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World Energy Projection System Plus: Main Module

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1. Introduction

Purpose of This Report

The Main Model of the World Energy Projection System Plus (WEPS+) is a computer program that evaluates and facilitates convergence of the model system. 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 2017* (*IEO2017*). WEPS+ is a modular system, consisting of a series of separate energy models that are joined together through the overall system model in order to communicate and work with each other. These models are each developed independently, but are designed with well-defined protocols for system communication and interactivity. The WEPS+ modeling system uses a common and shared database (the “restart” file) that allows all the models to communicate with each other when they are run in sequence over multiple 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 Module. 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 Module 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 economic theory of dynamic markets underlies the methodology that modifies projected demand and supply until they reach equilibrium.

Model Archival Citation

This documentation refers to the WEPS+ Main Module, 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 Main Module; its objectives and analytical issues; its general activities and relationships; its primary input and output variables; and its relationship to the other modules in the WEPS+ system. Chapter 3 of the report describes the rationale behind the Main Module's design, providing further insight into 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+ Main Model is to test model convergence at the end of each model iteration. When convergence is not achieved, convergence in future iterations is facilitated by adjusting price estimates to bring them nearer to the equilibrium prices.

Model Inputs and Outputs

Inputs

The Main Model relies primarily on exogenous data sources that are input from the MainOutxx.csv, MainInput.xlsx, and CtlItr.txt data files (Table 1).

Table 1: 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.xml	Tolerance factors for convergence of consumption and price
CtlItr.txt	Maximum iterations allowed
	Current model iteration number
	Switch specification of whether model run is the final model run

