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World Energy Projection System Plus Model Documentation 2010: Main Model

January 20, 2011

Energy Information Administration
Office of Integrated Analysis and Forecasting
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Washington, DC 20585

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1. Introduction

Purpose of This Report

The Main Model of the World Energy Projection System Plus (WEPS+) is a computer-based model that assesses the degree to which model system convergence has occurred and facilitates convergence. This report describes the version of the Main Model that was used in production of the world energy projections published in the *International Energy Outlook 2010* (*IEO2010*). The Main Model is one of 13 components of the WEPS+ modeling system. The WEPS+ is a modular system, consisting of a number of separate energy models that communicate and work together through the overall system model. These models are each developed independently, but are designed with well-defined protocols for system communication and interactivity. The WEPS+ modeling system uses a shared database (the "restart" file) that allows all the models to communicate with each other when they are run in sequence over a number of iterations. The overall WEPS+ system uses an iterative solution technique that allows for convergence of consumption and price to a simultaneous equilibrium solution.

This report documents the objectives, analytical approach and development of the WEPS+ Main Model. It also catalogues and describes critical assumptions, computational methodology, 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 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+ Main Model is used to evaluate and facilitate the convergence of the system at the end of a model run. This process is enabled by the communication mechanism associated with each of the demand, supply, and transformation models to achieve an overall equilibrium solution. The basic economic concept of dynamic markets is used to equilibrate prices with demand and supply. A second function of the Main Model is to facilitate calibration of WEPS+ projections to the Energy Information Administration's *Short-Term Energy Outlook* (*STEO*) world liquids consumption projections through 2011, proportionally distributing aggregated STEO petroleum consumption to the relevant WEPS+ regions and end-use sectors.

Model Archival Citation

This documentation refers to the WEPS+ Main Model, as archived for the *International Energy Outlook 2010* (*IEO2010*).

Model Contact

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Organization of This Report

Chapter 2 of this report discusses the purpose of the Main Model; its objectives and analytical issues; its general activities and relationships; its primary input and output variables, and its relationship to the other models in the WEPS+ system. Chapter 3 of the report describes the rationale behind the Main Model's design, providing further insight into assumptions utilized in the model. Chapter 4 describes the model structure in more detail, including flowcharts, variables, and equations.

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2. Model Purpose

Model Objectives

The primary objective of the WEPS+ Main Model is to test model convergence at the end of each WEPS+ system iteration. When convergence is not achieved, the Main Model facilitates convergence in future iterations by adjusting price estimates to bring them nearer to the equilibrium price. A second objective of the Main Model is to facilitate calibration of WEPS+ projections to the Energy Information Administration's *Short-Term Energy Outlook* (*STEO*) world liquids consumption projections through 2011, proportionally distributing aggregated STEO petroleum consumption to the relevant WEPS+ regions and end-use sectors.

As part of the WEPS+ system, the Main Model tests convergence for each of 16 WEPS+ world regions (Table 1). These regions consist of countries and country groupings defined either within or outside of the broad divide of the Organization of Economic Cooperation 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	China
OECD Europe	India
Japan	Other Non-OECD Asia
Australia/New Zealand	Middle East
South Korea	Africa
	Brazil
	Other Central and South America

Model Inputs and Outputs

Inputs

The Main Model relies on exogenous data sources input from the MainOutxx.txt, MainInput-JH121009.xml, and CtlItr.txt data files (Table 2).

Table 2 Main Model Input Data Series

Source Input File	Main Model Input
MainOutxx.txt	Projected annual fuel consumption by fuel type and end-use sector from the xx iteration of the model
	Projected fuel prices by fuel type and end-use sector from the xx iteration of the model
	Projected energy-related carbon dioxide emissions for each quantity of fuel consumed from the xx iteration of the model
MainInput-JH121009.xml	Tolerance factors for convergence of consumption
	Tolerance factors for convergence of price
	Liquids projections from the *Short-Term Energy Outlook*
CtlItr.txt	Maximum iterations allowed
	Current model iteration number
	Switch specification of whether model run is the final model run

Outputs

Upon completion of a Main Model run, results are exported into the WEPS+ restart file for use by other models (Table 3).

Table 3 Main Model Output and the WEPS+ Models that Use Them

Main Model Output	Destination
Portion of liquid fuels consumed in each end-use sector according the *Short-Term Energy Outlook* total consumption	Residential Model
	Commercial Model
	World Industrial Model
	International Transportation Model
	World Electricity Model
	District Heat Model
Fuel prices	Refinery Model
	Natural Gas Model
	Coal Model
	World Electricity Model
	District Heat Model

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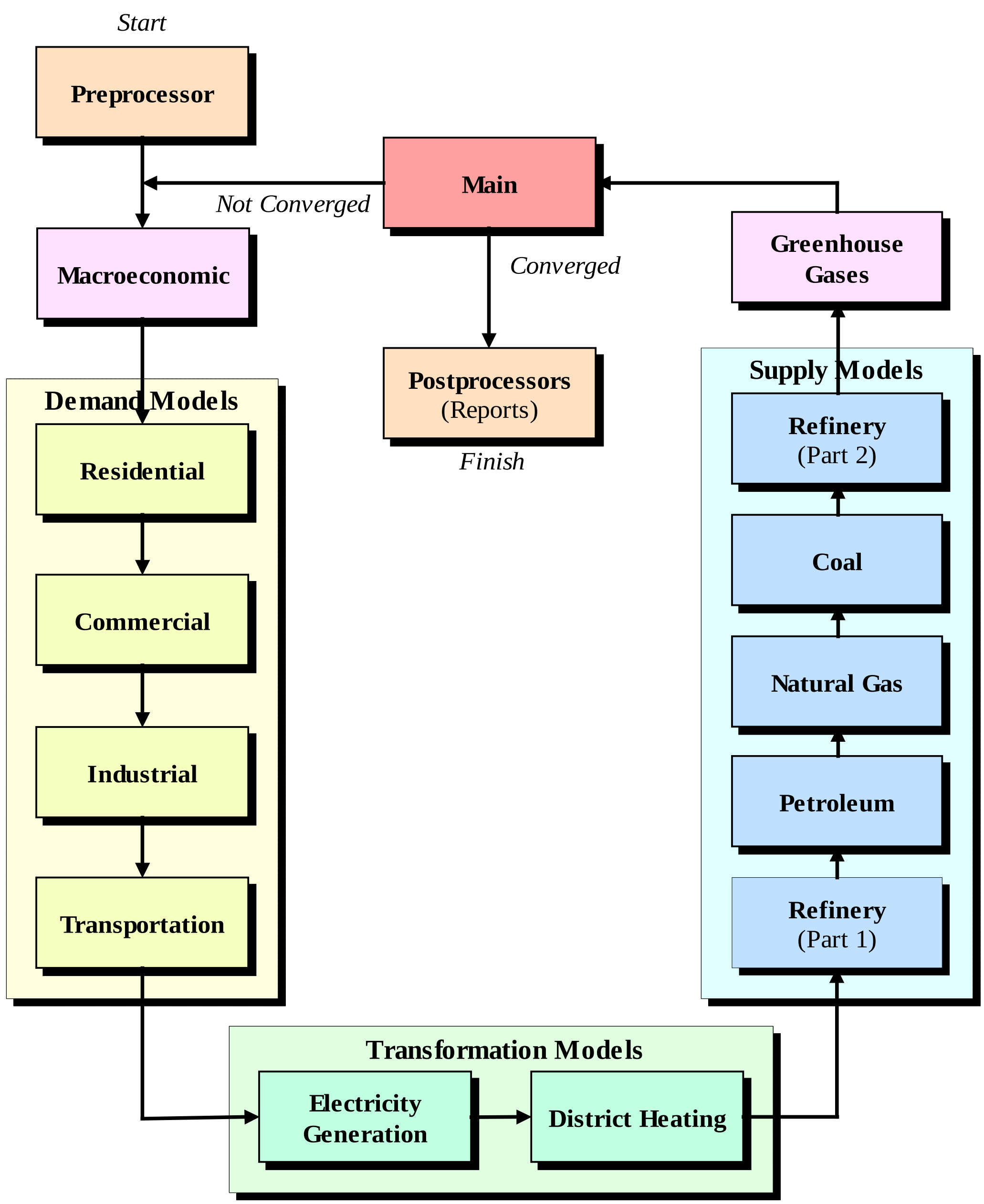
Relationship to Other Models

