6%	-12.9%	-34.2%	-87.6%	-36.1%	-73.9%
	Electricity Demand-Doubled Own Price	-18.6%	-79.2%	-29.4%	-23.7%	-23.6%	-42.2%	-89.1%	-43.9%	-77.1%
5	Electricity Demand-Halved Own Price	-15.2%	-77.4%	-22.7%	-19.7%	-20.2%	-39.7%	-88.5%	-41.4%	-76.1%
	Oil Demand-Doubled Own Price & Cross Price	-1.5%	-10.5%	-2.8%	-1.5%	-2.7%	-6.3%	0.7%	-7.7%	1.5%
6	Oil Demand-Halved Own Price & Cross Price	1.1%	7.7%	2.1%	1.1%	2.0%	4.6%	-0.3%	5.6%	-0.9%
	Gas Demand-Doubled Own Price & Cross Price	-9.6%	-2.5%	-8.5%	-9.1%	-9.0%	-6.8%	-1.3%	-6.6%	-2.7%
7	Gas Demand-Halved Own Price & Cross Price	6.1%	1.6%	5.3%	5.7%	5.7%	4.3%	0.8%	4.2%	1.7%
	Electricity Demand-Doubled Own Price & Cross Price	1.8%	0.9%	3.4%	2.1%	1.8%	1.3%	0.3%	1.3%	0.5%
8	Electricity Demand-Halved Own Price & Cross Price	-1.4%	-0.7%	-2.6%	-1.6%	-1.3%	-1.0%	-0.2%	-1.0%	-0.4%
	Oil Supply-Doubled Own Price	-19.7%	7.6%	-25.8%	-18.3%	-10.4%	4.2%	-0.3%	6.3%	-2.1%
9	Oil Supply-Halved Own Price	26.9%	-10.5%	35.7%	25.2%	14.3%	-5.8%	0.3%	-8.7%	2.9%
	Gas Supply-Doubled Own Price	-5.0%	-77.0%	-21.7%	-11.7%	-11.0%	-32.7%	-87.9%	-34.8%	-73.8%

A.3 Discrete Elasticity Sensitivities

The batched elasticity sensitivities described above informed the development of more targeted sensitivities focused on specific elasticity parameters (using the same E&D scenarios as applied in the batch sensitivities). If the sensitivity tests for a given elasticity batch in Table A-1 showed very little sensitivity to alternative values, it is unlikely that changes to just one of the parameters in that batch would lead to significant changes in model results. Thus, under those circumstances, this analysis did not pursue sensitivity testing for individual parameters in a given batch. Conversely, if a batch sensitivity identified in the previous section showed substantive changes in outputs, elasticity sensitivity tests were conducted for at least a subset of the individual elasticity parameters in that batch. The specific elasticity parameters to be examined were based on the criteria outlined below. For each elasticity parameter selected, two sensitivities were conducted, one in which the elasticity parameter of interest was set to double the default value and one in which it was half the default value. The overall goal of these discrete elasticity sensitivities was to understand which specific parameter(s) was the driver of results from the batch sensitivity testing.

As context for the selection of specific elasticity parameters to examine in the individual elasticity sensitivities, The list below shows the substitution categories included in MarketSim's results. For a given scenario, MarketSim estimates substitution effects across the categories listed in the table in both absolute and normalized terms, with the normalized values expressed as percentages that sum to 100 percent. Thus, if the model's results show 20 percent of the substitution effect for a scenario associated with domestic onshore oil production, that implies that, in the absence of the production included in the E&D scenario, domestic onshore oil production would substitute for 20 percent of the production included in the E&D scenario.

MarketSim Substitution Categories

- Onshore Oil Production
- Onshore Gas Production
- Offshore Oil Production
- Offshore Gas Production
- Oil Imports
- Gas Imports
- Biofuels Production
- Other Oil Production
- Other Gas Production
- Coal Production
- Coal Imports
- Electricity Production – Nuclear
- Electricity Production – Hydro
- Electricity Production – Solar
- Electricity Production – Onshore wind
- Electricity Production – Offshore Wind
- Electricity Production – Other
- Electricity Imports
- Reduced Oil Demand
- Reduced Natural Gas Demand
- Reduced Coal Demand
- Reduced Electricity Demand

In reviewing each set of batch elasticity sensitivity results listed in Table A-1, the testing focuses on substitution metrics for the MarketSim substitution categories that directly correspond to that batch. For example, for the batch focused on oil supply elasticities (batch 1), the testing focuses on substitution results related to onshore oil production, offshore oil production, biofuels production, other oil production, and oil imports. While other, indirectly related substitution results may suggest the potential need for an individual sensitivity (e.g., continuing the example above, reduced oil demand for the batch related to oil supply elasticities), other sets of batch results more directly related to those elasticity parameters are more appropriate for making those determinations (e.g., continuing the above example, the oil *demand* elasticity batch for reduced oil demand).

To identify the elasticity parameters for individual elasticity sensitivity testing, IEc relies on three key metrics from the batch sensitivity tests:

Metric 1. The relative change in substitution share (applied to supply elasticities and own price elasticities of demand only). For each substitution category that directly corresponds to a given batch sensitivity, IEc estimates the extent to which it changes as a percentage of the overall substitution effect in the batch test. As an example, if onshore oil production constitutes 10 percent of the substitution effect in the default elasticity scenario and 12.5 percent in the batch test with doubled oil supply elasticity values, the relative change in substitution share would be 25 percent. To be considered for inclusion in the discrete elasticity testing, the relative change in substitution share must be at least 15 percent relative to the substitution results based on default elasticity values. Thus, in the example above, because the relative change of 25 percent exceeds the 15 percent threshold, all elasticity values associated with onshore oil production would be considered for inclusion in the individual elasticity testing (subject to the Metric 2 threshold below).

Metric 2. The share of substitution under the default elasticity scenario for the categories in question (applied to all supply and demand elasticities). Not all relative substitution changes above the 15 percent threshold would represent a significant change in the model's results. For example, if a category represents 0.1 percent of all substitution in the default elasticity run and 0.2 percent in the batch sensitivity run, that represents a 100 percent change in its share of substitution impacts. However, given the small magnitude of this category's share of substitution relative to other categories, the change from 0.1 percent to 0.2 percent of substitution impacts is unlikely to affect conclusions drawn from the model, or the estimated greenhouse gas impacts estimated downstream in BOEM's analytic chain (e.g., in the OECM or GLEEM). On that basis, any of the substitution output variables that constitutes less than 1 percent of total substitution under the baseline scenario is excluded from the individual elasticity sensitivities.

Metric 3. The relative change in substitution share for own price and cross price demand elasticity batch tests (batches 7–9) versus own price only demand elasticity batch tests (batches 4–6). The purpose of Metric 3 is to determine which cross-price elasticities of demand to include in the individual elasticity sensitivities. To make this determination, Metric 3 compares the batch sensitivities for own price elasticities of demand against the batch sensitivities that include both own-price and cross-price elasticities. If IEc observes a substantive change in the substitution impact for the fuel in question, IEc recommends inclusion of the relevant cross-price elasticities in the discrete elasticity sensitivities. With that in mind, IEc calculates Metric 3 separately for the substitution effects associated with oil, gas, and electricity. For each energy source, Metric 3 is calculated as the percent change in observed substitution impacts, by energy source, when changing from the batch sensitivity with own price elasticity values modified to the batch sensitivity with own-price and cross-price elasticity values modified. The paired batches are those for oil demand (batch 4, own price only, and batch 7, own price and cross-price), gas demand (batch 5, own price only, and batch 8, own price and cross-price), and electricity demand (batch 6, own price only, and batch 9, own price and cross-price). As an example, if reduced oil demand's share of the total substitution effect in batch 4 is 5 percent, and reduced oil demand's share of the total substitution effect in batch 7 is 6 percent, then the relative change in substitution share for own price and cross-price demand elasticity batch tests for oil supply is 20 percent. Similar to Metric 2 described above, IEc adopts a threshold of 15 percent for this metric.

IEc applies Metrics 1 and 2 for supply elasticities and own-price elasticities of demand and Metrics 2 and 3 for cross-price elasticities of demand. The selections for discrete elasticity testing follow these decision rules:

- ***Supply elasticities and own price elasticities of demand:*** Elasticity sensitivities for individual elasticities modified in a given batch are selected if the value of Metric 1 (the proportional change in substitution impacts for the relevant substitution outputs) exceeds 15 percent and the value of Metric 2 (substitution impact with default elasticity values) exceeds 1 percent. This test is performed for individual substitution outputs applicable to a given batch. (e.g., for oil supply, it is applied to onshore oil production, offshore oil production, oil imports, biofuels production, and other oil production)

- ***Cross-price elasticities of demand:*** Elasticity sensitivities for individual cross-price elasticities modified in a given batch are selected if the value of Metric 3 (the relative change in substitution impacts when considering changes in cross-price elasticities and own price elasticities rather than just the latter) exceeds 15 percent and the value of Metric 2 (substitution impact with default elasticity values) exceeds 1 percent.

Tables A-15 through A-19 present our findings with respect to the metrics above. Based on these findings, the right-most column of each exhibit identifies the individual elasticity parameters that IEc and BOEM have selected for inclusion in the discrete elasticity testing. These include the following:

- Oil supply – Lower 48 Onshore (tight)
- Oil supply – Lower 48 Onshore (conventional)
- Oil supply – Alaska Onshore
- Gas supply – Lower 48 Conventional
- Gas supply – Lower 48 Unconventional
- Gas supply – Alaska Onshore
- Gas supply – Imports Pipeline
- Gas supply – Imports LNG
- Electricity supply – Solar
- Oil demand – Own price elasticity of residential demand
- Oil demand – Own price elasticity of commercial demand
- Oil demand – Own price elasticity of industrial demand
- Oil demand – Own price elasticity of transport sector demand
- Gas demand – Own price elasticity of residential demand
- Gas demand – Own price elasticity of commercial demand
- Gas demand – Own price elasticity of industrial demand
- Gas demand – Own price elasticity of transport sector demand

Table A-15. Selection of Discrete Elasticity Sensitivity Scenarios for Oil Supply

Batch No.	Batch Name	Applicable Substitution Categories from MarketSim	Findings Relative to Thresholds from Batch Sensitivity Testing	Selected for Discrete Test?	Elasticity Parameters to Assess in Discrete Sensitivities
1	Oil Supply	Onshore oil production	**Metric 1:** >15% change in substitution share relative to default elasticity run **Metric 2:** >1% of default substitution effects	Yes	Lower 48 Onshore (tight) Lower 48 Onshore (conventional) Alaskan Onshore
1	Oil Supply	Offshore oil production	**Metric 1:** >15% change in substitution share relative to default elasticity run (for halved elasticity only) **Metric 2:** <1% of default substitution effects	No	None—not selected for discrete testing
1	Oil Supply	Oil imports	**Metric 1:** <15% change in substitution share relative to default elasticity run **Metric 2:** >1% of default substitution effects	No	None—not selected for discrete testing
1	Oil Supply	Biofuels production	**Metric 1:** >15% change in substitution share relative to default elasticity run **Metric 2:** <1% of default substitution effects	No	None—not selected for discrete testing
1	Oil Supply	Other oil production	**Metric 1:** >15% change in substitution share relative to default elasticity run **Metric 2:** >1% of default substitution effects	Yes	Other Oil

Table A-16. Specification of Potential Discrete Elasticity Sensitivity Scenarios for Gas Supply