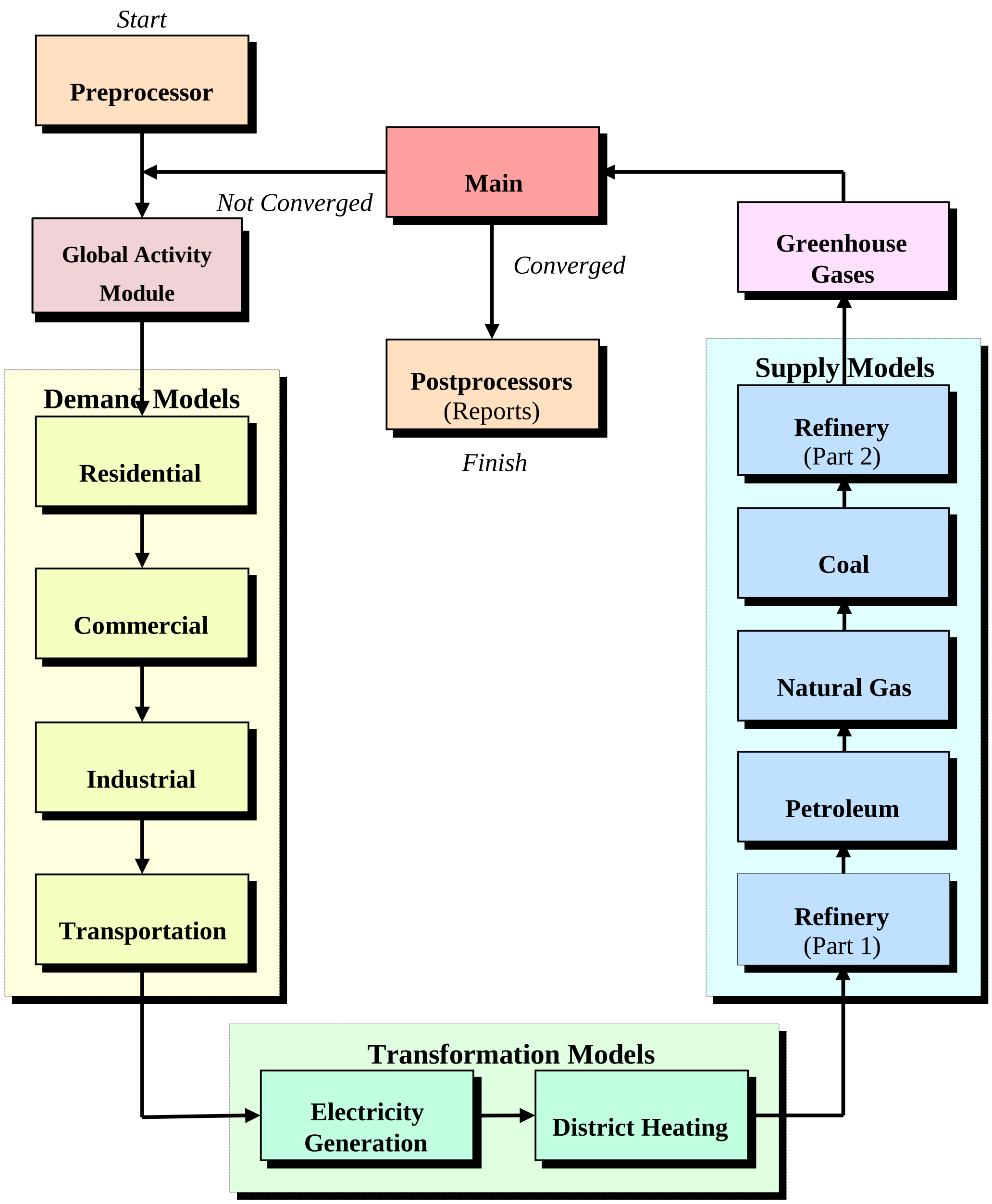
Outputs

Upon completion of a Main Model run, results are exported into the WEPS+ restart file for use by other models (Table 2).

Table 2: Main Model Output and the WEPS+ Models that Use Them

Source Input File	Main Model Input
Fuel Prices	Residential Model
	Commercial Model
	World Industrial Model
	International Transportation Model
	World Electricity Model
	District Heat Model
	Refinery Model
	Natural Gas Model
	Coal Model
	World Electricity Model
	District Heat Model

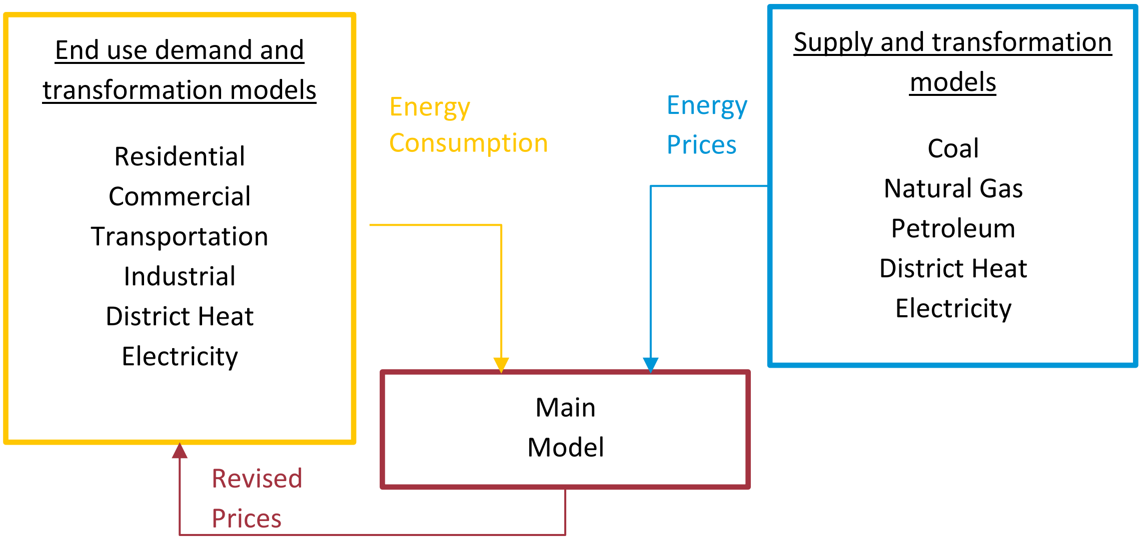
Figure 1: World Energy Projection System Plus (WEPS+) Model Sequence (Stylized)



Relationship to Other Models

The Main Model determines whether convergence has been achieved or if another model iteration is required. If another run is necessary, the Main Model provides a set of fuel prices that have been pre-estimated or "relaxed" to facilitate convergence in the next iteration. Thus, the Main Model provides key inputs to the other WEPS+ components (Figure 1, Figure 2). A summary description of the models, flows, and mechanics of the WEPS+ system used for the *IEO2017* report is available in a separate *Overview* documentation.

Figure 2: The Main Model Relationship to Other WEPS+ Models



3. Model Rationale

Theoretical Approach

The WEPS+ Main Model evaluates and facilitates the convergence of the WEPS+ 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 economic theory of dynamic markets underlies the methodology that modifies demand and supply projections until they reach equilibrium.

