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World Energy Projection System Plus: Coal Model

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1. Introduction

Purpose of this report

The Coal Model of the World Energy Projection System Plus (WEPS+) is a regional-level model for projecting retail and wholesale prices of coal. This report describes the version of the Coal Model that was used to produce the energy projections published in the *International Energy Outlook 2017* (*IEO2017*). It documents the objectives, analytical approach, and development of the model and describes critical assumptions, computational methodology, parameter estimation techniques, and model source code.

This document serves three purposes. First, it is a reference document providing a detailed description for model analysts, users, and the public. Second, it meets the legal requirement of the U.S. Energy Information Administration (EIA) to provide adequate documentation in support of its models (*Public Law 93-275, section 57.b.1*). Third, it facilitates continuity in model development by providing documentation from which energy analysts can undertake and analyze their own model enhancements, data updates, and parameter refinements for future projects.

Model summary

The WEPS+ Coal Model projects the retail price of coal, by region and end use sector, for use in the demand, supply, and transformation models of the WEPS+ system. In addition, wholesale coal prices are estimated by region. The Coal Model projects coal prices for each of the 16 WEPS+ regions, annually through 2050, for six end uses (residential, commercial, industrial, transportation, electric power, and district heat). Inputs for the model from other WEPS+ models include projected quantities of coal consumed in each of the end-use sectors. Historical and projected base benchmark wholesale prices, world coal demand, coal supply elasticities, and initial regional retail prices by end-use sector are also specified exogenously to the Coal Model. The retail coal prices generated by the Coal Model are exported to the shared restart file for use by the other WEPS+ models.

Model archival citation

This documentation refers to the WEPS+ Coal Model, as archived for the *International Energy Outlook 2017* (*IEO2017*).

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Organization of this report

Chapter 2 of this report discusses the purpose of the Coal Model, the objectives and the analytical issues it addresses, the general types of activities and relationships it embodies, the primary input and output variables, and the relationship of the model to the other models in the WEPS+ system. Chapter 3 of the report describes the rationale behind the Coal Model design, providing insights into further assumptions used in the model. Chapter 4 describes the model structure in more detail, including flowcharts, variables, and equations.

2. Model Purpose

Model objectives

The primary objective of the WEPS+ Coal Model is to calculate wholesale coal prices by region, as well as retail coal prices for each end use demand and transformation sector by year. The wholesale prices are based upon the U.S. coal price projections and on the historical relationship of U.S. coal price to international prices. The model also is able to employ an algorithm in which supply elasticities can be used to change the wholesale coal prices based upon changes in regional coal demand. The retail prices are based upon fixed sectoral markups from the wholesale prices. Upon completion of the model, the prices are exported into the shared restart file and thus made available for use by the demand and transformation models.

As an integral component of the WEPS+ system, the Coal Model provides coal prices to other WEPS+ models. It also contributes to the calculation of the overall energy supply and demand balance.

The Coal Model provides projections for each of 16 regions (Table 1). These regions consist of countries and country groupings within the broad divide of the Organisation for Economic Co-operation and Development (OECD) membership.

Table 1. Regional Coverage of the World Energy Projection System Plus Model

OECD Regions	Non-OECD Regions
United States	Russia
Canada	Other Non-OECD Europe and Eurasia
Mexico and Chile	China
OECD Europe	India
Japan	Other Non-OECD Asia
Australia and New Zealand	Middle East
South Korea	Africa
	Brazil
	Other Non-OECD Americas

Model inputs and outputs

Inputs

The Coal Model uses coal consumption and price projections imported from the WEPS+ common database. These inputs have been previously projected by the source models listed in Table 2.

Table 2. WEPS+ Models that Provide Inputs to the Coal Model

Coal Model Input	Source
Residential coal consumption	Residential Model
Commercial heat consumption	Commercial Model
Industrial heat consumption	Industrial Model
Transportation coal consumption	Transportation Model
Electricity coal consumption	Electricity Model
District heat coal consumption	District Heat Model
Revised retail coal prices	Main Model

The Coal Model imports several exogenous data series from the CoalInput.xml file (Table 3).