Batch No.	Batch Name	Applicable Substitution Categories from MarketSim	Findings Relative to Thresholds from Batch Sensitivity Testing	Selected for Discrete Test?	Elasticity Parameters to Assess in Discrete Sensitivities
2	Gas Supply	Onshore Gas Production	**Metric 1:** >15% change in substitution share relative to default elasticity run (for halved elasticity only) **Metric 2:** >1% of default substitution effects	Yes	Lower 48 Conventional Lower 48 Unconventional Alaska Onshore
2	Gas Supply	Offshore Gas Production	**Metric 1:** >15% change in substitution share relative to default elasticity run (for halved elasticity only) **Metric 2:** <1% of default substitution effects	No	None—not selected for discrete testing
2	Gas Supply	Gas Imports	**Metric 1:** >15% change in substitution share relative to default elasticity run (for halved elasticity only) **Metric 2:** >1% of default substitution effects	Yes	Imports Pipeline Imports LNG
2	Gas Supply	Other Gas Production	**Metric 1:** >15% change in substitution share relative to default elasticity run (for halved elasticity only) **Metric 2:** <1% of default substitution effects	No	None—not selected for discrete testing

Table A-17. Specification of Potential Discrete Elasticity Sensitivity Scenarios for Electricity Supply

Batch No.	Batch Name	Applicable Substitution Categories from MarketSim	Findings Relative to Thresholds from Batch Sensitivity Testing	Selected for Discrete Test?	Elasticity Parameters to Assess in Discrete Sensitivities
3	Electricity Supply	Electricity Production – Nuclear	**Metric 1:** >15% change in substitution share relative to default elasticity run **Metric 2:** <1% of default substitution effects	No	None—not selected for discrete testing
3	Electricity Supply	Electricity Production-Hydro	**Metric 1:** >15% change in substitution share relative to default elasticity run **Metric 2:** <1% of default substitution effects	No	None—not selected for discrete testing
3	Electricity Supply	Electricity Production – Solar	**Metric 1:** >15% change in substitution share relative to default elasticity run (for halved elasticity only) **Metric 2:** >1% of default substitution effects	Yes	Electricity Supply – Solar
3	Electricity Supply	Electricity Production – Onshore Wind	**Metric 1:** >15% change in substitution share relative to default elasticity run **Metric 2:** <1% of default substitution effects	No	None—not selected for discrete testing
3	Electricity Supply	Electricity Production – Offshore Wind	**Metric 1:** >15% change in substitution share relative to default elasticity run **Metric 2:** <1% of default substitution effects	No	None—not selected for discrete testing
3	Electricity Supply	Electricity Production – Other	**Metric 1:** >15% change in substitution share relative to default elasticity run **Metric 2:** <1% of default substitution effects	No	None—not selected for discrete testing
3	Electricity Supply	Electricity Production – Imports	**Metric 1:** >15% change in substitution share relative to default elasticity run **Metric 2:** <1% of default substitution effects	No	None—not selected for discrete testing

Table A-18. Specification of Potential Discrete Elasticity Sensitivity Scenarios for Own Price Elasticities of Demand

Batch No.	Batch Name	Applicable Substitution Categories from MarketSim	Findings Relative to Thresholds from Batch Sensitivity Testing	Selected for Discrete Test?	Elasticity Parameters to Assess in Discrete Sensitivities
4	Oil Demand, Own Price	Reduced Oil Demand	**Metric 1:** >15% change in substitution share relative to default elasticity run **Metric 2:** >1% of default substitution effects	Yes	Residential demand Commercial demand Industrial demand Transportation sector demand
5	Gas Demand, Own Price	Reduced Gas Demand	**Metric 1:** >15% change in substitution share relative to default elasticity run **Metric 2:** >1% of default substitution effects	Yes	Residential demand Commercial demand Industrial demand Transportation sector demand
6	Electricity Demand, Own Price	Reduced Electricity Demand	**Metric 1:** >15% change in substitution share relative to default elasticity run **Metric 2:** <1% of default substitution effects	No	None—not selected for discrete testing

Table A-19. Specification of Potential Discrete Elasticity Sensitivity Scenarios for Cross-Price Elasticities of Demand

Batch No.	Batch Name	Applicable Substitution Categories from MarketSim	Findings Relative to Thresholds from Batch Sensitivity Testing	Selected for Discrete Test?	Elasticity Parameters to Assess in Discrete Sensitivities
7	Oil Demand, Own Price and Cross-Price	Reduced Oil Demand	**Metric 2:** Reduced oil demand represents >1% of total default substitution. **Metric 3:** <15% difference between Batch 4 and Batch 7 tests for reduced oil demand's share of total substitution effect.	No	None—not selected for discrete testing
8	Gas Demand, Own Price and Cross-Price	Reduced Gas Demand	**Metric 2:** Reduced gas demand represents >1% of total default substitution. **Metric 3:** <15% change in substitution share for reduced gas demand in between Batch 5 and Batch 8 sensitivity tests for doubled and halved elasticity values.	No	None—not selected for discrete testing
9	Electricity Demand, Own Price and Cross-Price	Reduced Electricity Demand	**Metric 2:** Reduced electricity demand represents <1% of total default substitution impact. **Metric 3:** <15% difference between Batch 6 and Batch 9 tests for reduced electricity demand's share of total substitution effect.	No	None—not selected for discrete testing

Results – Discrete Elasticity Sensitivities

Given the number of sensitivity tests conducted (19 elasticity parameters each doubled and halved, for 38 total sensitivity tests), IEc developed a metric to reflect the magnitude of shifts in substitution effects due to the associated changes in elasticity values. This metric, which is termed the "substitution effect sensitivity," is defined according to the following formula:

$$SES_p = \sum_C \left[SE\%_C^B \left| SE\%_C^D - SE\%_C^B \right| + SE\%_C^B \left| SE\%_C^H - SE\%_C^B \right| \right]$$

where

SES_P = the substitution effect sensitivity for the given elasticity parameter *P*

$SE\%_C^B$ = the share of total substitution effects for a given substitution category *C* (e.g., domestic onshore oil production) using the baseline sensitivity value

$SE\%_C^D$ = the share of total substitution effects for a given supply category *C* using the doubled elasticity value

$SE\%_C^H$ = the share of total substitution effects for a given supply category *C* using the halved elasticity value

In the above formula, the difference between the baseline and adjusted (doubled and halved) substitution effects share values (by category) is weighted by that category's share of the baseline substitution effects. This weighted value is summed across all supply categories to develop the substitution effect sensitivity (*SES*) metric to reflect how sensitive substitution effects are to changes in the given elasticity parameter. The *SES* metric can be interpreted as a weighted indicator of the change in substitution outcomes under the doubled and halved elasticity cases relative to the base elasticity case.

Table A-20 (below) details the *SES* findings for the tests of each elasticity parameter. The elasticity parameters were assigned to "buckets" based on the *SES* metric. Elasticity parameters with *SES* scores greater than 10 percent are classified as "most sensitive," parameters with scores between one and 10 percent are classified as "somewhat sensitive," and those with scores under one percent are classified as "least sensitive."

The following bullets summarize key findings from the discrete elasticity tests impacts on substitution effects:

- The elasticity parameters with *SES* scores in the "most sensitive" buckets are dominated by the values for continental U.S. supply for both oil and gas, across both conventional and unconventional development techniques.
- The lone demand elasticity parameter in the "most sensitive" bucket is demand for natural gas exports. Otherwise, all "most sensitive" elasticities are for supply.
- The cross-price demand elasticity parameters are all in the "least sensitive" bucket.

Figures A-10 through A14 and Tables A-21 through A-25 detail the substitution effect changes for the five "most sensitive" discrete elasticity tests.

Table A-20. Discrete Elasticity Tests and Substitution Effects Sensitivity Scores

Resource	Own- or Cross-Price	Supply or Demand	Region/ Sector	Substitution Effects Sensitivity Score	Sensitivity Bucket
Gas	Own Price	Supply	L48 Unconventional	12.36%	Most sensitive
Oil	Own Price	Supply	L48 Onshore Tight	10.87%	Most sensitive
Gas	Own Price	Demand	Exports Demand	10.72%	Most sensitive
Oil	Own Price	Supply	L48 Onshore Conventional	10.70%	Most sensitive
Gas	Own Price	Supply	L48 Conventional	10.68%	Most sensitive
Oil	Own Price	Supply	Other	7.32%	Somewhat sensitive
Oil	Own Price	Demand	Rest of World Demand	7.22%	Somewhat sensitive
Gas	Own Price	Demand	Industrial Demand	6.06%	Somewhat sensitive
Oil	Own Price	Demand	Transportation Sector Demand	3.60%	Somewhat sensitive
Gas	Own Price	Demand	Residential and Commercial Demand	2.67%	Somewhat sensitive
Gas	Own Price	Supply	Imports Pipeline	1.94%	Somewhat sensitive
Gas	Own Price	Demand	Transportation Sector Demand	1.73%	Somewhat sensitive
Oil	Own Price	Demand	Industrial Demand	1.11%	Somewhat sensitive
Electricity	Own Price	Supply	Electricity Supply - Solar	1.04%	Somewhat sensitive
Oil	Own Price	Demand	Residential and Commercial Demand	0.53%	Least sensitive
Electricity	Own Price	Supply	Electricity Supply - Coal	0.50%	Least sensitive
Oil	Own Price	Supply	Alaskan Onshore	0.34%	Least sensitive
Gas	Own Price	Supply	Alaskan Onshore	0.30%	Least sensitive
Gas	Own Price	Supply	Imports LNG	0.16%	Least sensitive

Table A-21. Percent of Total Substitution—Lower 48 Unconventional Gas Supply Elasticity: Substitution Effects Results

Supply Category	Default Run with 15-yr Oil GOM Scenario	Doubled Own Price Elasticities Only	Halved Own Price Elasticities
Domestic Onshore Oil Production	0.69%	0.67%	1.15%
Domestic Offshore Oil Production	0.03%	0.03%	0.05%
Domestic Onshore Gas Production	75.54%	76.20%	61.47%
Domestic Offshore Gas Production	0.34%	0.33%	0.53%
Domestic Coal Production	1.08%	1.05%	1.71%
Oil Imports	3.52%	3.42%	5.40%
Gas Imports	2.29%	2.23%	3.55%
Coal Imports	0.00%	0.00%	0.00%
Electricity	2.78%	2.70%	4.35%
Reduced Demand	13.24%	12.89%	20.99%
Other Liquids	0.42%	0.41%	0.70%
Other Gas	0.07%	0.07%	0.10%

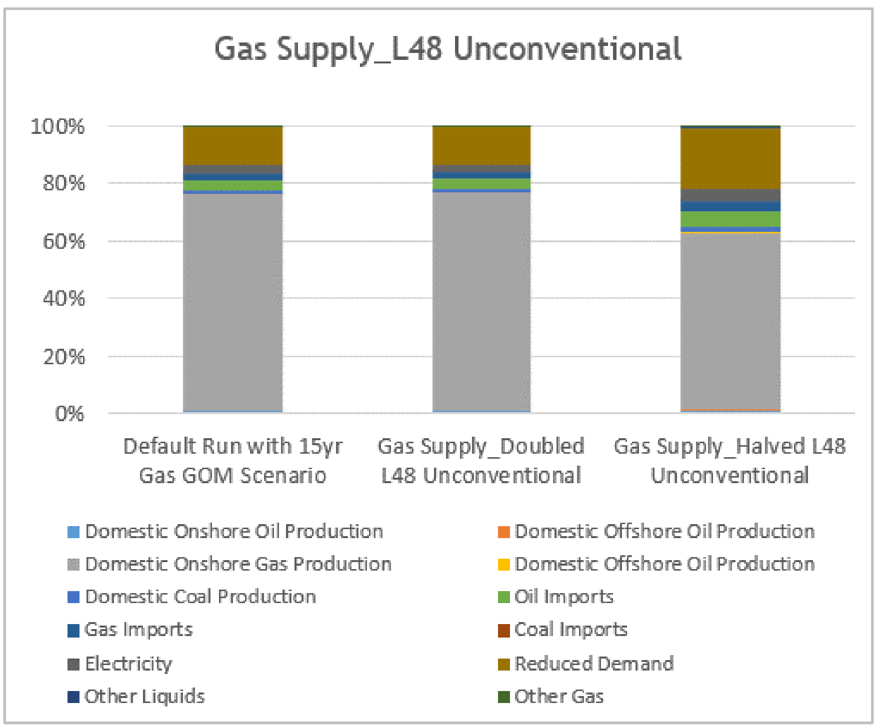

Figure A-10. Discrete Elasticity Sensitivities Substitution Effects Results—Lower 48 Unconventional Gas Supply Elasticity: Substitution Effects Results