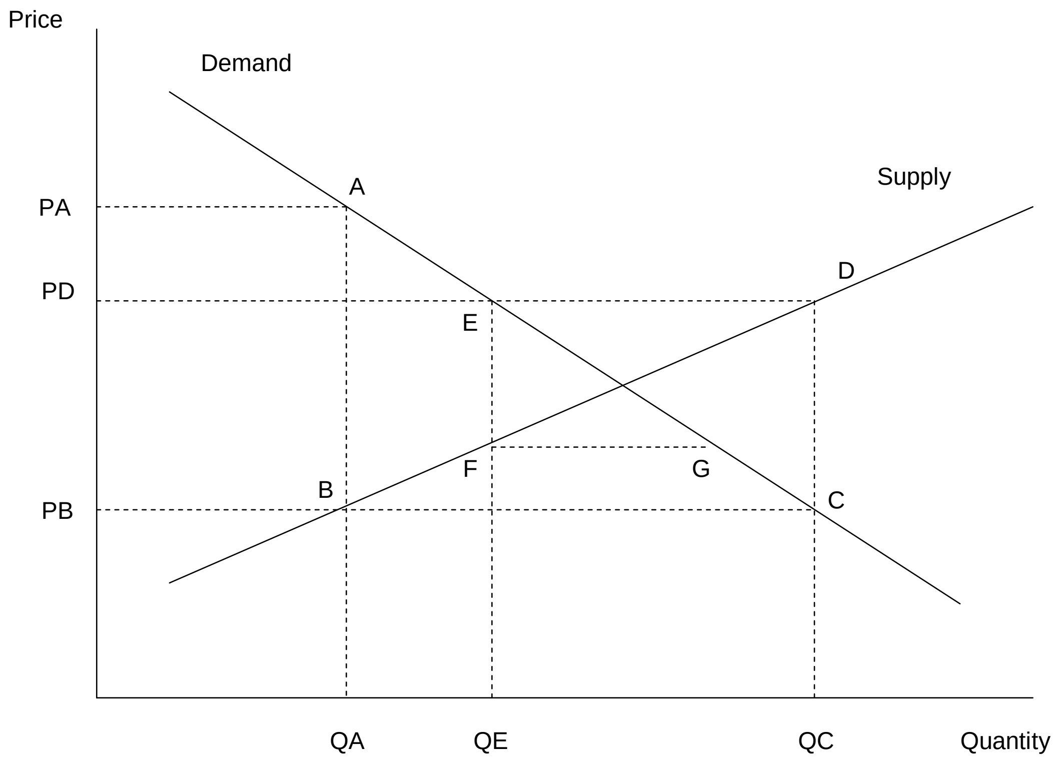
Fundamental Assumptions

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+, after the macroeconomic forecast is updated, the first models executed are the demand models, which begin with some assumed price from the Restart file. As illustrated 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 quantity is exported to the Restart file for subsequent use by the supply model.

When the supply model is 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 model in the next iteration of the model. 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. The system will begin another run of WEPS+, in which all the models will be executed again.

In the next iteration, after the macroeconomic forecast is updated, 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 quantity 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 quantity QC, and price PD is exported to the Restart file. Again, at the end of the system iteration, the Main Model is executed and a convergence check is made for quantities and prices. At the end of the previous iteration, the quantity was QA and the price was PB, and now at the end of this iteration they are QC and PD. The differences are now smaller than they were after the previous iteration, but are still too large, so the system has not achieved convergence, and the model system 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.” As a result, 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 equilibrium price pre-estimation 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 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 into the Restart file for use in the next system iteration. To explain the price relaxation technique, consider the illustration in Figure 3. Ordinarily, after the price has changed from PB to PD, the system would 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 exports 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, pre-estimated equilibrium price will cause the demand to be much nearer to the equilibrium demand and thus decreases the number of iterations needed for convergence.

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 represents 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 can be solving for an aggregate of many demands. 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 specifics of which are determined by the user, along with the tolerance levels for the specific fuels and prices. Third, in each system iteration, since the models in WEPS+ are run for all years over the projection horizon, the convergence checking is done for all projection years.

4. Model Structure

Structure Overview

The main purpose of the Main Model is to import projections of energy consumption and energy prices from 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 ease the convergence process and then exports the new prices to the shared restart file before another iteration is executed.