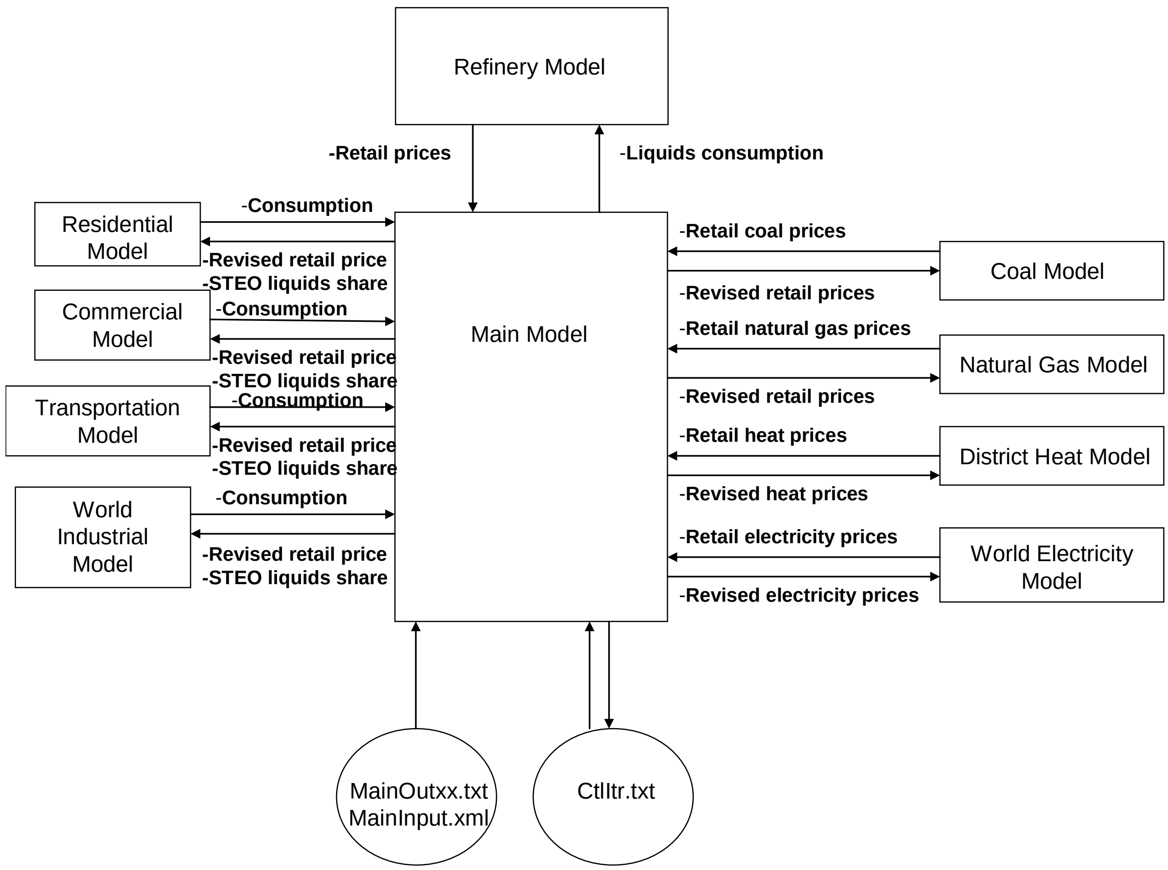
The Main Model determines whether the supply and demand models in WEPS+ system have converged to an equilibrium set of prices and quantities. If the system has not converged, another model iteration is required, and the Main Model provides a set of relaxed fuel prices for the next iteration to facilitate convergence. Thus, the Main Model provides key inputs to the other WEPS+ components (Figure 1). A summary description of the models, flows, and mechanics of the WEPS+ system used for the *IEO2010* report is available in a separate *Overview* document.

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



The Main Model exogenously receives assumptions and projections of gross domestic product, population, and gross output for 53 economic sectors. It provides these estimates (with some adjustments) to the WEPS+ demand models and the World Electricity Model (Figure 2).

Figure 2 The Main Model Relationship to Other WEPS+ Models



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3. Model Rationale

Theoretical Approach

The WEPS+ Main Model is used to evaluate and facilitate the convergence of the system at the end of a model run. This process is enabled by the communication mechanism associated with each of the demand, supply, and transformation models to achieve an overall equilibrium solution. The basic economic concept of dynamic markets is used to equilibrate prices with demand and supply. In the model process, this is straightforward for single relationships, but becomes much more complicated when all energy sources, end-use sectors, and regions are incorporated. A second function of the Main Model is to facilitate the STEO calibration process by allocating the aggregated STEO petroleum consumption to the relevant WEPS+ regions and end-use sectors.