Table A-22. Percent of Total Substitution—Lower 48 Onshore Tight Oil Supply Elasticity

Supply Category	Default Run with 15-yr Oil GOM Scenario	Doubled Own Price Elasticities Only	Halved Own Price Elasticities
Domestic Onshore Oil Production	16.34%	26.04%	10.47%
Domestic Offshore Oil Production	0.76%	0.67%	0.81%
Domestic Onshore Gas Production	1.80%	1.59%	1.92%
Domestic Offshore Gas Production	0.01%	0.01%	0.01%
Domestic Coal Production	0.24%	0.21%	0.26%
Oil Imports	66.01%	58.36%	70.64%
Gas Imports	0.05%	0.05%	0.05%
Coal Imports	0.00%	0.00%	0.00%
Electricity	0.39%	0.35%	0.42%
Reduced Demand	4.64%	4.09%	4.96%
Other Liquids	9.77%	8.64%	10.46%
Other Gas	0.00%	0.00%	0.00%

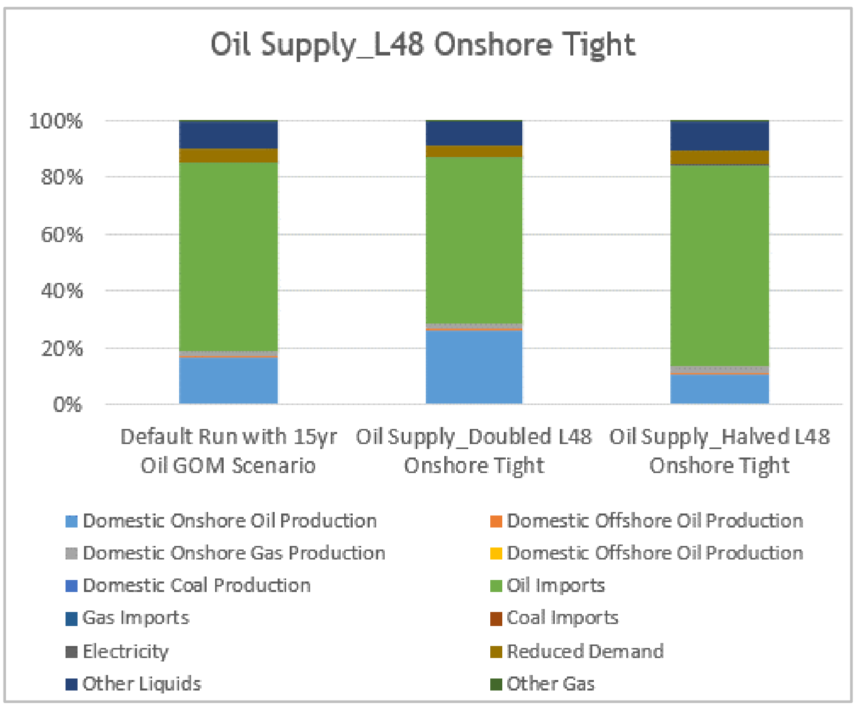

Figure A-11. Discrete Elasticity Sensitivities Substitution Effects Results—Lower 48 Onshore Tight Oil Supply Elasticity

Table A-23. Percent of Total Substitution—Natural Gas Exports Demand Elasticity

Supply Category	Default Run with 15-yr Oil GOM Scenario	Doubled Own Price Elasticities Only	Halved Own Price Elasticities
Domestic Onshore Oil Production	0.69%	0.64%	0.73%
Domestic Offshore Oil Production	0.03%	0.03%	0.03%
Domestic Onshore Gas Production	75.54%	68.06%	79.85%
Domestic Offshore Gas Production	0.34%	0.31%	0.35%
Domestic Coal Production	1.08%	0.99%	1.14%
Oil Imports	3.52%	3.17%	3.70%
Gas Imports	2.29%	2.07%	2.42%
Coal Imports	0.00%	0.00%	0.00%
Electricity	2.78%	2.52%	2.93%
Reduced Demand	13.24%	21.76%	8.34%
Other Liquids	0.42%	0.39%	0.45%
Other Gas	0.07%	0.06%	0.07%

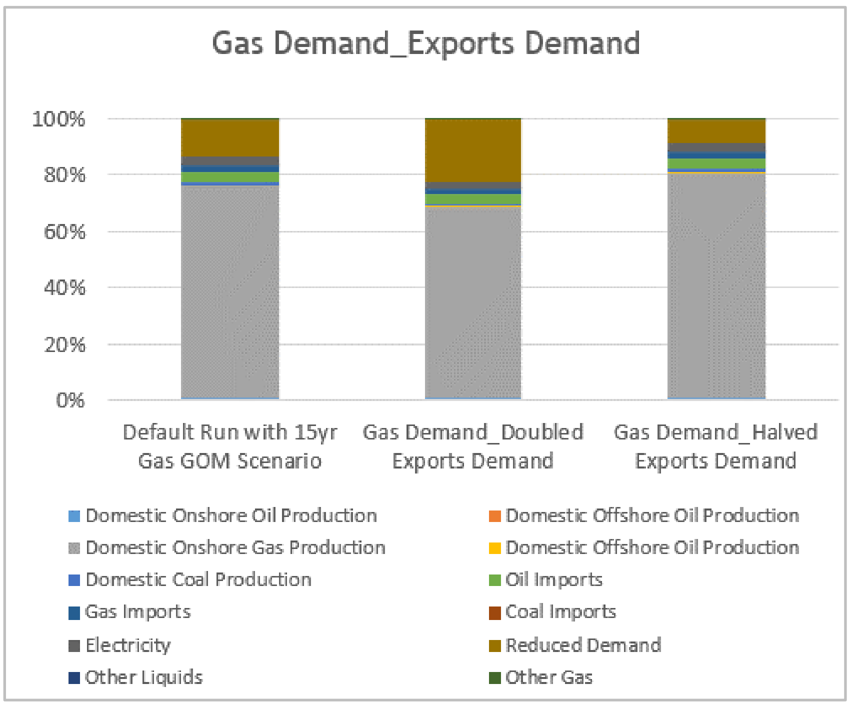

Figure A-12. Discrete Elasticity Sensitivities Substitution Effects Results—Natural Gas Exports Demand Elasticity

Table A-24. Percent of Total Substitution—Lower 48 Onshore Conventional Oil Supply Elasticity

Supply Category	Default Run with 15-yr Oil GOM Scenario	Doubled Own Price Elasticities Only	Halved Own Price Elasticities
Domestic Onshore Oil Production	16.34%	30.46%	15.14%
Domestic Offshore Oil Production	0.76%	0.63%	0.77%
Domestic Onshore Gas Production	1.80%	1.49%	1.82%
Domestic Offshore Gas Production	0.01%	0.01%	0.01%
Domestic Coal Production	0.24%	0.20%	0.24%
Oil Imports	66.01%	54.87%	66.95%
Gas Imports	0.05%	0.04%	0.05%
Coal Imports	0.00%	0.00%	0.00%
Electricity	0.39%	0.33%	0.40%
Reduced Demand	4.64%	3.85%	4.70%
Other Liquids	9.77%	8.13%	9.91%
Other Gas	0.00%	0.00%	0.00%

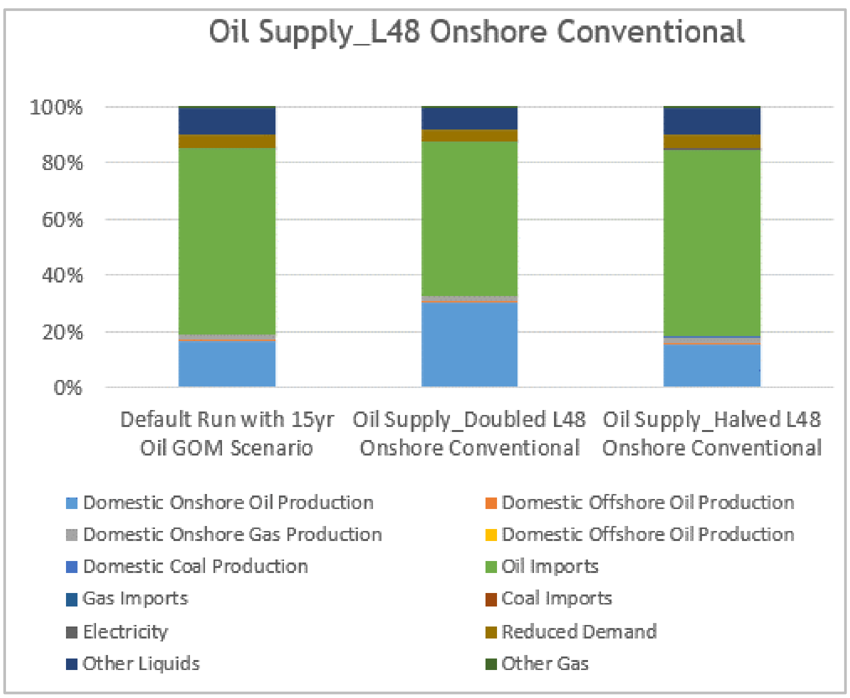

Figure A-13. Discrete Elasticity Sensitivities Substitution Effects Results—Lower 48 Onshore Conventional Oil Supply Elasticity

Table A-25. Percent of Total Substitution—Lower 48 Conventional Gas Supply Elasticity

Supply Category	Default Run with 15-yr Oil GOM Scenario	Doubled Own Price Elasticities Only	Halved Own Price Elasticities
Domestic Onshore Oil Production	0.69%	0.67%	1.09%
Domestic Offshore Oil Production	0.03%	0.03%	0.05%
Domestic Onshore Gas Production	75.54%	76.35%	63.61%
Domestic Offshore Gas Production	0.34%	0.32%	0.50%
Domestic Coal Production	1.08%	1.05%	1.61%
Oil Imports	3.52%	3.39%	5.08%
Gas Imports	2.29%	2.22%	3.37%
Coal Imports	0.00%	0.00%	0.00%
Electricity	2.78%	2.68%	4.11%
Reduced Demand	13.24%	12.81%	19.81%
Other Liquids	0.42%	0.41%	0.67%
Other Gas	0.07%	0.07%	0.10%

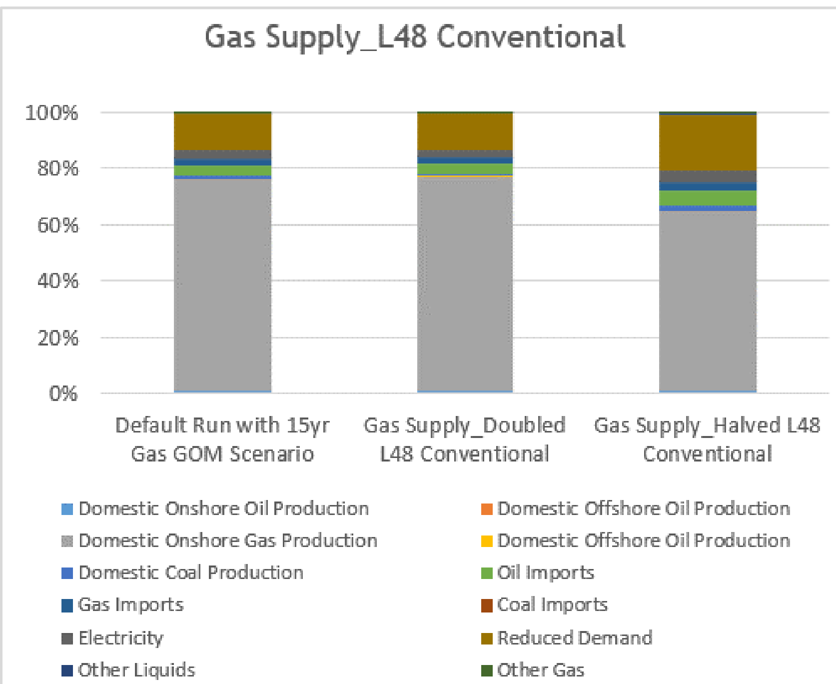

Figure A-14. Discrete Elasticity Sensitivities Substitution Effects Results—Lower 48 Conventional Gas Supply Elasticity

The results of the discrete elasticity sensitivity tests with respect to the emissions impacts estimated by the OECM are presented in Tables A-26 through A-29 below for the E&D scenario and the No Action Alternative. Tables A-26 and A-27 present these outputs in physical units for the E&D scenario and No Action Alternative, respectively.[19] Tables A-28 and A-29 present these results as the percentage change relative to the appropriate baseline results, respectively, under the E&D scenario and No Action Alternative.