Table 3. Major Exogenous Coal Model Input Data Series

Source Input File	Model Input
CoalInput.xml	U.S. coal prices (2013 dollars)
	World coal demand (quadrillion Btu)
	Supply elasticities
	DoElas switch (o=no, 1=yes)
	Regional wholesale price of coal
	End use sector price ratio of coal
	Coal prices for power generation
	Natural gas price growth rate relative to coal
	First year after which to apply natural gas price growth rate relative to coal

Outputs

The Coal Model projects retail coal prices by end-use sector and region. The model also calculates regional wholesale prices. Upon completion of a model run, these values are exported to the WEPS+ common database for use by other models (Table 4).

Table 4. Coal Model Outputs and the WEPS+ Models that Use Them

Coal Model Output	Destination
Retail price of coal in the residential sector	Residential Model
Retail price of coal in the commercial sector	Commercial Model
Retail price of coal in the industrial sector	Industrial Model
Retail price of coal in the transportation sector	Transportation Model
Retail price of coal in the electric power sector	Electricity Model
Retail price of coal in the district heat sector	District Heat Model
Wholesale price of coal	-

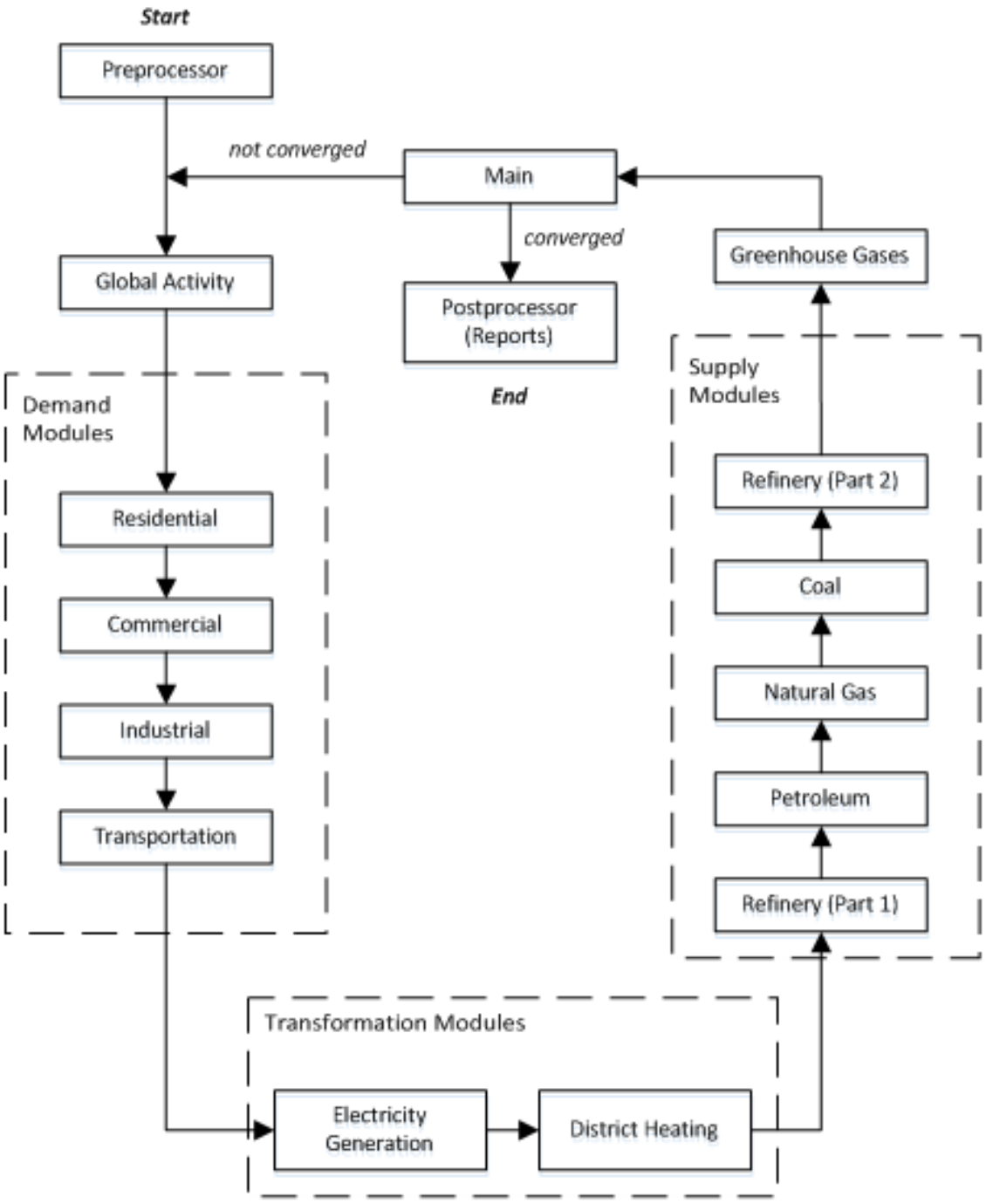
Relationship to other models

The Coal Model depends on other models in the WEPS+ system for some of its key inputs. In turn, the Coal Model provides projections of coal retail prices, on which other models in the system depend for their key inputs (Figure 1). A summary description of the models, flows, and mechanics of the WEPS+ system is available in a separate *Overview* document.

Through the system, the Coal Model receives coal consumption projections from the demand and transformation models. It also receives revised coal retail price projections from the Main Model. In turn, the Coal Model provides price projections, through the system, back to the demand, supply, and transformation models, as well as the Main Model.

Although the Coal Model is an integral part of the WEPS+ system, it can also run as a standalone model, outside of the system. To do that, the Coal Model would input consumption and price projections from the WEPS+ system common database created in a prior run of the system.

Figure 1. World Energy Projection System Plus (WEPS+) Model Sequence



3. Model Rationale

Theoretical approach and assumptions