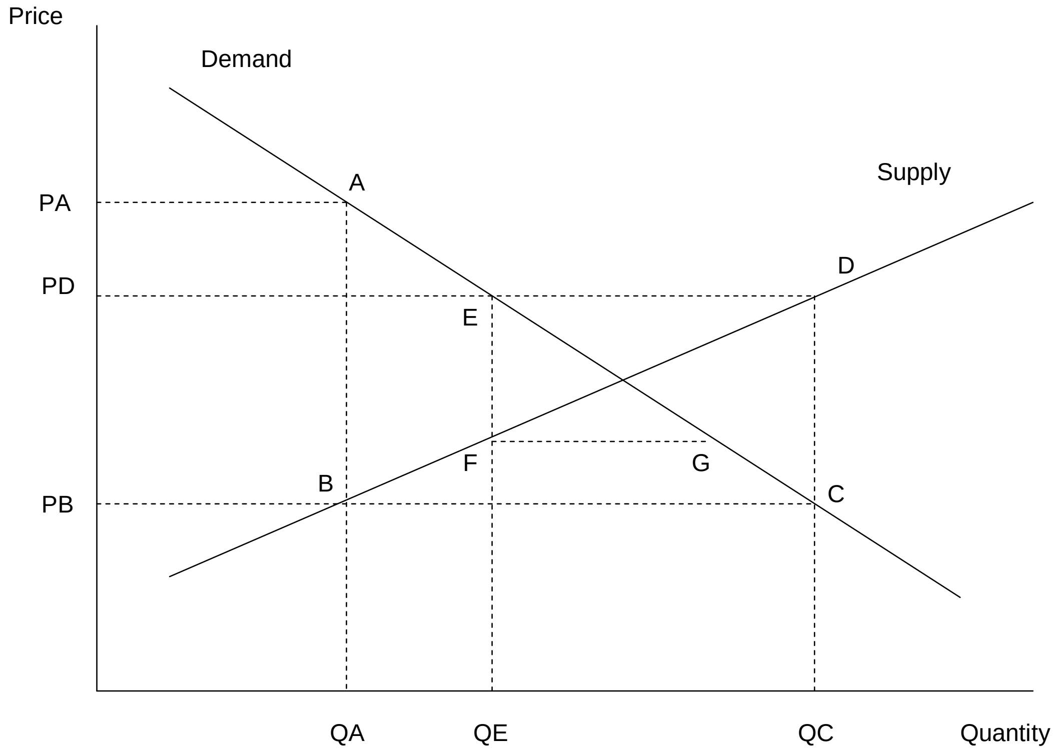
Fundamental Assumptions

The equilibrating process in WEPS+ is illustrated in Figure 3. The demand, supply, and transformation models relate consumption to prices on a demand curve and relate supply to prices on a supply curve. In WEPS+, the first models executed are the demand models, which begin with some assumed price from the restart file. In Figure 3, this would mean an initial price, PA, is used to estimate the appropriate quantity QA at the demand curve point A. Once the demand model has been used to solve for a quantity QA, that amount is exported to the restart file for subsequent use by the supply model.

When the supply model are executed, the QA demand is imported from the Restart file and the supply model determines from its supply requirements, that the price needed to supply QA is actually PB (at point B on the supply curve). The new price, PB, is exported to the restart file for use by the demand models in the next iteration of the system. At the end of the iteration, the Main Model is executed and determines whether a convergence of the quantities and the prices has been achieved. The quantities and prices from the previous iteration are compared to the QA and PB estimated in the current iteration. If QA is not sufficiently similar to the prior quantity and PB is not sufficiently similar to PA, the system has not achieved convergence and therefore begins another run of WEPS+, in which all the models are executed again.

In the next iteration, the demand model reads the price PB from the Restart file and the demand model calculates a new quantity, QC (this is at the point C on the demand curve) and exports that amount to the restart file. When the supply model is again executed, the QC quantity is imported and the model determines that the price PD (this is at the point D) is required to produce QC and PD is exported to the restart file. Again, at the end of the system iteration, the Main Model is executed and checks for convergence of quantities and prices. At the end of the previous iteration, the quantity was QA and the price was PB; now, at the end of this iteration, they are QC and PD. The differences are now smaller than they were after the last iteration, but are still deemed to be too large, so the system has not achieved convergence must be executed once more.

Figure 3 Illustration of Convergence in WEPS+



In the final iteration, demand is estimated to be at point E and on the demand curve and supply is estimated to be at point F on the supply curve. The differences between the starting points and the ending points for consumption and prices have narrowed substantially and the differences are smaller than the user-determined convergence "tolerance." The results are sufficiently close to the equilibrium point, so the model has achieved convergence. After the modeling system has converged, the post-processing tasks (i.e. report writing) are initiated.

The convergence process described above is a simplification of the WEPS+ system. In fact, the WEPS+ process also includes a price adjustment or "price relaxation" that facilitates model convergence when necessary. Price relaxation is done for two primary reasons. First, it is possible that the shapes of the demand and supply curves are such that it is not possible to reach convergence and, instead, supply and demand diverge (this depends on the relative elasticity of each curve). Price relaxation makes this less likely. Second, price relaxation can greatly reduce the number of iterations and speed the movement to convergence.

Price relaxation is used when the system has not converged and it is moving to the next iteration. Instead of using the price from the current iteration to start the next iteration, the Main Model estimates the equilibrium price and exports that estimate to the Restart file for use in the next system iteration.

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The following example illustrates the price relaxation technique. After the iteration in which the price has changed from PB to PD, the system would ordinarily start the next iteration with the price PD in the Restart file. But with price relaxation, instead of using the price PD, the Main Model estimates the equilibrium price by choosing the price that falls midway between PB and PD. The original price PD, which the supply model exported into the Restart file, is then replaced with this alternative midpoint price. This simple midpoint estimate allows the price to be much closer to the equilibrium price. When the demand model is then executed in the next iteration, the alternative, "relaxed" price will cause the demand to be much nearer to the equilibrium demand. Thus the price relaxation greatly accelerates the convergence process.

There are a number of additional complications in the WEPS+ system relative to the simplified convergence process discussed. First, the WEPS+ system does not consist of one single demand and supply curve, but instead consists of a large number of energy sources and end use sectors in 16 regions. Moreover, some of the demand and supply models may be interrelated and in some cases the supply models are solving for an aggregate over many demand sectors. Second, the actual convergence criteria that are used are based on an overall weighted average rating which can involve several fuels for a particular region or other aggregates. This is referred to as the convergence "GPA." The user determines the specifics of the convergence GPA and the convergence tolerance levels for the specific fuels and prices. Third, in each system iteration, the models in WEPS+ are run for all years over the projection horizon. This makes it much easier to code the models, making the models more independent and allowing each model to be run independently. As a result, the convergence checking is done for all projection years.

4. Model Structure

Structural Overview

The main purpose of the Main Model is to import projections of energy consumption, energy prices, and energy-related carbon dioxide emissions generated in the previous model iteration and compare them to the current iteration results to determine whether model convergence has been achieved. If convergence has not been achieved, the model calculates any required adjustments to the prices to accelerate the convergence process, and then exports the new prices to the shared restart file before another iteration is executed. In addition, the Main Model calculates the regional portions of liquids consumed by end-use sector, based on projections from EIA's *Short-Term Energy Outlook* through 2010, for use in the supply, demand, and transformation sector models.

The basic structure of the Main Model is illustrated in Figure 4. A call from the WEPS+ interface to the Main Model opens the restart file and initiates the ReadCtlItr and ReadLYr subroutines, which both import data from prior model iterations. ReadCtlItr imports data from the CurItr.txt file identifying the maximum number of iterations allowed, the current iteration number, and indicator of whether the final iteration has occurred. ReadLYr imports all consumption, price, and energy-related carbon dioxide projections from the previous model iteration from the MainOutxx.txt file.