Table A-26. Discrete Elasticity Sensitivities OECM Air Emissions Impacts—E&D Scenario (1,000s of tons)

Scenario	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
Baseline Oil Scenario	23.23	1.93	0.64	0.61	6.59	4.22	2,497.72	14.44	0.08
Baseline Gas Scenario	22.94	1.89	0.63	0.60	6.56	3.95	2,438.37	14.26	0.07
Doubled L48 Onshore Tight Oil Supply Elasticity	23.22	1.93	0.64	0.61	6.58	4.21	2,492.04	14.42	0.08
Halved L48 Onshore Tight Oil Supply Elasticity	23.23	1.93	0.64	0.61	6.59	4.23	2,501.15	14.45	0.08
Doubled L48 Onshore Conventional Oil Supply Elasticity	23.21	1.93	0.64	0.61	6.58	4.21	2,489.47	14.42	0.08
Halved L48 Onshore Conventional Oil Supply Elasticity	23.23	1.93	0.64	0.61	6.59	4.23	2,498.42	14.44	0.08
Doubled Alaskan Onshore Oil Supply Elasticity	23.22	1.93	0.64	0.61	6.59	4.22	2,497.53	14.44	0.08
Halved Alaskan Onshore Oil Supply Elasticity	23.23	1.93	0.64	0.61	6.59	4.22	2,497.82	14.44	0.08
Doubled Other Oil Supply Elasticity	23.22	1.93	0.64	0.61	6.59	4.21	2,493.60	14.43	0.08
Halved Other Oil Supply Elasticity	23.23	1.93	0.64	0.61	6.59	4.23	2,500.09	14.45	0.08
Doubled L48 Conventional Gas Supply Elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.89	14.26	0.07
Halved L48 Conventional Gas Supply Elasticity	22.95	1.89	0.63	0.60	6.56	3.96	2,439.21	14.26	0.07
Doubled L48 Unconventional Gas Supply Elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.89	14.26	0.07
Halved L48 Unconventional Gas Supply Elasticity	22.95	1.89	0.63	0.60	6.56	3.96	2,439.23	14.26	0.07
Doubled Alaskan Onshore Gas Supply Elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.88	14.26	0.07
Halved Alaskan Onshore Gas Supply Elasticity	23.02	1.90	0.63	0.60	6.56	4.07	2,487.01	14.41	0.08
Doubled Imports Pipeline Gas Supply Elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.88	14.26	0.07
Halved Imports Pipeline Gas Supply Elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.91	14.26	0.07
Doubled Imports LNG Gas Supply Elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.89	14.26	0.07
Halved Imports LNG Gas Supply elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.88	14.26	0.07

[19] As noted previously in Section A.2 on the batched elasticity tests, for the E&D emissions for scenarios that involve gas production but not oil production, the results do not reflect emissions associated with oil exports. In a scenario involving OCS gas production but not oil, such emissions would likely be minimal. After completing these sensitivities, BOEM modified MarketSim and the OECM to capture these emissions impacts.

Scenario	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
Doubled Electricity Supply - Solar Electricity Supply elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.88	14.26	0.07
Halved Electricity Supply - Solar Electricity Supply elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.90	14.26	0.07
Doubled Electricity Supply - Coal Electricity Supply elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.90	14.26	0.07
Halved Electricity Supply - Coal Electricity Supply elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.90	14.26	0.07
Doubled Residential and Commercial Demand Oil Demand elasticity	23.22	1.93	0.64	0.61	6.59	4.22	2,497.39	14.44	0.08
Halved Residential and Commercial Demand Oil Demand elasticity	23.23	1.93	0.64	0.61	6.59	4.22	2,497.89	14.44	0.08
Doubled Industrial Demand Oil Demand elasticity	23.22	1.93	0.64	0.61	6.59	4.22	2,497.04	14.44	0.08
Halved Industrial Demand Oil Demand elasticity	23.23	1.93	0.64	0.61	6.59	4.22	2,498.07	14.44	0.08
Doubled Transportation Sector Demand Oil Demand elasticity	23.22	1.93	0.64	0.61	6.59	4.22	2,495.53	14.44	0.08
Halved Transportation Sector Demand Oil Demand elasticity	23.23	1.93	0.64	0.61	6.59	4.23	2,498.90	14.45	0.08
Doubled Rest of World Demand Oil Demand elasticity	23.27	1.94	0.64	0.61	6.59	4.30	2,530.33	14.54	0.08
Halved Rest of World Demand Oil Demand elasticity	23.19	1.93	0.64	0.61	6.58	4.17	2,476.10	14.37	0.08
Doubled Residential and Commercial Demand Gas Demand elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.87	14.26	0.07
Halved Residential and Commercial Demand Gas Demand elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.91	14.26	0.07
Doubled Industrial Demand Gas Demand elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.88	14.26	0.07
Halved Industrial Demand Gas Demand elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.94	14.26	0.07
Doubled Transportation Sector Demand Gas Demand elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.90	14.26	0.07
Halved Transportation Sector Demand Gas Demand elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.91	14.26	0.07
Doubled Exports Demand Gas Demand elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.86	14.26	0.07
Halved Exports Demand Gas Demand elasticity	22.94	1.89	0.63	0.60	6.56	3.96	2,438.91	14.26	0.07

Table A-27. Discrete Elasticity Sensitivities OECM Air Emissions Impacts—No Action Alternative (1,000s of tons)

Scenario	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
Baseline Oil Scenario	3.29	0.68	0.06	0.04	0.42	9.48	6,904.43	55.44	0.08
Baseline Gas Scenario	16.52	0.19	0.19	0.16	1.54	13.80	868.98	75.05	0.03
Doubled L48 Onshore Tight Oil Supply Elasticity	3.01	0.93	0.06	0.04	0.47	12.91	6,287.88	80.27	0.07
Halved L48 Onshore Tight Oil Supply Elasticity	3.46	0.53	0.07	0.05	0.40	7.40	7,278.61	40.38	0.09
Doubled L48 Onshore Conventional Oil Supply Elasticity	2.89	1.04	0.05	0.04	0.49	14.47	6,005.97	91.60	0.07
Halved L48 Onshore Conventional Oil Supply Elasticity	3.32	0.65	0.07	0.05	0.42	9.05	6,980.94	52.36	0.08
Doubled Alaskan Onshore Oil Supply Elasticity	3.28	0.68	0.06	0.04	0.42	9.44	6,877.88	55.22	0.08
Halved Alaskan Onshore Oil Supply Elasticity	3.30	0.68	0.06	0.04	0.43	9.49	6,917.79	55.54	0.08
Doubled Other Oil Supply Elasticity	3.01	0.62	0.06	0.04	0.39	8.67	6,321.04	50.74	0.08
Halved Other Oil Supply Elasticity	3.45	0.71	0.07	0.05	0.45	9.94	7,239.19	58.13	0.09
Doubled L48 Conventional Gas Supply Elasticity	16.81	0.18	0.19	0.17	1.57	14.36	890.35	77.58	0.03
Halved L48 Conventional Gas Supply Elasticity	13.63	0.17	0.18	0.14	1.28	11.64	805.28	63.32	0.02
Doubled L48 Unconventional Gas Supply Elasticity	16.76	0.19	0.19	0.17	1.57	14.25	886.58	77.12	0.03
Halved L48 Unconventional Gas Supply Elasticity	13.12	0.17	0.17	0.14	1.23	11.26	794.82	61.23	0.02
Doubled Alaskan Onshore Gas Supply Elasticity	16.36	0.19	0.19	0.16	1.53	13.66	860.66	74.33	0.03
Halved Alaskan Onshore Gas Supply elasticity	1.69	0.48	0.04	0.02	0.28	7.52	6,837.09	55.20	0.08
Doubled Imports Pipeline Gas Supply Elasticity	16.19	0.19	0.18	0.16	1.51	13.52	883.96	73.55	0.02
Halved Imports Pipeline Gas Supply Elasticity	16.70	0.19	0.19	0.17	1.56	13.94	860.77	75.85	0.03
Doubled Imports LNG Gas Supply Elasticity	16.50	0.19	0.19	0.16	1.54	13.77	868.60	74.93	0.03
Halved Imports LNG Gas Supply Elasticity	16.54	0.19	0.19	0.16	1.54	13.81	868.98	75.12	0.03
Doubled Electricity Supply - Solar Electricity Supply Elasticity	16.26	0.18	0.18	0.16	1.52	13.58	851.23	73.80	0.02
Halved Electricity Supply - Solar Electricity Supply Elasticity	16.71	0.19	0.19	0.17	1.56	13.95	882.21	75.94	0.03
Doubled Electricity Supply - Coal Electricity Supply Elasticity	16.52	0.20	0.20	0.17	1.54	13.78	869.83	75.15	0.03
Halved Electricity Supply - Coal Electricity Supply Elasticity	16.53	0.18	0.18	0.16	1.54	13.81	868.31	75.01	0.03
Doubled Residential and Commercial Demand Oil Demand Elasticity	3.27	0.68	0.06	0.04	0.42	9.41	6,856.64	55.05	0.08