The Coal Model assumes that changes in wholesale coal prices in the WEPS+ regions are correlated directly with changes in U.S. wholesale coal prices. An optional supply elasticity approach is included in the model to allow for changes in the benchmark wholesale price series in response to projected changes in global coal demand between model iterations. These price assumptions can be overridden by analyst judgment, when appropriate. Retail coal price projections are derived from the wholesale coal prices using retail markups that are fixed over time.

4. Model Structure

Structural overview

The main purpose of the Coal Model is to estimate wholesale and retail coal prices for use by the demand and transformation models of the WEPS+ system. In the Coal Model, price projections are based upon historical regional prices and projections of U.S. coal prices that are used as a benchmark for changes over time in the rest of the world. The model also includes an algorithm by which supply elasticities are used to change the wholesale coal prices based upon changes in regional coal demand. This capability was not used for the *IEO2017*.

The basic structure of the Coal Model is illustrated in Figure 3. A call from the WEPS+ interface to the Coal Model initiates importation from the restart file of the supporting information needed to complete the projection calculations. The Coal Model then executes the MainCoal subroutine, which is the major component of the model and the location in which most of the model computations are made. In its final step, the model executes the subroutine that exports all projections to the restart file for use by other WEPS+ models.

The MainCoal subroutine (Figure 4) is initiated by a call from the main Coal Model. Exogenous data series that are required by the model are imported through a call to the CoalInput subroutine, which imports the following data series from the CoalInput.xml data file.

CoalInput.xml includes the following data items:

- Base (U.S.) benchmark wholesale coal prices (in real 2013 dollars per million Btu)
- World coal demand (2005 through 2050)
- Supply elasticities (2005 through 2050—five year increments)
- Regional wholesale coal prices (2015)
- Retail coal prices by end-use sector and region (2005 through 2050)
- Wholesale coal prices for electricity generation by region (2005 though 2050)
- Fractional weight by which coal prices rise relative to natural gas prices (and year after which factor applied)

Once the data are imported, the subroutine begins by adding together all coal consumed in each of the demand and transformation sectors to determine how much global coal supply is needed in each year. Next, a determination is made as to whether or not the supply elasticity option is to be used (this option is used in *IEO2017*).