After the "read" subroutines have completed, the Main Model calls the Converge subroutine (Figure 5), which tests for model convergence. The Converge subroutine begins by importing the consumption (or quantity) tolerances and price tolerances for each product number and region from the MainInput.xml file. Retail prices available from the restart file are next adjusted according to any carbon price scenario specified by the user (this feature was not used in the *IEO2010*.

Once the data imports have been completed, the Converge subroutine uses the following steps to calculate a convergence "grade point average" (GPA) for the quantities and prices:

- Compute proportional differences between the quantities/prices for the current model iteration and the corresponding values for the previous iteration.
- Divide the proportional differences by the imported tolerance for each product/price.
- Subtract the absolute value of this quotient from 5.

Summary measures (a simple average across time) of the GPAs are calculated on a worldwide, regional, and fuel/end-use sector basis. The regional ones are used to check for convergence. If all of the regional GPAs for quantities and prices are greater than 3.50, the model is deemed to have converged. If not, retail prices are revised to fall half way between the prices from the current model iteration and the previous one. Finally, the quantities, prices (revised or not), and carbon dioxide emissions from the current iteration are exported to a new MainOutxx.txt file that is associated with the current iteration.

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Once the Converge Subroutine has completed, Main Model determines whether a calibration to the *Short-Term Energy Outlook* (*STEO*) output is required. If it is, the model calls the STEOCalib subroutine. The subroutine begins by importing the latest *STEO* projection for regional liquids demand, from 2007 to 2011, from the MainInput.xml data file. The variable STEOLYr, representing the final year of the STEO projections (2011 for *IEO2010*), is also imported from the MainInput.xml file.

Next, the model begins the process of proportionally allocating the *STEO* regional projections to the WEPS+ regional aggregates and the end use sectors (excluding liquids for electric power). First the WEPS+ regional sectoral liquids consumption estimates are computed for the years 2008 to 2011. WEPS+ end use sector consumption for the *STEO* projection years are calibrated to the *STEO* total liquids consumption estimates. After the Main Model calculates *STEO*-based liquid consumption estimates at the sector level, it writes them to the restart file for use in the demand, supply, and transformation models.

The remaining subroutines that follow STEOCalib are all used to write reports or output to data files. The WriteCtlItr subroutine generates a new CurItr.txt file, for use in the next system iteration, identifying the maximum number of iterations allowed, the current iteration number, and indicator of whether the final iteration has occurred. After the WriteCtlItr subroutine has executed, the Main Model calls the WriteRestart subroutine, which writes projections to the restart file for use in future iterations of WEPS+.

Flow Diagrams

Figure 4. Flowchart for the Main Model

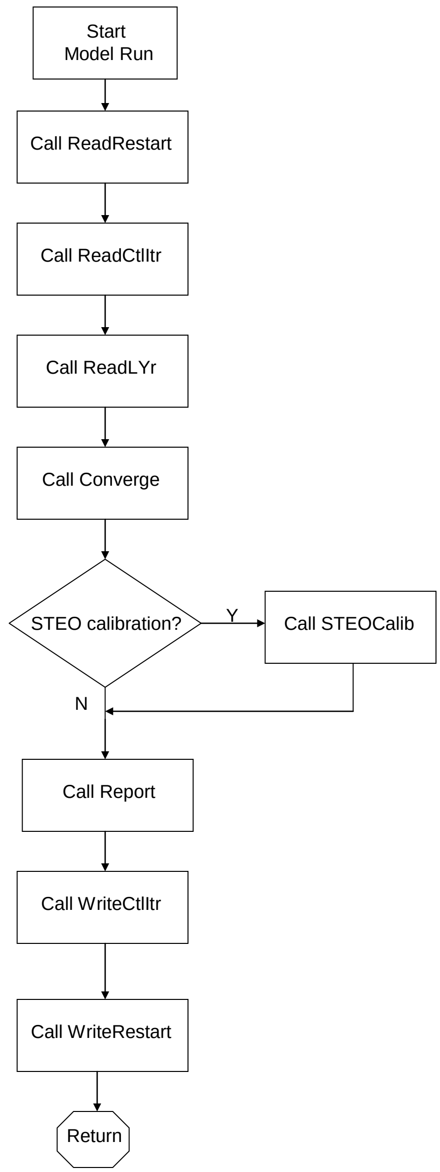

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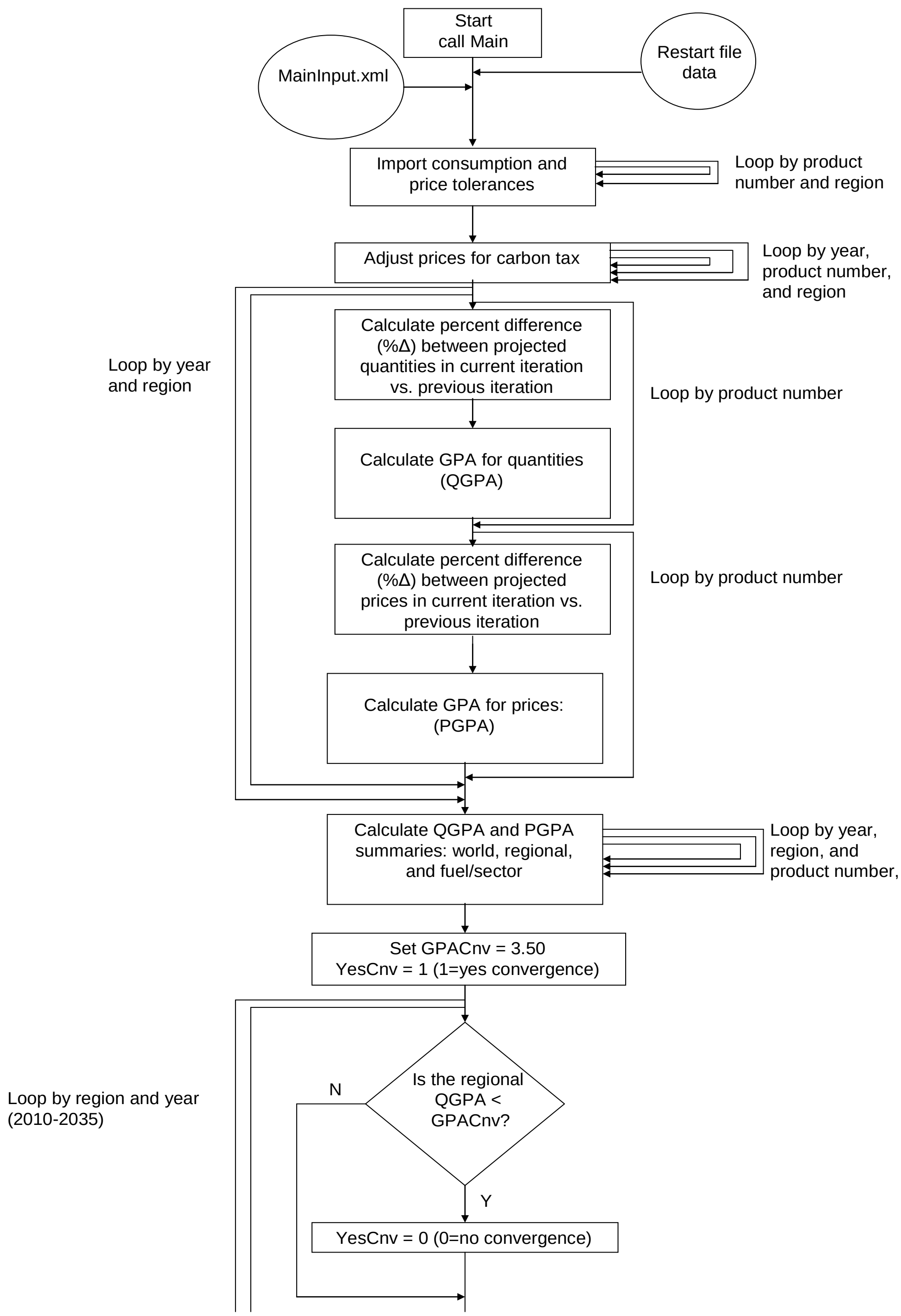
Figure 5. Flowchart for the Converge Subroutine