Scenario	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
Halved Residential and Commercial Demand Oil Demand elasticity	3.30	0.68	0.06	0.04	0.43	9.51	6,928.54	55.63	0.08
Doubled Industrial Demand Oil Demand elasticity	3.24	0.67	0.06	0.04	0.42	9.34	6,805.59	54.64	0.08
Halved Industrial Demand Oil Demand elasticity	3.31	0.68	0.07	0.04	0.43	9.54	6,954.87	55.84	0.08
Doubled Transportation Sector Demand Oil Demand elasticity	3.14	0.65	0.06	0.04	0.41	9.04	6,589.48	52.91	0.08
Halved Transportation Sector Demand Oil Demand elasticity	3.37	0.70	0.07	0.05	0.44	9.71	7,073.61	56.79	0.08
Doubled Rest of World Demand Oil Demand elasticity	3.12	0.61	0.06	0.04	0.39	8.37	7,255.46	47.49	0.09
Halved Rest of World Demand Oil Demand elasticity	3.40	0.72	0.07	0.05	0.45	10.21	6,670.71	60.73	0.08
Doubled Residential and Commercial Demand Gas Demand elasticity	16.12	0.19	0.18	0.16	1.50	13.46	848.20	73.20	0.02
Halved Residential and Commercial Demand Gas Demand elasticity	16.74	0.19	0.19	0.17	1.56	13.98	879.47	76.03	0.03
Doubled Industrial Demand Gas Demand elasticity	15.61	0.18	0.18	0.16	1.46	13.03	821.45	70.90	0.02
Halved Industrial Demand Gas Demand elasticity	17.02	0.20	0.19	0.17	1.59	14.21	893.36	77.31	0.03
Doubled Transportation Sector Demand Gas Demand elasticity	16.26	0.19	0.19	0.16	1.52	13.58	854.75	73.86	0.02
Halved Transportation Sector Demand Gas Demand elasticity	16.66	0.19	0.19	0.17	1.55	13.91	875.47	75.68	0.03
Doubled Exports Demand Gas Demand elasticity	14.94	0.17	0.17	0.15	1.39	12.48	786.09	67.90	0.02
Halved Exports Demand Gas Demand elasticity	17.43	0.20	0.20	0.17	1.63	14.56	916.21	79.18	0.03

Table A-28. Discrete Elasticity Sensitivities OECM Air Emissions Percentage Change from Baseline—E&D Scenario

Scenario	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
Doubled L48 Onshore Tight Oil Supply elasticity	0.0%	-0.1%	0.0%	0.0%	0.0%	-0.3%	-0.2%	-0.1%	-0.3%
Halved L48 Onshore Tight Oil Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.1%	0.1%	0.2%
Doubled L48 Onshore Conventional Oil Supply elasticity	-0.1%	-0.1%	0.0%	0.0%	0.0%	-0.4%	-0.3%	-0.2%	-0.5%
Halved L48 Onshore Conventional Oil Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Doubled Alaskan Onshore Oil Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Halved Alaskan Onshore Oil Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Doubled Other Oil Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%	-0.2%	-0.1%	-0.3%
Halved Other Oil Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%
Doubled L48 Conventional Gas Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Halved L48 Conventional Gas Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
Doubled L48 Unconventional Gas Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Halved L48 Unconventional Gas Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
Doubled Alaskan Onshore Gas Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Halved Alaskan Onshore Gas Supply elasticity	0.3%	0.5%	0.2%	0.2%	0.1%	2.8%	2.0%	1.1%	3.1%
Doubled Imports Pipeline Gas Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Halved Imports Pipeline Gas Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Doubled Imports LNG Gas Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Halved Imports LNG Gas Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Doubled Electricity Supply - Solar Electricity Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Halved Electricity Supply - Solar Electricity Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Doubled Electricity Supply - Coal Electricity Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Halved Electricity Supply - Coal Electricity Supply elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Doubled Residential and Commercial Demand Oil Demand elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Halved Residential and Commercial Demand Oil Demand elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Doubled Industrial Demand Oil Demand elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Halved Industrial Demand Oil Demand elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Doubled Transportation Sector Demand Oil Demand elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	-0.1%	0.0%	-0.1%

Scenario	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
Halved Transportation Sector Demand Oil Demand elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.1%
Doubled Rest of World Demand Oil Demand elasticity	0.2%	0.3%	0.1%	0.1%	0.1%	1.8%	1.3%	0.7%	2.0%
Halved Rest of World Demand Oil Demand elasticity	-0.1%	-0.2%	-0.1%	-0.1%	0.0%	-1.2%	-0.9%	-0.5%	-1.3%
Doubled Residential and Commercial Demand Gas Demand elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Halved Residential and Commercial Demand Gas Demand elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Doubled Industrial Demand Gas Demand elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Halved Industrial Demand Gas Demand elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Doubled Transportation Sector Demand Gas Demand elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Halved Transportation Sector Demand Gas Demand elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Doubled Exports Demand Gas Demand elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Halved Exports Demand Gas Demand elasticity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table A-29. Discrete Elasticity Sensitivities OECM Air Emissions Percentage Change from Baseline—No Action Alternative

Scenario	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
Doubled L48 Onshore Tight Oil Supply elasticity	-8.4%	36.2%	-11.5%	-11.6%	11.1%	36.2%	-8.9%	44.8%	-11.6%
Halved L48 Onshore Tight Oil Supply elasticity	5.1%	-21.9%	7.3%	7.1%	-6.7%	-22.0%	5.4%	-27.2%	7.1%
Doubled L48 Onshore Conventional Oil Supply elasticity	-12.2%	52.7%	-16.6%	-16.8%	16.2%	52.7%	-13.0%	65.2%	-16.9%
Halved L48 Onshore Conventional Oil Supply elasticity	1.0%	-4.5%	1.5%	1.5%	-1.4%	-4.5%	1.1%	-5.6%	1.4%
Doubled Alaskan Onshore Oil Supply elasticity	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%
Halved Alaskan Onshore Oil Supply elasticity	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Doubled Other Oil Supply elasticity	-8.5%	-8.5%	-8.4%	-8.5%	-8.5%	-8.5%	-8.4%	-8.5%	-8.4%
Halved Other Oil Supply elasticity	4.9%	4.9%	5.0%	4.9%	4.9%	4.9%	4.8%	4.9%	4.8%
Doubled L48 Conventional Gas Supply elasticity	536.3%	-74.7%	305.2%	370.3%	313.0%	45.4%	-87.1%	31.6%	-69.0%
Halved L48 Conventional Gas Supply elasticity	415.9%	-76.7%	267.7%	288.3%	236.4%	17.9%	-88.3%	7.4%	-73.9%
Doubled L48 Unconventional Gas Supply elasticity	534.3%	-74.6%	303.0%	367.0%	311.6%	44.4%	-87.1%	30.8%	-68.9%
Halved L48 Unconventional Gas Supply elasticity	396.6%	-77.2%	263.1%	277.0%	224.2%	14.0%	-88.5%	3.9%	-74.8%
Doubled Alaskan Onshore Gas Supply elasticity	519.3%	-74.2%	289.4%	347.9%	301.0%	38.4%	-87.5%	26.1%	-69.0%
Halved Alaskan Onshore Gas Supply elasticity	-36.1%	-34.0%	-19.1%	-48.6%	-25.7%	-23.8%	-0.7%	-6.4%	-2.3%
Doubled Imports Pipeline Gas Supply elasticity	512.7%	-74.5%	285.3%	343.2%	296.8%	36.9%	-87.2%	24.8%	-69.3%
Halved Imports Pipeline Gas Supply elasticity	531.9%	-73.6%	297.4%	357.0%	309.2%	41.2%	-87.5%	28.7%	-68.4%
Doubled Imports LNG Gas Supply elasticity	524.3%	-73.9%	292.6%	351.6%	304.3%	39.5%	-87.4%	27.1%	-68.7%
Halved Imports LNG Gas Supply elasticity	525.8%	-74.0%	293.4%	352.6%	305.3%	39.9%	-87.4%	27.4%	-68.7%
Doubled Electricity Supply - Solar Electricity Supply elasticity	515.2%	-74.7%	279.7%	343.5%	298.1%	37.5%	-87.6%	25.2%	-69.3%
Halved Electricity Supply - Solar Electricity Supply elasticity	532.5%	-73.4%	303.0%	358.6%	309.7%	41.3%	-87.2%	28.8%	-68.3%
Doubled Electricity Supply - Coal Electricity Supply elasticity	525.0%	-72.3%	324.3%	358.6%	305.8%	39.6%	-87.4%	27.5%	-68.7%
Halved Electricity Supply - Coal Electricity Supply elasticity	525.5%	-74.8%	276.6%	348.9%	304.5%	39.8%	-87.4%	27.3%	-68.7%
Doubled Residential and Commercial Demand Oil Demand elasticity	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%

Scenario	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
Halved Residential and Commercial Demand Oil Demand elasticity	0.3%	0.3%	0.4%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
Doubled Industrial Demand Oil Demand elasticity	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%
Halved Industrial Demand Oil Demand elasticity	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%
Doubled Transportation Sector Demand Oil Demand elasticity	-4.5%	-4.6%	-4.6%	-4.5%	-4.5%	-4.5%	-4.6%	-4.5%	-4.6%
Halved Transportation Sector Demand Oil Demand elasticity	2.5%	2.4%	2.4%	2.5%	2.5%	2.5%	2.5%	2.4%	2.5%
Doubled Rest of World Demand Oil Demand elasticity	-5.0%	-9.7%	-6.9%	-2.8%	-8.6%	-11.7%	5.1%	-14.3%	6.3%
Halved Rest of World Demand Oil Demand elasticity	3.4%	6.5%	5.0%	2.0%	5.8%	7.8%	-3.4%	9.6%	-4.2%
Doubled Residential and Commercial Demand Gas Demand elasticity	509.8%	-74.6%	283.5%	341.1%	294.9%	36.3%	-87.7%	24.2%	-69.5%
Halved Residential and Commercial Demand Gas Demand elasticity	533.4%	-73.6%	298.3%	358.1%	310.1%	41.5%	-87.2%	29.0%	-68.3%
Doubled Industrial Demand Gas Demand elasticity	490.6%	-75.4%	271.8%	327.3%	282.5%	32.0%	-88.1%	20.3%	-70.4%
Halved Industrial Demand Gas Demand elasticity	544.1%	-73.1%	304.8%	365.8%	317.1%	43.9%	-87.0%	31.2%	-67.8%
Doubled Transportation Sector Demand Gas Demand elasticity	515.3%	-74.3%	287.0%	345.0%	298.4%	37.5%	-87.6%	25.3%	-69.2%
Halved Transportation Sector Demand Gas Demand elasticity	530.5%	-73.7%	296.5%	356.0%	308.3%	40.9%	-87.3%	28.4%	-68.4%
Doubled Exports Demand Gas Demand elasticity	465.5%	-76.4%	256.1%	309.2%	266.2%	26.4%	-88.6%	15.2%	-71.7%
Halved Exports Demand Gas Demand elasticity	559.7%	-72.5%	314.5%	377.1%	327.2%	47.4%	-86.7%	34.3%	-67.0%

A.4 Baseline Data Sensitivities

To assess the effects of potential future changes to baseline data, IEc conducted a set of sensitivity analyses using alternate baseline supply and demand data in MarketSim. The bullets below describe the two categories of tests conducted to understand the sensitivity of the model to changes in these inputs.

- ***AEO model inputs instead of specialized NEMS run***. Given potential changes in the availability of EIA's special NEMS runs for developing baseline data without new offshore leases for MarketSim moving forward, this analysis tested differences in the use of the standard AEO baseline data versus the special NEMS run. To accomplish this, the model was run using both sets of baseline data and differences in outputs were assessed between the different runs.

- ***Across-the-board demand increases/decreases.*** To assess the model's sensitivity to the overall size of energy market, additional sensitivities were conducted using two scenarios with alternative baseline data, one scenario in which all baseline supply and demand data were increased by 10 percent and another in which these data were reduced by 10 percent.

To conduct each of these sensitivities, IEc used the full representative E&D scenario described in the introduction to this appendix. The entire time horizon of the E&D scenario was used rather than just the first 15 years of production because the differences between the baseline data currently in the model and in the alternative baselines grow over time.

Results – Baseline Data Sensitivities

The results of the sensitivity tests with respect to MarketSim's substitution effects are shown in Figure A-15 and Table A-30 below. Key findings are as follows:

- **Overall, MarketSim appears to be relatively insensitive to slight changes in the underlying baseline data.** When compared with the other sensitivity tests recently summarized in this appendix, which frequently saw changes in individual substitution categories on the order of doubling or halving, the changes in baseline data tested here appear to have much smaller overall effects.