If this option is selected, the base benchmark wholesale coal price is adjusted by applying the specified supply elasticity to the difference between the world demand for coal in the current model iteration and the base world coal demand for each year in the projection. If the elasticity option is not used, the benchmark wholesale coal price series is not adjusted between iterations.

After the base wholesale price is adjusted, the retail coal prices by end-use sector and region are adjusted to reflect the change in the base benchmark wholesale coal price. The model allows the option

of further adjusting the retail end-use price for coal used in electricity generation based on the ratio of regional natural gas prices to coal (this option is not used in *IEO2017*).

After the CoalMain subroutine has completed, the WriteRestart subroutine is executed. WriteRestart provides projections to the restart file for use in future iterations of WEPS+. These output data series include end-use sector retail prices and wholesale prices associated with coal.

Flow diagrams

Figure 2. Flowchart for the Coal Model

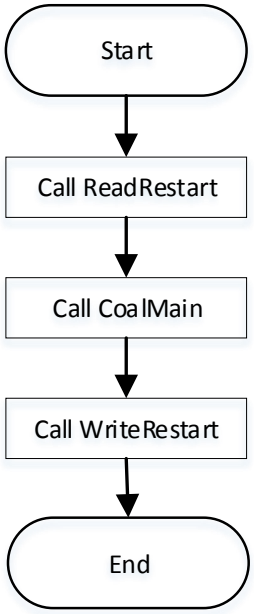
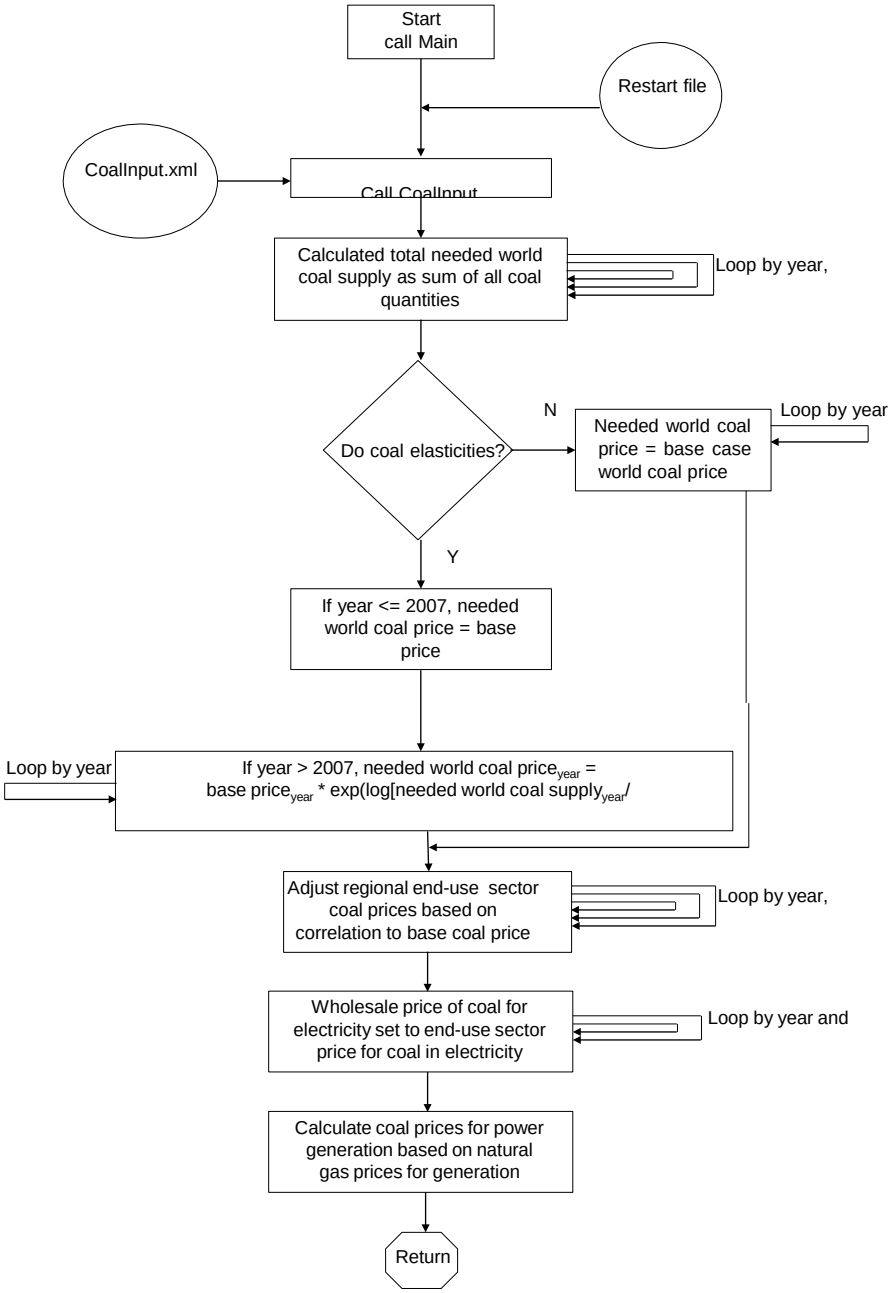