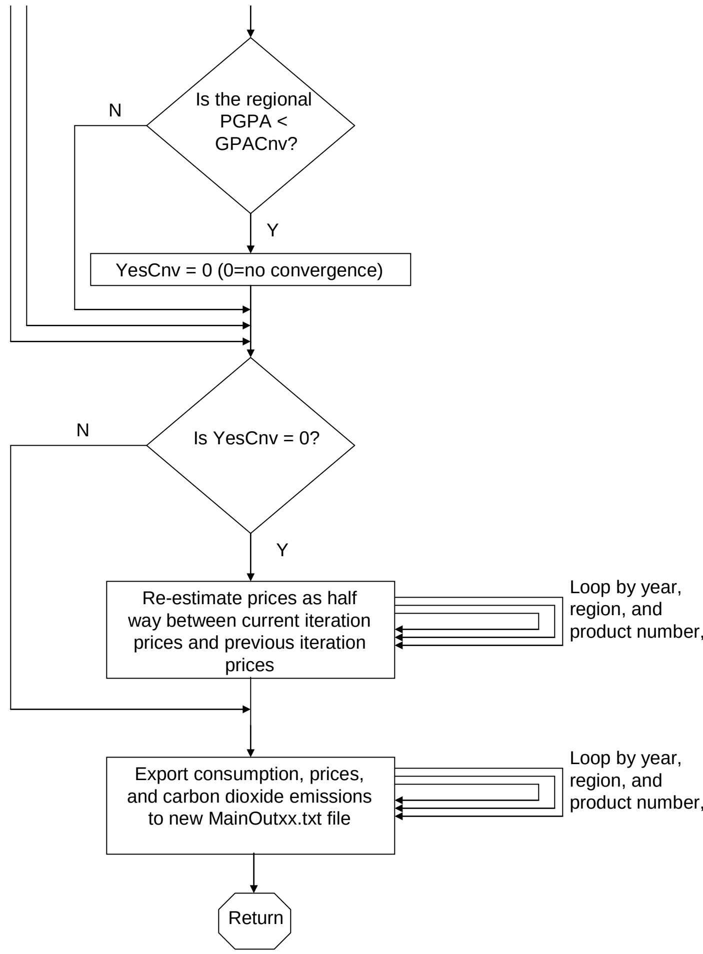
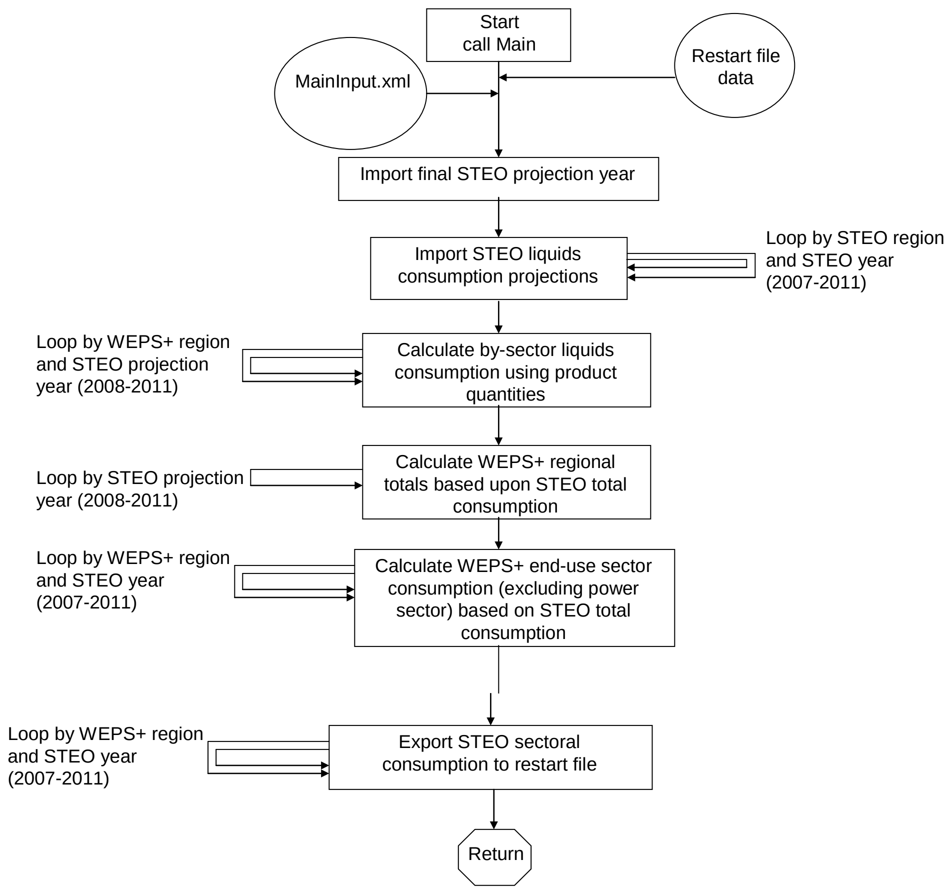

N
Is the regional PGPA < GPACnv?
Y
YesCnv = 0 (0=no convergence)
N
Is YesCnv = 0?
Y
Re-estimate prices as half way between current iteration prices and previous iteration prices
Loop by year, region, and product number,
Export consumption, prices, and carbon dioxide emissions to new MainOutxx.txt file
Loop by year, region, and product number,
Return

Figure 6. Flowchart for the STEOCalib Subroutine



Key Computations

Convergence Check

When the WEPS+ system is run, the system runs each model in sequence with the last being the Main Model. A single run of the complete system of models is referred to as one "iteration". A complete run could consist of several iterations (the iterative process) as the system attempts to "converge" to a simultaneous equilibrium solution as illustrated in the Model Assumptions section of this report. The WEPS+ system also has the capability to allow users to run individual models outside of the iterative process. A pre-processor is run before the iterative process begins and is typically used to set initial parameters and assumptions. After the iterative process completes, a post-processor is run to generate reports.