- **Domestic gas production makes up a slightly larger share of total substitution in all three sensitivity scenarios, while reduced demand takes a slightly smaller share.** In both the AEO 2020 scenario and the scenario with baseline data +/- 10 percent of the AEO 2020, domestic gas's share of total substitution increases by approximately 1.6 percentage points from 11.7 percent to 13.3 percent. Conversely, reduced demand's share of substitution falls by 1.5 to 1.7 percentage points in all three scenarios, from approximately 9.6 percent to 7.8–8.7 percent.

- **The substitution patterns for the special NEMS +10 percent and special NEMS -10 percent scenarios are nearly identical.** This likely reflects the fact that the proportional changes in the baseline projection are the same in both directions (+10 percent and -10 percent), while prices are held constant between scenarios. Under these conditions, all of the scaling parameters in MarketSim move in proportional lockstep between baseline scenarios (i.e., the proportional relationship between the scaling parameter for residential oil demand and the scaling parameter for industrial oil demand is constant between baseline scenarios). Thus, these two sensitivities are similar in terms of the degree to which their substitution pattern differs from that observed when using the primary baseline data.

Table A-30. Percent of Total Substitution: Baseline Sensitivities Substitution Effects Results

Supply Category	Baseline 2020 Special NEMS	Doubled Own Price Elasticities Only	Halved Own Price Elasticities
Domestic Onshore Oil Production	12.06%	13.21%	12.61%
Domestic Offshore Oil Production	0.47%	0.65%	0.52%
Domestic Onshore Gas Production	11.67%	13.30%	13.29%
Domestic Offshore Gas Production	0.06%	0.10%	0.06%
Domestic Coal Production	0.96%	0.55%	0.54%
Oil Imports	55.94%	57.39%	55.89%
Gas Imports	0.46%	0.47%	0.47%
Coal Imports	0.00%	0.00%	0.00%
Electricity	1.62%	1.25%	1.22%
Reduced Demand	9.59%	8.06%	7.86%
Other Liquids	7.15%	4.99%	7.54%
Other Gas	0.01%	0.01%	0.01%

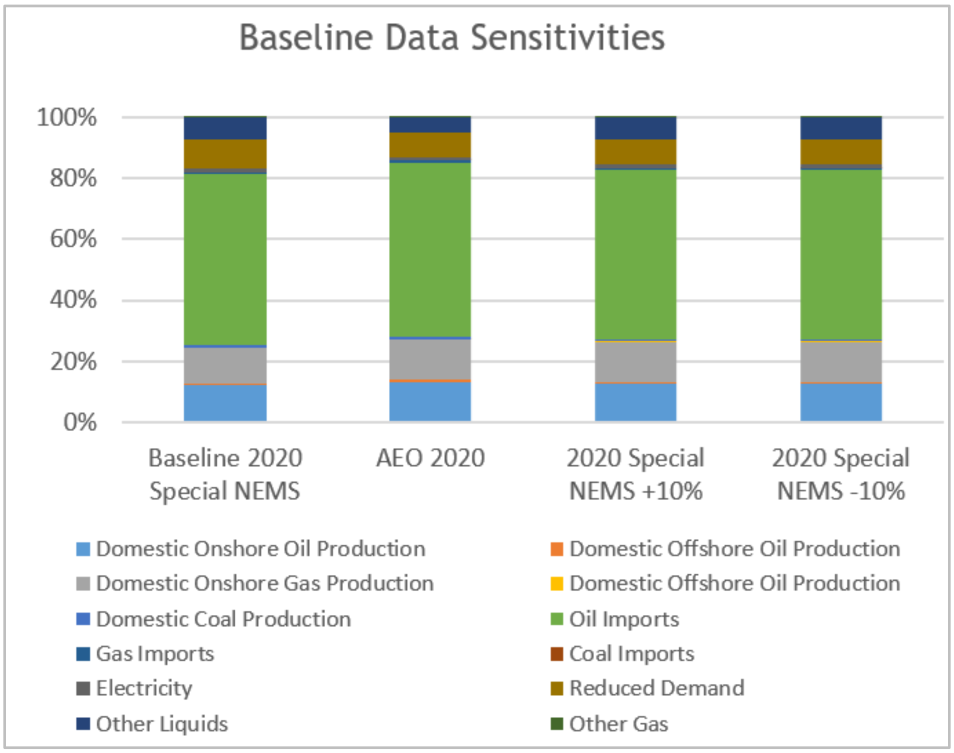

Figure A-15. Baseline Sensitivities Substitution Effects Results

The results of the sensitivity tests with respect to the emissions impacts estimated by the OECM are below in Tables A-31 and A-32, separated by scenario. Table A-31 presents these results in physical units by scenario, and Table A-32 presents these results as the percent change relative to results based on the default data. As indicated in the tables, the E&D results across all three scenarios are identical. This reflects the fact that the same scenario was run incremental to each baseline. Although E&D emissions results may vary based on projected oil exports, projected exports were virtually identical across all three scenarios. The tables also show that the emissions results for the 2020 NEMS + 10 percent and 2020 NEMS – 10 percent scenarios are identical for the No Action Alternative. This result is consistent with the substitution patterns presented above in Figure A-15.

Table A-31. Baseline Sensitivities OECM Air Emissions Impacts (1,000s of tons)

E&D or NAA	Baseline	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
E&D	Baseline 2020 NEMS	21.35	0.60	0.51	0.48	4.89	3.63	1,699.16	9.21	0.07
	AEO 2020	21.35	0.60	0.51	0.48	4.89	3.63	1,697.49	9.21	0.07
	2020 NEMS +10%	21.33	0.60	0.50	0.48	4.89	3.61	1,692.58	9.19	0.07
	2020 NEMS -10%	21.33	0.60	0.50	0.48	4.89	3.61	1,692.58	9.19	0.07
NAA	Baseline 2020 NEMS	14.82	0.52	13.86	0.32	3.79	45.14	12,308.80	244.06	0.15
	AEO 2020	16.31	0.48	15.75	0.34	4.19	49.37	12,788.76	255.86	0.16
	2020 NEMS +10%	16.11	0.46	15.73	0.34	4.09	47.19	12,480.61	249.00	0.15
	2020 NEMS -10%	16.11	0.46	15.73	0.34	4.09	47.18	12,481.72	249.00	0.15

Note: NAA = No Action Alternative

Table A-32. Baseline Sensitivities OECM Air Emissions Percentage Change from Baseline (1,000s of tons)

E&D or NAA	Baseline	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
E&D	AEO 2020	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	-0.1%	-0.1%	-0.1%
	2020 NEMS +10%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.5%	-0.4%	-0.2%	-0.4%
	2020 NEMS -10%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.5%	-0.4%	-0.2%	-0.4%
NAA	AEO 2020	10.0%	-7.4%	13.7%	6.9%	10.4%	9.4%	3.9%	4.8%	3.5%
	2020 NEMS +10%	8.7%	-10.2%	13.5%	5.4%	7.9%	4.5%	1.4%	2.0%	0.8%
	2020 NEMS -10%	8.7%	-10.2%	13.5%	5.4%	7.9%	4.5%	1.4%	2.0%	0.8%

A.5 Decarbonization Scenarios Sensitivities

To address the potential U.S. transition toward a significantly decarbonized energy future, this section outlines sensitivity scenarios for MarketSim tailored to such a system. Three specific sensitivities related to this transition were conducted:

1. Sensitivity test with MarketSim's baseline data altered to reflect a future decarbonized scenario
2. Sensitivity test with multiple elasticity values in MarketSim changed to reflect potential changes in supply/demand responsiveness to price changes in a less carbon-intensive energy system
3. Sensitivity test reflecting both the baseline data changes and modified elasticity values in the first two tests

These additional sensitivities are described in greater detail below.

To conduct each of these sensitivities, IEc used the full representative E&D scenario described in the introduction to this appendix. The entire time horizon of the E&D scenario was used rather than just the first 15 years of production because the differences between the baseline data currently in the model and in the alternative baselines grow over time.

To specify a more decarbonized baseline in MarketSim, this analysis used publicly available scenario data from Princeton's Net-Zero America project, which defines five decarbonization scenarios as well as a reference scenario based on AEO 2019 baseline data.[20] These six scenarios from the Net-Zero America project are as follows:[21]

1. **High Electrification (E+),** including near-full electrification of transport and buildings by 2050, no land-use changes for biomass supply, and few other constraints on energy supply options

2. **Less-High Electrification (E-),** including less rapid electrification of transport and buildings, no land-use changes for biomass supply, and few other constraints on energy supply options

3. **High Biomass (E-B+),** including less rapid electrification of transport and buildings, biomass supply requiring converting some agricultural land from food to energy crops, and few other constraints on energy supply options

4. **Renewable Constrained (E+RE-),** including near-full electrification of transport and buildings by 2050, no land-use changes for biomass supply, solar and wind annual capacity additions constrained to historical maximums, and few other constraints on energy supply options

5. **100% Renewable (E+RE+),** including near-full electrification of transport and buildings by 2050, no fossil fuel use allowed by 2050, no land-use changes for biomass supply, no new nuclear power construction and existing plants retired, and no underground storage of CO_2

6. **Reference (REF),** based on AEO 2019, with no greenhouse gas emission constraints imposed

This analysis uses a comparison of Scenario 5 (100% Renewable) and Scenario 2 (Less-High Electrification) relative to Scenario 6 (Reference) to develop scaling factors, which are used to adjust MarketSim's current baseline supply and demand data into a decarbonized baseline. More specifically,

[20] Information on the Net-Zero America scenarios is available at https://netzeroamerica.princeton.edu/?explorer=pathway&state=national&table=e-positive&limit=200.

[21] The abbreviations provided with each scenario name in parentheticals are the abbreviated names given to each scenario by the Net-Zero American Project. They are provided to enable the use of the abbreviated names in the figures below.

IEc uses ratios of Scenario 5 and Scenario 2 data to Scenario 6 data as the basis for modifying the baseline data currently in MarketSim. Scenario 5 was chosen for this sensitivity test because it is the most aggressive scenario specified by the Net-Zero America project. Scenario 2 was included as a less aggressive scenario that still results in significant shifts in the baseline data.

Note that the data from Net-Zero America do not include projections of rest-of-world (ROW) oil supply or oil demand, in contrast to MarketSim, which captures both U.S. and ROW supply and demand for oil. In the absence of such projections in the Net-Zero America data, this analysis specified ROW oil supply and demand based on the global oil supply projection included in International Energy Agency's net-zero scenario, net of the U.S. projections included in the Net-Zero America data (IEA 2021).

Although the direction of potential future changes in supply and demand quantities in a decarbonized scenario are relatively straightforward to anticipate, the direction of changes in elasticity values is less clear. In public comments submitted to BOEM, the New York University School of Law's Institute for Policy Integrity (IPI) suggests a framework for how elasticities might change in a decarbonized future (Howard *et al.* 2022). This analysis has adapted their suggestions into a batched test of changes to the MarketSim's elasticity values. The key difference between this batch sensitivity test for elasticities and the batch tests outlined above is that this batch focuses on potential elasticities as the economy decarbonizes and includes simultaneous increases in some elasticity values and reductions in others. Table A-33 outlines the selected changes to various elasticities.

For supply, this analysis applies halved elasticities for oil and gas following IPI's suggestion that producers' decision-making will be influenced more by policy and the internalization of environmental costs, as opposed to energy price changes. For electricity, this analysis uses doubled elasticity values to reflect a potential future in which increased electrification and renewable generation capacity development is aided by policy and decreases in technology costs. Coal makes up a minute share of overall substitution effects and is not included in BOEM E&D scenarios; accordingly, supply elasticity values for coal are left at default values to simplify the interpretation of results.