Figure 3. Detailed Flowchart for the Coal Model



Key computations

The WEPS+ Coal Model determines wholesale coal prices by region and subsequently derives the retail prices for each end use annually through 2050. The wholesale prices are based on the coal price projections and on the historical relationship of U.S. coal prices to international prices. Regional end-use coal prices represent regional weighted averages of steam and metallurgical coal price projections, except for coal for electricity generation, which is a function of steam coal prices. The model is also able to employ an algorithm in which supply elasticities can be used to change the wholesale coal prices based on changes in regional coal demand. This capability was not used for the *IEO2017*.

The retail price projections are based on fixed sectoral markups from the wholesale prices. Upon completion of the model, the prices are exported to the shared restart file that is read in by the following demand and transformation models:

- Residential
- Commercial
- Industrial
- Transportation
- Electric Power
- District Heat

The Coal Model includes an algorithm to allow coal prices to change based on changes in coal demand. This algorithm uses a base benchmark wholesale price for coal, which is assumed to be the U.S. coal price. The base benchmark wholesale coal price path is associated with a reference level of coal supply in each projection year. The price is specified in real 2013 dollars per million British thermal unit (Btu). The input file includes coal price elasticities by year that define the relationship of the bench-marked coal price to changes in global coal supply. These elasticities can be used to solve for adjusted benchmark wholesale coal prices. Generally, the base world coal supply is the same as in the IEO Reference case at the start of the first model iteration.

The model treats the elasticity with coal price as a supply elasticity so that the relationship is defined as

$$CoalSupElas(r,y) = \frac{ln(NewCoalQty(r,y)/BaseCoalQty(r,y))}{ln(NewCoalPrc(r,y)/BaseCoalPrc(r,y))},$$

where, for region r and year y,

NewCoalQty and *BaseCoalQty* are the new (changed) and base coal supply/demand quantity;

NewCoalPrc and *BaseCoalPrc* are the new (resulting) and base benchmark coal price; and

CoalSupElas is the coal supply elasticity.

The above equation can be used to solve for the changes in coal prices due to changes in coal supply. Thus, large elasticities cause small changes in the coal prices and conversely. For *IEO2017*, large supply elasticities were used in the Reference case, meaning that the prices have only a modest impact. Further, prices used in the *IEO2017* were exogenously specified in the Reference case.

U.S. coal prices were used as the basis of coal prices in other regions. Regional power generation coal prices for 2015 were determined using exogenous sources and were imported into the Coal Model from the CoalInput.xml file. The relationships between these prices and the U.S. price are used as the basis for the price changes in the projections. As the U.S. benchmark price moves over time as described above, the other regional coal prices move in a similar fashion.

Appendix A: Model Abstract

Model Name:
Coal Model of the World Energy Projection System Plus

Model Acronym:
Coal Model

Model Description:
The Coal Model of the World Energy Projection System Plus is a computer-based energy supply modeling system that is primarily used to estimate the retail and wholesale price of coal regionally.