The specific sequence of model execution in WEPS+ is important, because each model uses results of models whose execution precedes it to calculate a new projection. The WEPS+ system uses the restart file as a common, shared database for communication between the models. The Residential Model, for instance, calculates residential sector energy consumption projections based on the prices imported from the restart file. In the first iteration, the prices in the restart file are the results of a previous run. Through additional iterations, these prices are adjusted based on the projection results from the supply models. In turn, the energy consumption projected by the Residential Model is used by the supply models to re-calculate prices.

In addition, the transformation models (the World Electricity and District Heat Models) use both the consumption projected by the demand models and the fuel prices adjusted in the supply models to calculate fuel consumption projections which are then used in the supply models. This exchange of data can be characterized as basically a set of demand curves and supply curves which, through a series of successive approximation, converge to an equilibrium solution.

The Main Model is run at the end of each WEPS+ iteration. It imports all the consumption and price projections from the restart file. All these values are results of the execution of all of the other WEPS+ models in a single iteration. The Main Model also imports all the consumption and price projections that were in the Restart file before the current iteration began and prior to the re-estimation of new projections. When a system run begins, the preprocessor imports consumption and price values from the existing version of the Restart file before the component models are run. At the end of each iteration, the Main Model creates a file called "MainOutxx.txt" containing all the current Restart file values, where "xx" denotes the iteration number associated with the current system execution. At the end of system run, all of these "MainOut" files are available and the user can track the evolution of the convergence process.

The Main Model thus has two sets of consumption and price projections: one from *before* the iteration began and one from *after* the iteration ended. The Main Model compares these two sets of consumption and price projections to determine the extent of the change that resulted from the model iteration. For each consumption and price value by fuel, region, and year, the proportional change in consumption and price are calculated:

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$$PCQty(f,r,y) = \left(\frac{ConBefore(f,r,y)}{ConAfter(f,r,y)} \right) - 1$$

$$PCPrc(f,r,y) = \left(\frac{PrcBefore(f,r,y)}{PrcAfter(f,r,y)} \right) - 1$$

where, for fuel *f* in region *r* and year *y*,

PCQty(f,r,y) = proportional change in consumption

PCPrc(f,r,y) = proportional change in price

ConBefore(f,r,y) = consumption estimate before the system iteration

ConAfter(f,r,y) = consumption estimate after the system iteration

PrcBefore(f,r,y) = price estimate before the system iteration

PrcAfter(f,r,y) = price estimate after the system iteration

The Main Model imports a set of convergence tolerance levels from an input file. These tolerances specify for each consumption and price value the amount of proportional change from iteration to iteration that is considered reasonable. These convergence tolerances are specified for each fuel in each region and for the *IEO2010* were typically set to be 0.02 (or about 2 percent) for both quantities and prices.

The degree to which the proportional change for each of the consumption and price values comes close to its tolerance level is measured in a value named the “grade point average” (GPA). This is a concept taken from the Energy Information Administration’s National Energy Modeling System (NEMS) and used in the WEPS+ Main Model, although the way it is calculated differs in some cases. If the tolerance level equals or exceeds the proportional change in a consumption or price projection, the GPA for that projection is set to 4.0. Otherwise, it is calculated as follows, and bounded to be no greater than 4.0 and no less than 0.0:

$$GPACon(f,r,y) = 5 - \left(\frac{PCCon(f,r,y)}{QTol(f,r,y)} \right)$$

$$GPAPrc(f,r,y) = 5 - \left(\frac{PCPrc(f,r,y)}{PTol(f,r,y)} \right)$$

where, for fuel *f* in region *r* and year *y*,

GPACon(f,r,y) = consumption GPA

GPAPrc(f,r,y) = price GPA

QTol(f,r,y) = consumption tolerance

PTol(f,r,y) = price tolerance

As an example, if the tolerance is 0.02 and the proportional change is 0.02 or less, the GPA is 4.0. On the other hand, if the proportional change is 0.04, then the GPA would be 3.0. Any proportional change greater than or equal to 0.10 would have a GPA of 0.0.

The GPAs are a convenient way to measure the degree of the convergence with respect to the tolerance level. To obtain overall measures of convergence, the model calculates summary GPAs for consumption and for prices. (The summary measures exclude categories for which the tolerance is not being considered, for example, the mostly exogenous consumption estimates for renewable energy sources, which are determined more by government policy than by price changes.)

The Main Model uses the GPAs to determine whether convergence has been achieved in the current iteration. The model used for the *IEO2010* determines if GPAs for consumption and price (over fuels, regions, and years) have reached a score of 3.5 or higher. If each has, then the system has converged and there will be an additional iteration solely for the purpose of "report writing." If the system has not achieved convergence, then it will continue with further iterations until it has converged or until it has reached the maximum number of iterations allowed. The Main Model communicates that the iteration is the final one by exporting the appropriate information to the output file, "CtlItr.txt." The system reads and acts upon this information.

If the modeling system has not achieved convergence and is going to continue with iterations, the Main Model adjusts ("relaxes") the prices to facilitate convergence. Calculated to shift the demand projections closer to the equilibrium point, the adjusted price for each fuel, region, and year lies halfway between the price at the start of the iteration and the price at the end of the iteration:

$$PrcNew(f,r,y) = \frac{PrcBefore(f,r,y) + PrcAfter(f,r,y)}{2}$$

where *PrcNew(f,r,y)* = the new relaxed price for fuel *f* in region *r* and year *y*.

Although this algorithm is fairly simple, it is very effective.

STEO Allocations for Sector Calibration

The EIA *Short-Term Energy Outlook* (*STEO*) projects international liquids consumption through 2011 by region. The *STEO* regions are more aggregate than in the WEPS+ regions, and *STEO* provides no sectoral or product detail. At the *STEO* aggregate levels, however, the *IEO2010* projections through 2011 are adjusted to replicate the *STEO* values. The Main Model imports the *STEO* liquids projections and allocates total regional liquids consumption to the more detailed WEPS+ regions and end-use sectors. The Main Model calculates the sectoral allocations and exports them to the restart file for use in the demand models and the District Heat Model. The

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power generation sector is not included in the allocation algorithm, because its consumption of liquid fuels is very small and because of the complex energy transformation structure simulated in the World Electricity Model.

The first step is to allocate the *STEO* consumption for the years 2008 through 2011 to the 16 WEPS+ regions. This is straightforward, because each of the nine *STEO* regions is a collection of all super-sets of the WEPS+ regions. For each year, the consumption from each *STEO* region is allocated to the WEPS+ regions it comprises in proportion to the WEPS+ regional projections.