For demand elasticities, this analysis uses doubled own-price elasticity values for oil, gas, and electricity following IPI's suggestion that improved access to alternative fuel energy technologies will lead to a consumer base more responsive to changes in prices. Similarly, this analysis uses doubled cross-price elasticities for electricity with respect to fossil fuels to reflect future changes in electrification across sectors that will facilitate switching between energy sources. Potential changes for other cross-price demand elasticities under a net-zero scenario are less clear, and these parameters were left at default values. Coal makes up a minute share of overall substitution effects and is not included in BOEM E&D scenarios; accordingly, demand elasticity values for coal are left at default values to simplify the interpretation of results.

This analysis also tests an additional decarbonized scenario where both the decarbonized batch of elasticity changes and the decarbonized baseline data are incorporated into MarketSim for sensitivity testing. While potentially not as informative as the more targeted tests described in the previous sections for determining the model's sensitivity to changes in specific parameters, this combined decarbonization test represents an assessment of the intersectional or additive effects of the various individual tests.

Table A-33. Decarbonization Scenario Elasticity Adjustments—Supply

Resource	Own- or Cross-Price	Region/ Sector	Default Elasticity	Change in Elasticity	Altered Elasticity
Oil	Own-Price	Lower Offshore	0.19	Halved	0.095
		Alaska Offshore	0.58	Halved	0.29
		Alaska Onshore	0.42	Halved	0.21
		Canada	0.38	Halved	0.19
		Rest of World	0.28	Halved	0.14
		Lower 48 Conventional	0.93	Halved	0.465
		Lower 48 Tight	0.73	Halved	0.365
		Other	0.67	Halved	0.335
Natural Gas	Own-Price	Lower 48 Conventional	0.75	Halved	0.353
		Lower 48 Unconventional	0.68	Halved	0.34
		Lower 48 Offshore	0.19	Halved	0.095
		Alaska Onshore	1.29	Halved	0.645
		Alaska Offshore	1.29	Halved	0.645
		Other	0.51	Halved	0.255
		Pipeline Imports	0.52	Halved	0.26
		LNG Imports	1	Halved	0.5
Electricity	Own-Price	Onshore Wind	0.65	Doubled	1.30
		Offshore Wind	0.01	Doubled	0.02
		Solar	2.03	Doubled	4.06
		Coal	0.27	Doubled	0.54
		Natural Gas	1.50	Doubled	3.0

Table A-34. Decarbonization Scenario Elasticity Adjustments—Demand

Resource	Own- or Cross-Price	Region/ Sector	Default Elasticity	Change in Elasticity	Altered Elasticity
Oil	Own-Price	Residential & Commercial	-1.002 (R) -0.939 (C)	Doubled	-2.004 (R) -1.878 (C)
	Own-Price	Industrial	-0.264	Doubled	-0.528
	Own-Price	Transportation	-0.3	Doubled	-0.6
	Own-Price	Rest of World	-0.15	Doubled	-0.30
	Cross-Price with Gas	Residential & Commercial	0.2 (R) 0.2 (C)	Default	-
	Cross-Price with Gas	Industrial	0.249	Default	-
Natural Gas	Own-Price	Residential & Commercial	-0.313 (R) -0.296 (C)	Doubled	-0.626 (R) -0.592 (C)
	Own-Price	Industrial	-0.13	Doubled	-0.26
	Cross-Price with Oil	Residential & Commercial	0.07 (R) 0.07 (C)	Default	No change from default
	Cross-Price with Oil	Industrial	0.172	Default	No change from default
	Cross-Price with Electricity	Residential & Commercial	0.507 (R) 0.419 (C)	Default	No change from default
Electricity	Own-Price	Residential & Commercial	-0.287 (R) -0.134 (C)	Doubled	-0.574 (R) -0.268 (C)
	Cross-Price with Oil	Residential & Commercial	0.214 (R) 0.092 (C)	Doubled	0.428 (R) 0.184 (C)
	Cross-Price with Oil	Industrial	0.009	Doubled	0.018
	Cross-Price with Gas	Residential & Commercial	0.072 (R) 0.041 (C)	Doubled	0.144 (R) 0.082 (C)
	Cross-Price with Gas	Industrial	0.118	Doubled	0.236

Results – Decarbonization "Net-Zero" Scenarios Sensitivities

As context for the results of the sensitivity tests described above, Figure A-16 shows demand and supply under each baseline scenario—the default baseline in MarketSim and the two alternative baselines derived from Princeton's Net-Zero America project. Consistent with the scope of markets represented in MarketSim, the figure show global projections for oil and other liquids (with supply and demand presented separately for the U.S. and the rest of the world) and domestic projections (with imports and exports) for natural gas, electricity, and coal. The key differences between the two sets of adjusted net-zero baseline data scenarios are as follows:

- Overall liquids consumption is lower in the 100% Renewables scenario (E+RE+), with what consumption remains in the later years dominated by biofuels and synthetic liquids. Some domestic oil supply and consumption remains in the later years in the Less-High Electrification scenario (E-).

- Electricity makes up a larger proportion of total energy consumption in the 100% Renewables scenario (E+RE+).

- The Less-High Electrification scenario (E-) contains more natural gas consumption than the 100% Renewables scenario (E+RE+) in the later years.

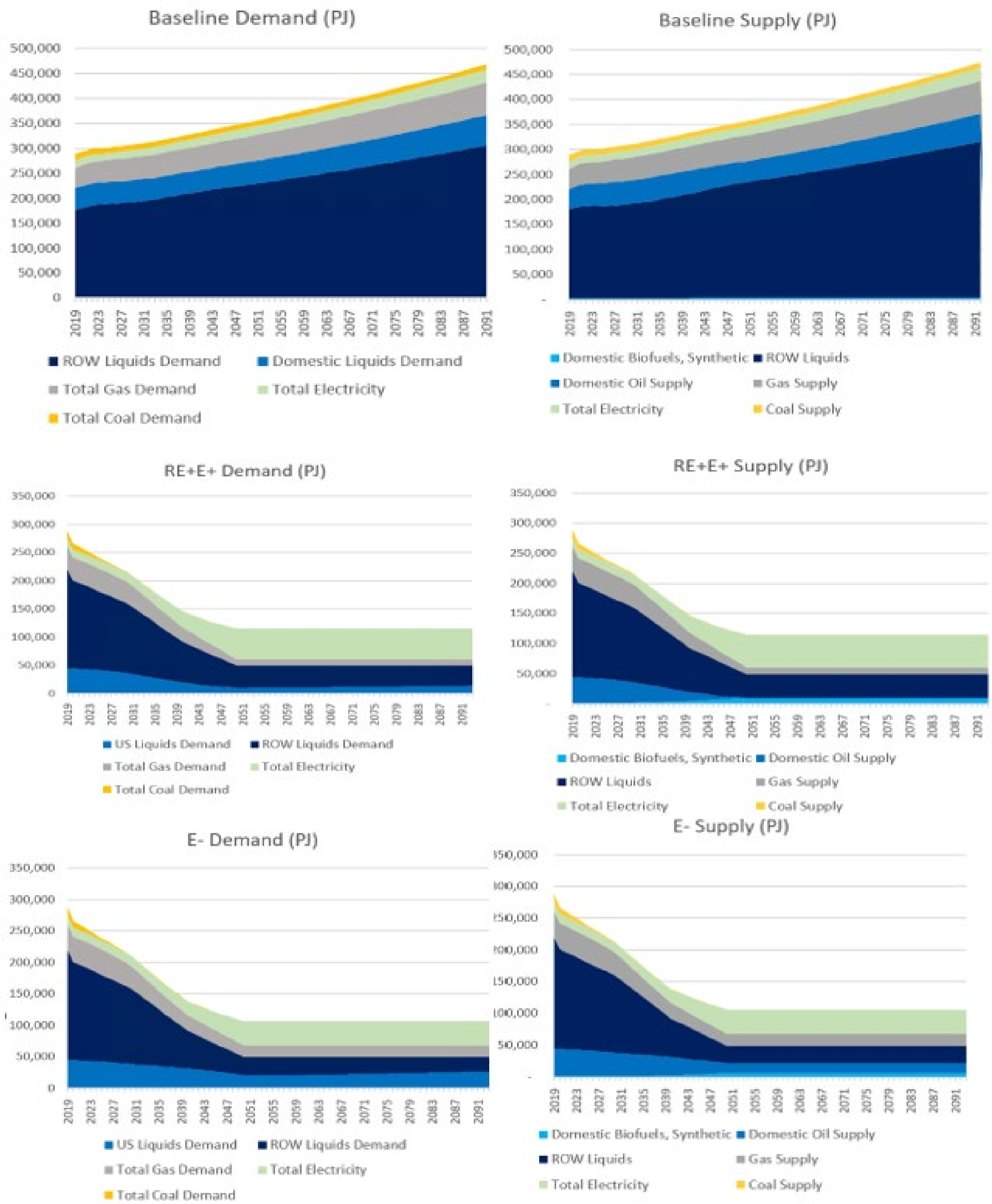

Figure A-16. Baseline Supply and Demand Projections – MarketSim Default and Alternatives

The results of the sensitivity tests with respect to MarketSim's substitution effects are shown in Figures A-17 to A-18 and Tables A-35 to A-36 below. Key findings are as follows:

- **The most pronounced shifts are with respect to reduced demand's share of total substitution, which increases under both the elasticity and baseline data net-zero tests.** The elasticity adjustments increase reduced demand's share of total substitution from 10 to 23 percent, while the baseline data adjustments increase reduced demand's share to 12 and 16 percent in the E+RE+ and E- scenarios, respectively. The more pronounced substitution effect for demand under the E- scenario reflects the higher baseline domestic demand for oil and other liquids under this scenario. Given the structure of the demand functions in MarketSim (i.e., isoelastic demand), a given change in price will have a greater impact on demand in *absolute* terms when baseline demand is higher. Thus, with higher baseline demand under the E- scenario, energy consumers under that scenario have more latitude to change their consumption in response to the E&D scenario.

- **The net-zero elasticity adjustments and net-zero baseline data adjustments have varying shifts on domestic onshore oil production's substitution**, with the elasticity adjustments cutting domestic onshore oil's share of substitution from 12 percent in the MarketSim default to 6 percent. This reflects the lower (halved) supply elasticities for oil production, which make this sector less sensitive to changes in price. The baseline data adjustments also decrease domestic oil's share to 9 percent in the E+RE+ scenario but increase to 17 percent in the E- scenario. The combined tests result in substitution of 4 percent under the E+RE+ scenario and 8 percent in the E- scenario.

- **The impact on oil imports' substitution is split, with the baseline data adjustments driving the combined effect.** The elasticity adjustments slightly increase oil imports' share of total substitution from 56 to 57 percent, while the baseline data adjustments decrease oil imports' share to 55 and 39 percent in the E+RE+ and E- scenarios, respectively. The combined effect is an overall reduction in oil imports' share, at 52 percent (E+RE+) and 38 percent (E-). Also, although the E+RE+ and E- scenarios are designed to approach net zero GHG emissions, the date for reaching the respective GHG reduction targets for each scenario is 2050, allowing new OCS production to displace imports for much of the analytic time horizon reflected in the results.

- **Impacts on gas substitution are aligned between the elasticity and baseline data adjustments, with the elasticity adjustments driving the combined effect of reducing gas's share of total substitution.** The elasticity adjustments decrease domestic gas production's share of total substitution from 12 to 5 percent, while the baseline data adjustments decrease domestic gas production's share to 10 percent in each scenario. The combined effect is an overall reduction in domestic gas's substitution, at 4 percent in each scenario. Similar changes are evident in gas imports, though this represents a much smaller (less than 1 percent) share of total substitution.