Model Purpose:
The Coal Model determines wholesale coal prices by region and subsequently derives the retail coal prices for each end use sector annually through 2050. The wholesale prices are based on the U.S. coal price projections and on the historical relationship of U.S. coal price to international prices. The model also is able to employ an algorithm in which supply elasticities can be used to change the wholesale coal prices based on changes in regional coal demand. This capability was not used for *IEO2017*. The model provides a tool for analysis of international coal supply prices within the WEPS+ system, and can also run independently as a standalone model.

Most Recent Model Update:
January 2017

Part of Another Model:
World Energy Projection System Plus (WEPS+)

Model Interfaces:
The Coal Model receives inputs from and provides outputs to a variety of other models in the WEPS+ system, through the common, shared interface file of the WEPS+.

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Documentation:
Energy Information Administration, U.S. Department of Energy, *World Energy Projection System Plus: Coal Model*, DOE/EIA-M082 (2018) (Washington, DC, January 2018).

Archive Information:
The model is archived as part of the World Energy Projection System Plus archive of the runs used to generate the *International Energy Outlook 2017*.

Energy System Described:
International coal prices

Coverage:
Geographic: Sixteen WEPS+ regions: U.S., Canada, Mexico, OECD Europe, Japan, Australia/New Zealand, South Korea, Russia, Other non-OECD Europe and Eurasia, China, India, other non-OECD Asia, Middle East, Africa, Brazil, and Other non-OECD Americas.

Mode: regional retail and wholesale coal prices.

Time Unit/Frequency: Annual, through 2050.

Modeling Features:
The WEPS+ Coal Model determines wholesale coal prices by region and subsequently derives the retail prices for each end use sector annually through 2050. The wholesale prices are based on the U.S. coal price projections and on the historical relationship of U.S. coal price to international prices. The retail price projections are based on fixed end use sector markup factors from the wholesale prices.

DOE Input Sources:
Energy Information Administration (EIA), U.S. Department of Energy, *Annual Energy Outlook 2017*, Washington, DC, January 2017.

Non-DOE Input Sources:
International Energy Agency, Energy Statistics and Balances of OECD Countries, web site www.iea.org (subscription site).

International Energy Agency (IEA), *Coal Information 2016*, Paris, 2016.

International Energy Agency (IEA), *Energy Prices and Taxes*, Quarterly Report (various issues), Paris, 2016.

IHS, *McCloskey* Coal and Petcoke Prices, 2016

Independent Expert Reviews:
None

Computing Environment:
Hardware/Operating System: Basic PC with Windows

Language/Software Used: Fortran 90/95 (not required at runtime), Python

Run Time/Storage: Standalone model with one iteration runs in about 3-4 seconds, CPU memory is minimal, inputs/executable/outputs require less than 20MB storage.

Special Features: None.

Appendix B. Input Data and Variable Descriptions

The following variables represent data input from the file CoalInput.xml. Classification: Input variable.

Subscripts: (*y*): year; (*r*): region; (*x*): end-use sector.

BWCP(y): Average minemouth price of coal in the United States by year (2013 dollars per million Btu)

BWCS(y): Baseline world coal demand by year (quadrillion Btu)

EWCP(y): Supply elasticities by year

DoCElas: Switching indicating whether supply elasticities will by used in the run (0=no, 1=yes)

CRWPFacIn(r): Regional coal prices (in 2013 dollars per metric ton) [*Note: this variable is recalculated as the ratio between the price in a region relative to the price in the United States*]

CPPFac(x,y): By-end-use-sector price ratio to the regional wholesale price (not used in *IEO2017*)

CPrcEU(r,y): End-use sector coal prices by region and year (2013 dollars per million Btu)

CPrcPG(r,y): Coal prices in the electric power sector by region and year (2013 dollars per million Btu)

GGRFyr(r): Year after which coal prices increase as a weighted average of the original coal price and the wholesale natural gas price by region (not used in *IEO2017*)

GGRGas(r): Fractional weight by which coal prices rise relative to natural gas prices (value between 0 and 1; not used in *IEO2017*)

The following variables represent data input from the WEPS+ common database, for all regions for years 2005-2050.