Next, the model uses the WEPS+ consumption projections by end-use sector, within each WEPS+ region, to allocate the *STEO* consumption totals to the end-use sectors. Because the electric power generation sector is not included in the allocation, liquids consumption for electricity generation is first subtracted from the *STEO* total for each region and year:

$$RemSTEO(r,y) = TotSTEO(r,y) - WEPSSector(s = electricity, r, y)$$

where, for region *r* in year *y*,

TotSTEO(r,y) = total liquids consumption from *STEO*

WEPSSector(s=electricity,r,y) = liquids consumption from WEPS+ for electricity generation

RemSTEO(r,y) = remaining liquids consumption from STEO

Finally, the *STEO* liquids consumption is allocated according to each end-use sector based on the sector's consumption share, as estimated in WEPS+:

$$STEOSector(s,r,y) = TotSTEO(r,y) * \frac{WEPSSector(s,r,y)}{WEPSTot(r,y) - WEPSSector(s = electricity, r, y)}$$

where, for region *r* in year *y*,

STEOSector(s,r,y) = *STEO*-allocated liquids consumption for sector *s*

WEPSSector(s,r,y) = WEPS+ liquids consumption for sector *s*

WEPSTot(r,y) = total WEPS+ liquids consumption

The allocations of *STEO* consumption by end use sector, region, and year from 2008 through 2011 are written to the restart file for use by each component model to perform sector-level *STEO* calibration.

Appendix A. Model Abstract

Model Name:

Main Model of the World Energy Projection System Plus

Model Acronym:

None

Model Description:

The Main Model of the World Energy Projection System Plus (WEPS+) is a computer-based model that assesses the degree to which model system convergence has occurred and facilitates convergence.

Model Purpose:

The primary purpose of the WEPS+ Main Model is to test model convergence at the end of each WEPS+ system iteration. When convergence is not achieved, the Main Model facilitates convergence in future iterations by adjusting price estimates to bring them nearer to the equilibrium price. A second objective of the Main Model is to facilitate calibration of WEPS+ projections to the Energy Information Administration's *Short-Term Energy Outlook* (*STEO*) world liquids consumption projections through 2011. The model proportionally allocates aggregated STEO petroleum consumption to the relevant WEPS+ regions and end-use sectors.

Most Recent Model Update:

December 2009.

Part of Another Model:

World Energy Projection System Plus (WEPS+).

Model Interfaces:

From the WEPS+ restart file, the Main Model imports the outputs generated by a complete iterative cycle of the WEPS+ system. It checks to see whether an individual model iteration has achieved model convergence and, if it has not, facilitate convergence by adjusting retail end use sector prices for the next model cycle. The Main Model also imports liquids consumption projections from the Energy Information Administration's *Short-Term Energy Outlook* (*STEO*) through 2011 so that the model results may be calibrated to *STEO* projections in the WEPS+ demand and transformation models.

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Documentation:

Energy Information Administration, U.S. Department of Energy, *Main Model of the World Energy Projection System Plus: Model Documentation 2010*, DOE/EIA-M080(2010) (Washington, DC, August 2010).

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 2010*.

Energy System Described:

Evaluating model convergence of energy consumption and retail energy price projections.

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 Central and South America.

- Mode: grade point averages and regional end-use sector liquid fuels to 2011.

- Time Unit/Frequency: Annual, 2008 through 2035.

Modeling Features:

The WEPS+ Main Model is used to evaluate and facilitate the convergence of the modeling system. Driving this process is the basic economic concept of dynamic markets using prices to equilibrate demand and supply.

DOE Input Sources:

Energy Information Administration, International Energy Statistics Database, web site www.eia.gov/emeu/international (as of November 30, 2009).

Energy Information Administration, *Short Term Energy Outlook* (*STEO*), Washington, D.C., (January 2010 release).

Non-DOE Input Sources:

International Energy Agency (IEA), *Energy Balances of OECD Countries*, Paris, 2009.

International Energy Agency (IEA), *Energy Balances of Non-OECD Countries*, Paris, 2009.

Independent Expert Reviews:

None

Computing Environment:

Hardware/Operating System: Basic PC with Windows XP (or other Windows OS).

Language/Software Used: Fortran 90/95 (Currently using Compaq Visual Fortran), not required at runtime.

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.

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Appendix B. Input Data and Variable Descriptions

The following variables represent data input from the file MainOutxx.txt. (In some cases, different variable names have been used in the text of this document, for the sake of readability.)

Classification: Input variable.

QBak(x,r,y):	Quantity of fuel consumption by fuel type and end-use sector (73 different quantities) and by region and year (years 2005 through 2035)
PBak(x,r,y):	Price of fuel, according to fuel type and end-use sector (47 different prices) and by region and year (years 2005 through 2035)
EBak(x,r,y):	Energy-related carbon dioxide emissions for each quantity of fuel consumed (73 different quantities) and by region and year (years 2005 through 2035)

The following variables represent data input from the file MainInput-JH121009.xml.

Classification: Input variable.

QTol(x,r):	Consumption tolerance factor for each quantity (products by sector—73 total) and region
PTol(x,r):	Price tolerance factor for each price (by fuel and end-use sector—47 total)
STEOLYr:	Last year of the *Short-Term Energy Outlook* calibration routine (2010 for *IEO2010*)
SQty(r,y):	*STEO* liquids consumption projections by region and year (years 2007 to 2010).

The following variables represent data input from the file CtlItr.txt.

Classification: Input variable.

MaxItr:	The maximum number of model iterations allowed (specified by the user)
CurItr:	The current iteration the model is executing
RptItr:	Switch that identifies whether the current iteration is the final iteration (0=no, 1=yes)

The following variables represent data input from the Restart file.

Classification: Input variable from the demand models.

FConEqu(r,y,x):	Quantity of fuel consumption according to product number (by fuel and end-use sector—73 total), and by region and year
FPrcNum(r,y,x):	Retail prices of each fuel according to product number (by fuel and end-use sector—47 total), and by region and year
APrcEqu(r,y,x):	Carbon price adjustment according to product number (by fuel and end-use sector—47 total), and by region and year
DSMap(x):	Index to map each consumption quantity number to an end-use sector (1=residential; 2=commercial; 3=industrial; 4=transportation; 5=electric power; 6=district heat)
DFMap(x):	Index to map each consumption quantity number to one of 25 fuel types (1=motor gasoline; 2=distillate; …; 24=nuclear; and 25=hydrogen)
PSMap(x):	Index to map each price number to an end-use sector (1=residential; 2=commercial; 3=industrial; 4=transportation; 5=electric power; 6=district heat)
PFMap(x):	Index to map each price number to one of 25 fuel types (1=motor gasoline; 2=distillate; …; 24=nuclear; and 25=hydrogen)
QDSRS(r,y):	Distillate fuel consumption in the residential sector by region and year (years 2008 through 2010)
QKSRS(r,y):	Kerosene consumption in the residential sector by region and year (years 2008 through 2010)
QLGRS(r,y):	Liquefied petroleum gas consumption in the residential sector by region and year (years 2008 through 2010)
QMGCM(r,y):	Motor gasoline consumption in the commercial sector by region and year (years 2008 through 2010)
QDSCM(r,y):	Distillate fuel consumption in the commercial sector by region and year (years 2008 through 2010)
QRSCM(r,y):	Residual fuel consumption in the commercial sector by region and year (years 2008 through 2010)
QKSCM(r,y):	Kerosene consumption in the commercial sector by region and year (years 2008 through 2010)