- **Impacts on electricity substitution are also aligned between the elasticity and baseline data adjustments, with each adjustment contributing to increase electricity's share of total substitution.** The elasticity adjustments increase electricity's share of total substitution from 2 to 3 percent, while the baseline data adjustments increase electricity's share to 5 and 4 percent in the E+RE+ and E- Scenarios, respectively. The combined effect is an overall increase in electricity's share, to 9 and 7 percent in the E+RE+ and E- scenarios, respectively.

- **Oil imports make up a larger share of total substitution in the E+RE+ scenario than under the E- scenario, while reduced demand and domestic onshore oil production make up a larger share in the E- scenario.** This result is likely driven by higher oil/liquids demand in the E- scenario, leaving the demand response more room to change in response to new OCS production due to the structure of the demand functions in MarketSim (see the first bullet above). Because oil/liquids demand is lower under the E+RE+ scenario, changes in imports play a larger role in the substitution pattern under that scenario than with the E- scenario.

Table A-35. Percent of Total Substitution—E+RE+Baseline Data Scenario

Supply Category	MarketSim Default	Net Zero Elasticities Only	NZ Supply/ Demand Projections Only	Combined
Domestic Onshore Oil Production	12.06%	6.01%	8.59%	4.15%
Domestic Offshore Oil Production	0.48%	0.24%	0.38%	0.18%
Domestic Onshore Gas Production	11.67%	4.98%	10.20%	4.06%
Domestic Offshore Gas Production	0.06%	0.02%	0.05%	0.02%
Domestic Coal Production	0.96%	1.25%	0.05%	0.05%
Oil Imports	55.94%	57.44%	54.69%	52.05%
Gas Imports	0.46%	0.19%	0.40%	0.16%
Coal Imports	0.00%	0.00%	0.00%	0.00%
Electricity	1.62%	2.88%	5.18%	9.26%
Reduced Demand	9.59%	23.42%	12.47%	26.26%
Other Liquids	7.15%	3.56%	7.99%	3.82%
Other Gas	0.01%	0.01%	0.01%	0.00%

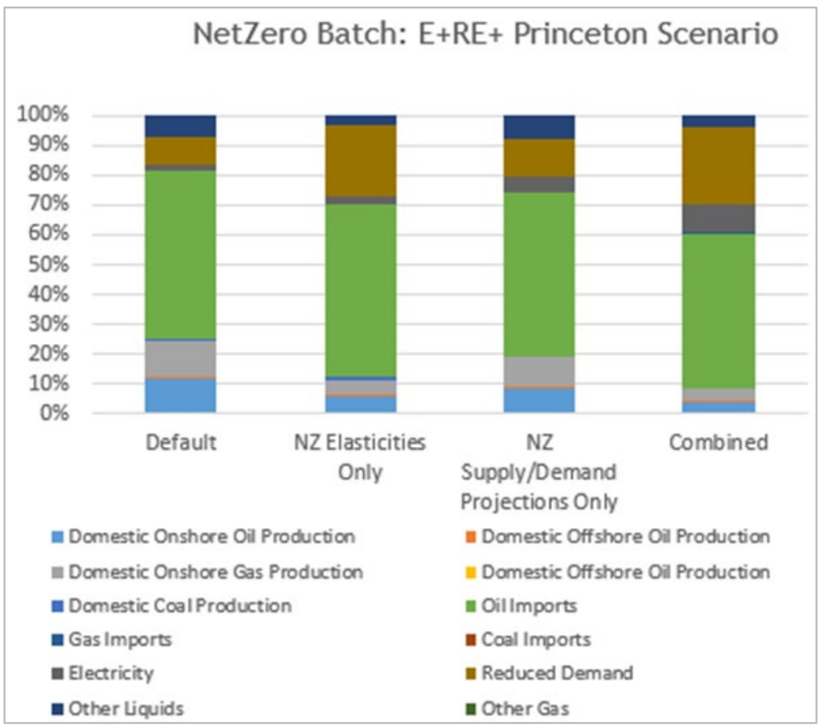

Figure A-17. Decarbonization Scenario Substitution Effect Results—E+RE+Baseline Data Scenario

Table A-36. Percent of Total Substitution—E- Baseline Data Scenario

Supply Category	MarketSim Default	Net Zero Elasticities Only	NZ Supply/ Demand Projections Only	Combined
Domestic Onshore Oil Production	12.06%	6.01%	17.30%	8.50%
Domestic Offshore Oil Production	0.48%	0.24%	0.66%	0.33%
Domestic Onshore Gas Production	11.67%	4.98%	10.42%	4.21%
Domestic Offshore Gas Production	0.06%	0.02%	0.05%	0.02%
Domestic Coal Production	0.96%	1.25%	0.06%	0.08%
Oil Imports	55.94%	57.44%	39.34%	38.42%
Gas Imports	0.46%	0.19%	0.41%	0.16%
Coal Imports	0.00%	0.00%	0.00%	0.00%
Electricity	1.62%	2.88%	4.11%	7.49%
Reduced Demand	9.59%	23.42%	16.46%	35.29%
Other Liquids	7.15%	3.56%	11.18%	5.49%
Other Gas	0.01%	0.01%	0.01%	0.00%

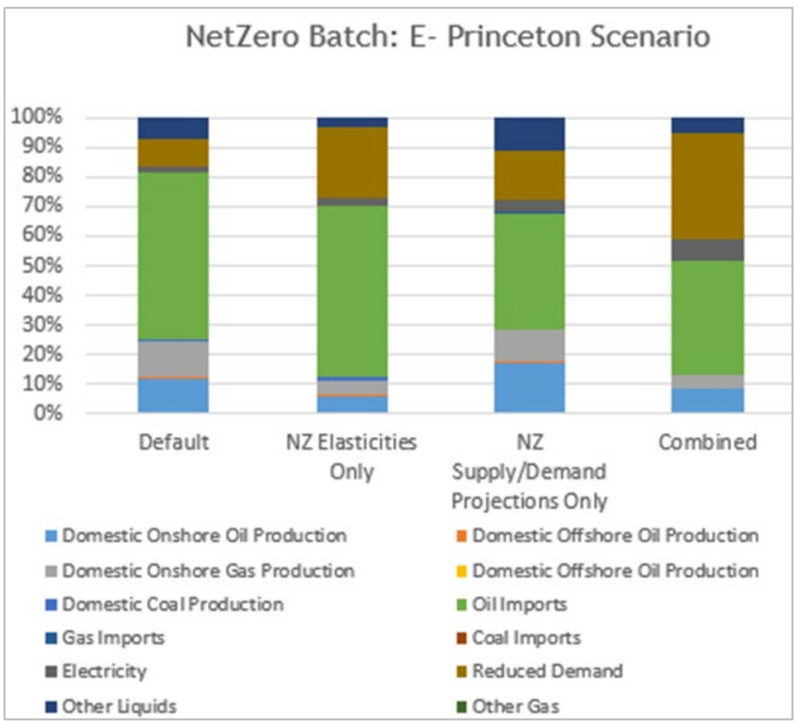

Figure A-18. Decarbonization Scenario Substitution Effect Results—E- Baseline Data Scenario

The results of the sensitivity tests with respect to emissions estimated by the OECM are presented in Tables A-37 and A-38 below, separated by scenario. Table A-37 presents these results in physical units by scenario, and Table A-38 presents these results as the percent change relative to results based on the default data. As shown in the tables, the emissions impacts for the E&D scenario are similar between the default data and the alternative scenarios. This result is not unexpected, as the changes examined in these sensitivities are limited to inputs to MarketSim, which has limited influence on the E&D impact estimates generated by the OECM, namely impacts related to oil exports. In contrast, the No Action Alternative emissions impacts with alternative elasticity parameters and baseline data are generally lower than those under the default. This reflects the greater role of reduced demand as a substitution response relative to the default model runs. As shown in Figures A-17 to A-18 and Tables A-35 to A-36 above, reduced demand makes up a greater fraction of substitution effects under all of the decarbonized sensitivity runs than under the default runs.

The results in Tables A-37 and A-38 also show that the reduction in NAA emissions impacts relative to the default is highest when applying both alternative elasticities and baseline data reflective of a more decarbonized energy system. This finding is consistent with the substitution effects presented above, which show that the substitution response for domestic substitutes is lowest under this scenario, while the substitution response for reduced demand is at its highest under this scenario.

An important limitation of the emissions results presented here is that they are limited to the upstream emissions impacts captured in the OECM. They do not reflect additional life cycle emissions impacts captured by BOEM's GLEEM or those emissions impacts captured by neither the OECM nor GLEEM.

Table A-37. Decarbonization Scenario OECM Air Emissions Impacts (1,000s of tons)

E&D or NAA	Scenario	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
E&D	Default	21.35	0.60	0.51	0.48	4.89	3.63	1,699.16	9.21	0.07
	Elasticities	21.58	0.61	0.51	0.48	4.91	3.80	1,760.05	9.40	0.08
	E+RE+	21.38	0.60	0.51	0.48	4.89	3.65	1,707.84	9.24	0.07
	E-	21.47	0.61	0.51	0.48	4.90	3.72	1,734.02	9.32	0.07
	E+RE+_ Elasticities	21.60	0.61	0.51	0.48	4.92	3.82	1,770.58	9.43	0.08
	E-_Elasticities	21.75	0.61	0.51	0.49	4.93	3.93	1,809.92	9.55	0.08
NAA	Default	14.82	0.52	13.86	0.32	3.79	45.14	12,308.80	244.06	0.15
	Elasticities	9.23	0.45	6.10	0.20	2.06	23.87	11,391.21	203.66	0.14
	E+RE+	12.49	0.29	11.69	0.24	2.97	31.85	11,801.95	222.22	0.14
	E-	12.22	0.38	11.96	0.27	3.98	60.91	8,857.35	205.31	0.10
	E+RE+_ Elasticities	7.27	0.20	4.61	0.13	1.51	16.25	9,874.01	170.31	0.12
	E-_Elasticities	6.77	0.22	4.73	0.13	1.89	28.29	7,738.48	149.41	0.10

Table A-38. Decarbonization Scenario OECM Air Emissions Percent Change from Baseline (1,000s of tons)

E&D or NAA	Scenario	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
E&D	Elasticities	1.1%	1.1%	0.6%	0.5%	0.5%	4.7%	3.6%	2.0%	4.0%
	E+RE+	0.1%	0.1%	0.1%	0.1%	0.1%	0.5%	0.5%	0.3%	0.6%
	E-	0.6%	0.6%	0.3%	0.3%	0.3%	2.5%	2.1%	1.2%	2.3%
	E+RE+_ Elasticities	1.2%	1.2%	0.6%	0.6%	0.5%	5.2%	4.2%	2.4%	4.6%
	E-_Elasticities	1.8%	1.9%	1.0%	0.9%	0.9%	8.2%	6.5%	3.7%	7.2%
NAA	Elasticities	-37.8%	-12.7%	-56.0%	-38.9%	-45.7%	-47.1%	-7.5%	-16.6%	-5.0%
	E+RE+	-15.8%	-44.1%	-15.7%	-24.1%	-21.7%	-29.4%	-4.1%	-8.9%	-9.1%
	E-	-17.6%	-27.0%	-13.7%	-14.6%	5.0%	34.9%	-28.0%	-15.9%	-31.5%
	E+RE+_ Elasticities	-51.0%	-61.9%	-66.7%	-60.7%	-60.3%	-64.0%	-19.8%	-30.2%	-20.1%
	E-_Elasticities	-54.3%	-56.5%	-65.8%	-58.0%	-50.1%	-37.3%	-37.1%	-38.8%	-37.0%