Classification: Input variable from the Residential Model, Commercial Model, Industrial Model, Refinery Model, Petroleum Model, Natural Gas Model, and Electricity Model.

QCLRS(r,y): Amount of coal consumed in the residential sector by region and year

QCLCM(r,y): Amount of coal consumed in the commercial sector by region and year

QCLIN(r,y): Amount of coal consumed in the industrial sector by region and year

QCLTR(r,y): Amount of coal consumed in the transportation sector by region and year

QCLPG(r,y): Amount of coal consumed in the electric power sector by region and year

QCLDH(r,y): Consumption of coal used for district heat generation by region and year

The following variables represent data calculated in the subroutine CoalInput.

Classification: Computed variable.

CPPFac(x,y):	End Use sector price ratio by sector and year is imported in 5-year increments and interpolated between years to get annual factors
CRWPFacIn(r):	Imported as a price variable, but then the variable is changed into a ratio of regional wholesale coal prices relative to U.S. values

The following variables represent data calculated in the subroutine CoalMain.

Classification: Computed variable.

PCLRS(r,y):	Retail price of coal used in the residential sector by region and year
PCLCM(r,y):	Retail price of coal used in the commercial sector by region and year
PCLIN(r,y):	Retail price of coal in the industrial sector by region and year
PCLTR(r,y):	Retail price of coal in the transportation sector by region and year
PCLDH(r,y):	Retail price of coal for district heat generation by region and year
PCLPG(r,y):	Retail price of coal in the electric power sector by region and year
PNGPG(r,y):	Retail price of natural gas in the electric power sector by region and year
PCLWD(r,y):	Wholesale price of coal by region and year

Appendix C. References

1. Alpha C. Chiang, *Fundamental Methods of Mathematical Economics* (McGraw-Hill Book Company, NY: NY, 1967).

2. Energy Information Administration, *Coal Market Module of the National Energy Modeling System: Model Documentation 2010*, DOE/EIA-M060(2014) (Washington, DC, 2014).

3. Energy Information Administration, *Annual Coal Report 2015*, DOE/EIA-0584(2015) (Washington, DC, November 2016).

4. Energy Information Administration, *Annual Energy Outlook 2017*, DOE/EIA-0383(2017) (Washington, DC, January 2017).

5. International Energy Agency, *World Energy Outlook 2016 Edition* (Paris, France, November 2016).

6. International Energy Agency, *Coal Information 2017* (Paris, France, 2016).

7. International Energy Agency, *Energy Prices and Taxes* (Quarterly report, Paris, France, 2017).

8. International Energy Agency, *Energy Statistics and Balances of OECD Countries*, web site www.iea.org (subscription site).

9. International Energy Agency, *Energy Statistics and Balances of Non-OECD Countries*, web site www.iea.org (subscription site).

10. Walter Nicholson, *Microeconomic Theory: Basic Principles and Extensions* (Harcourt College Publishers, Fort Worth: Texas, 1972).

11. SSY Consultancy and Research, Ltd., *SSY's Coal Trade Forecast*, Vol. 24, No. 3 (London, United Kingdom, May 2017).

12. Wayne L. Winston, *Operations Research: Applications and Algorithms* (Brooks/Cole—Thomson Learning, Belmont, CA, 2004).

Appendix D. Data Quality

Sources of Input Data

Sources of input data include:

- *Annual Energy Outlook* – The Energy Information Administration provides projections of U.S. average minemouth coal price projections through 2050. These data are used as the historical basis for regional projections that appear in the *IEO2017*.

- *International Energy Agency* – The international coal prices were estimated, in part, using information from the International Energy Agency's *Coal Information 2017* and the quarterly report, *Energy Prices and Taxes*, 2017 editions.

Data Quality Verification

As a part of the input and editing procedure, an extensive program of edits and verifications was used, including:

- Checks on world and U.S. retail coal prices, based on previous values, responses, and regional and technical knowledge
- Consistency checks
- Technical edits to detect and correct errors, extreme variability