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QLGCM(r,y):	Liquefied petroleum gas consumption in the commercial sector by region and year (years 2008 through 2010)
QMGIN(r,y):	Motor gasoline consumption in the industrial sector by region and year (years 2008 through 2010)
QDSIN(r,y):	Distillate fuel consumption in the industrial sector by region and year (years 2008 through 2010)
QRSIN(r,y):	Residual fuel consumption in the industrial sector by region and year (years 2008 through 2010)
QLGIN(r,y):	Liquefied petroleum gas consumption in the industrial sector by region and year (years 2008 through 2010)
QPCIN(r,y):	Petroleum coke consumption in the industrial sector by region and year (years 2008 through 2010)
QSPIN(r,y):	Sequestered petroleum consumption in the industrial sector by region and year (years 2008 through 2010)
QOPIN(r,y):	Other petroleum consumption in the industrial sector by region and year (years 2008 through 2010)
QCDIN(r,y):	Crude oil consumption in the industrial sector by region and year (years 2008 through 2010)
QETIN(r,y):	Ethanol consumption in the industrial sector by region and year (years 2008 through 2010)
QOBIN(r,y):	Other biofuels consumption in the industrial sector by region and year (years 2008 through 2010)
QMGTR(r,y):	Motor gasoline consumption in the transportation sector by region and year (years 2008 through 2010)
QDSTR(r,y):	Distillate fuel consumption in the transportation sector by region and year (years 2008 through 2010)
QRSTR(r,y):	Residual fuel consumption in the transportation sector by region and year (years 2008 through 2010)
QLGTR(r,y):	Liquefied petroleum gas consumption in the transportation sector by region and year (years 2008 through 2010)
QJFTR(r,y):	Jet fuel consumption in the transportation sector by region and year (years 2008 through 2010)

QSPTR(r,y): Sequestered petroleum consumption in the transportation sector by region and year (years 2008 through 2010)

QOPTR(r,y): Other petroleum consumption in the transportation sector by region and year (years 2008 through 2010)

QCDTR(r,y): Crude oil consumption in the transportation sector by region and year (years 2008 through 2010)

QETTR(r,y): Ethanol consumption in the transportation sector by region and year (years 2008 through 2010)

QOBTR(r,y): Other biofuels consumption in the transportation sector by region and year (years 2008 through 2010)

QDSPG(r,y): Distillate fuel consumption in the electric power sector by region and year (years 2008 through 2010)

QRSPG(r,y): Residual fuel consumption in the electric power sector by region and year (years 2008 through 2010)

QCDPG(r,y): Crude oil consumption in the electric power sector by region and year (years 2008 through 2010)

QDSDH(r,y): Distillate fuel consumption for district heat by region and year (years 2008 through 2010)

QRSDH(r,y): Residual fuel consumption for district heat by region and year (years 2008 through 2010)

QCDDH(r,y): Crude oil consumption for district heat by region and year (years 2008 through 2010)

The following variables represent data calculated in the subroutine STEOCalib.

Classification: Computed variable.

STEOPTRS(r,y): The portion of petroleum consumed in the residential sector based upon the *Short-Term Energy Outlook* projection by region and year (year 2008-2010)

STEOPTCM(r,y): The portion of petroleum consumed in the commercial sector based upon the *Short-Term Energy Outlook* projection by region and year (year 2008-2010)

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STEOPTIN(r,y): The portion of petroleum consumed in the industrial sector based upon the *Short-Term Energy Outlook* projection by region and year (year 2008-2010)

STEOPTTR(r,y): The portion of petroleum consumed in the transportation sector based upon the *Short-Term Energy Outlook* projection by region and year (year 2008-2010)

STEOPTPG(r,y): The portion of petroleum consumed in the electric power sector based upon the *Short-Term Energy Outlook* projection by region and year (year 2008-2010)

STEOPTHT(r,y): The portion of petroleum consumed for district heat based upon the *Short-Term Energy Outlook* projection by region and year (year 2008-2010)

The following variables represent data calculated in the subroutine Converge.

Classification: Computed variable.

QGPA(x,r,y): Grade point average for consumption convergence test by product number code (total of 73) and region and year

PGPA(x,r,y): Grade point average for price convergence test by price code (total of 47) and region and year

WQGPA(y): World summary consumption grade point average by year

WPGPA(y): World summary price grade point average by year

RQGPA(r,y): Regional consumption grade point average by year

RPGPA(r,y): Regional price grade point average by year

FQGPA(x,y): By fuel product consumption (total of 73) grade point average by year

FPGPA(x,y): By price (total of 47) grade point average by year

YesCnv: Switch to confirm convergence has occurred (0=no; 1=yes)

FPrcEqu(r,y,x): Calculated relaxed fuel price by region, year, and price product number, if convergence is not met

Appendix C. References

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

2. Franklin J. Stermole and John M. Stermole, *Economic Evaluation and Investment Decision Methods: Eleventh Edition* (Investment Evaluations Corporation, Lockwood, CO, 2006).

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

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

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

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

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Appendix D. Data Quality

Introduction

The WEPS+ Main Model is used to evaluate and facilitate the convergence of the system at the end of a model run. It is also used to facilitate calibration of WEPS+ projections to the Energy Information Administration's *Short-Term Energy Outlook* (*STEO*) world liquids consumption projections through 2011 proportionally distributing aggregated STEO petroleum consumption to the relevant WEPS+ regions and end-use sectors. These computations use the data elements as detailed in Appendix B of this report. Chapter 4 of this documentation ("Model Structure") details transformations, estimation methods, and data inputs required to implement the model algorithms. The quality of the principal sources of input data is discussed in this Appendix. Information regarding the quality of parameter estimates and user inputs is provided where available.

Source and Quality of Input Data

Sources of Input Data

- *STEO* – Short-term liquid fuel consumption from 2005 to 2011 are provided by region from EIA's *Short-Term Energy Outlook.* The *IEO2010* results are benchmarked to the STEO results from the January 2010 edition of the report.

- *International Statistics Database* – The Energy Information Administration provides historical data on international energy consumption by fuel type from 1980 through 2008. These data are used as the historical basis for all regional projections that appear in the *IEO2010*. While the numbers are continuously updated, WEPS+ used a "snapshot" of the database as it existed on November 30, 2009 as the source of its international data.

- *International Energy Agency* – The subscription site www.iea.org provides OECD and non-OECD balances and statistics databases by country, which include historical energy consumption data by end-use sector and product. These data are benchmarked to the historical aggregate energy consumption data provided in the Energy Information Administration's international statistical data base.

Data Quality Verification

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

- Consistency checks

- Technical edits to detect and correct errors, extreme variability