Appendix 4A: Uncertainty in Natural Gas Consumption in Electricity

This appendix describes the use of the US-MARKAL Electric Sector model for uncertainty analysis of future natural gas consumption.

**MARKAL Model Structure**

MARKAL\(^1\) is an optimization framework that provides a general structure for modeling an energy system, and specific models consist of databases of the technologies, fuels and end-use demands in the system. Any database developed for MARKAL contains the structure of the energy system to be modeled, including resource supplies, energy conversion technologies and end-use demands. Also included are the technologies used to satisfy these demands with the data to characterize each of the technologies and resources used, including fixed and variable costs, technology availability and performance, and pollutant emissions.

Using straightforward linear programming techniques, MARKAL then calculates the best way to satisfy the specified demands, at least cost, subject to any constraints a user wishes to impose. Outputs of the model include a determination of the technological mix at intervals into the future, estimates of total system cost, energy services (by type and quantity), estimates of criteria and greenhouse gas (GHG) emissions, and estimates of energy commodity prices.

The US-EPA MARKAL model\(^2\) is a model of the U.S. energy system from 2000 to 2050 in 5-year steps. For this study, we developed a version of US-EPA MARKAL that represents only the electric power sector, in which electricity demand and fuel inputs are exogenous. In this version, we have extended the original version to divide each year into 12 time slices, consisting of three seasons (summer, winter, spring/fall) and for each season four different times of day (night, morning, afternoon, peak).

For the reference (no uncertainty) case, we use the resulting electricity demand and fuel prices from the EPPA model analysis of Chapter 3 of this report. Moreover, the supply for natural gas and coal are based on an exogenous supply curve estimated from the same EPPA model version. The reference costs of new generation technologies use the same values as EPPA, based on the U.S. Energy Information Administration (EIA) 2010 values.\(^3\)

The analyses presented below apply the “No Policy” and the “Price-Based” policy from Chapter 3. For each policy case the resulting CO\(_2\) emissions from the electric sector in the EPPA model are specified as the emission limits in MARKAL in each period. The resulting generation for the reference case under these two scenarios is shown in Chapter 4, Figures 4.2 and 4.3.

**Uncertainty Analysis Methodology**

Using the US-EPA MARKAL Electric Sector model described above, we apply Monte Carlo simulation to propagate uncertainty in input assumptions through to uncertainty in outputs. Specifically, we represent uncertainty in electricity demand, fuel prices and the costs of new generation technologies. For each of these parameters in the model we have developed probability distributions from which values are randomly sampled.

The uncertainties in electricity demand and fuel prices are derived from the results of an uncertainty analysis of an earlier version of the EPPA model.\(^4\) In that study, a Monte Carlo simulation of EPPA version 4 used randomly sampled
values for over 100 parameters, including population growth, labor productivity growth, energy efficiency improvement, elasticities of substitution and fossil fuel resources. Here we use the frequency distribution of electricity demand, natural gas price and coal price over time, and normalize those distributions to have a mean of unity.

In the MARKAL analysis presented here, we sample from the normalized distributions to obtain an uncertainty factor, and multiply the reference input from EPPA by this factor to obtain a new sample value. This procedure is straightforward in the case of demand. Because the fuel supply is not modeled explicitly (the supply curve derived from the EPPA model is applied) we sample from a probability distribution centered on 1.0 to obtain a scaling factor, which is then used to multiply the prices for the supply curves to simulate shifting the curves up or down.

The uncertainty in the cost of future technologies is more challenging, since no data source exists. Usually, uncertainty studies rely on expert elicitation to obtain distributions, an endeavor that requires significant time and expense. For this study, we assumed simple, illustrative distributions for cost uncertainties. Distributions are developed for three canonical technology types, one with least uncertainty in cost, one with moderate uncertainty, and one with the greatest uncertainty.

All distributions utilize the Beta family of probability functions, and are skewed with longer upper tails (higher cost side).

The least uncertainty category assumes the cost uncertainty has a standard deviation of ±10% and 90% range of 0.9 to 1.3 relative to the reference assumption. This category includes new coal steam technologies and next generation natural gas power plants (combined cycle and combustion turbine).

The moderate uncertainty category assumes a distribution with a standard deviation of ±25% and a 90% range of 0.7 to 1.6 relative to the reference cost. This category includes nuclear light water reactors, coal integrated gasification combined cycle (IGCC) and wind technologies.

The largest uncertainty category assumes a distribution with a standard deviation of ±40% and a 90% range of 0.66 to 2.1 relative to the reference cost. This category includes technologies using carbon capture and sequestration (CCS), solar technologies and advanced nuclear generation technologies.

The sampling from these distributions is performed using Latin Hypercube to obtain a representative sample with fewer sample points. We use this approach to construct 400 sample scenarios. Each sample is used to simulate MARKAL under both the No Policy and the Price-Based Policy cases. The resulting consumption of natural gas, generation from each technology, and other results from these 400 runs are then used to construct frequency distributions to characterize the uncertainty in these projections.

**RESULTS**

Here, we present the resulting uncertainty in natural gas consumption. We summarize the uncertainty by giving the median consumption over time, the 50% probability interval and the 80% probability interval.
Figure 4A.1 Natural Gas Use in U.S. Electricity Sector

**With No Climate Policy**

- 80% Probability bounds
- 50% Probability bounds
- Median

**With Price-Based Climate Policy**

- 80% Probability bounds
- 50% Probability bounds
- Median
NOTES


3The EIA source is the U.S. Energy Administration Assumptions to the Annual Energy Outlook, 2010 Early Release. See also Appendix 3A of this report.