The basic structure of the Main Model is illustrated in Figure 4. The WEPS+ integrating program calls the Main model via the *main_run* function, which accepts the restart file and a list of user-specified keys as arguments. *main_run* sequentially calls several additional functions:

main_run first calls *ReadCtlItr*, which reads ctlitr.txt. This control file contains information about the maximum number of iterations and the current iteration.

main_run then calls *ReadLYr*, which reads main_outXX.txt, where the XX corresponds to the prior iteration number. This text file contains the energy price, energy quantity, and emission quantity values from the prior WEPS+ iteration.

main_run then calls *converge,* which compares the energy prices and energy quantities calculated in the prior iteration to the energy prices and quantities from the current iteration. *converge* reads tolerance values from maininput.xml, then calculates grade point averages (GPAs) for the prices and quantities. This is done by computing percent differences between the quantities/prices for the current model iteration and the previous one, divided by the tolerance for each product/price. Then the absolute value of this quotient is subtracted from 5.0. Summary GPAs are next calculated on a worldwide, regional, and fuel/end-use-sector basis.

In *convergecheck*, the regional GPAs are used to check for convergence. If the regional GPAs for quantities and prices are greater than 3.50, the model has converged. If not, retail prices are revised to fall halfway between the prices from the current model iteration and those from 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. *converge_writer* produces a log file.

main_run then calls *WriteCtlItr*, which is used to generate a new CurItr.txt file identifying the maximum number of iterations allowed, the current iteration number, and an indicator of whether the final iteration has occurred. *main_run* then calls a local report writer function (*summaryreport)* and executes the WriteRestart command. WriteRestart provides projections to the restart file for use in future iterations of WEPS+.

main_run returns an in-memory copy of the restart file to the integrating program.

Flow Diagrams

Figure 4: Simplified Flowchart for the Main Model

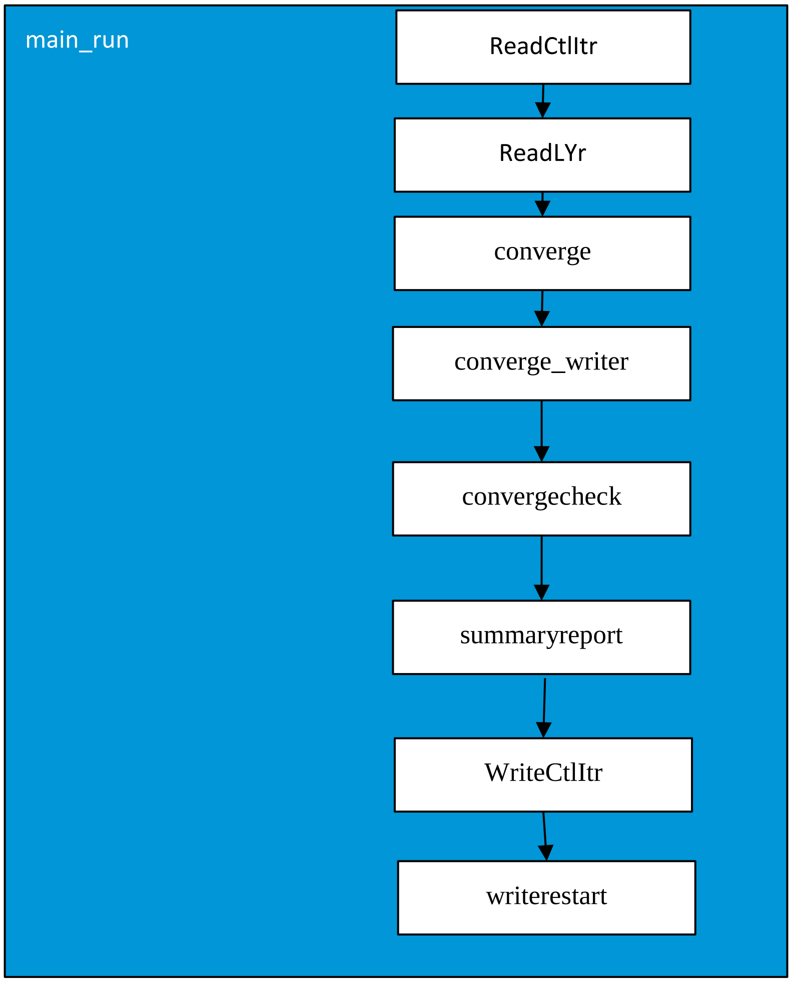
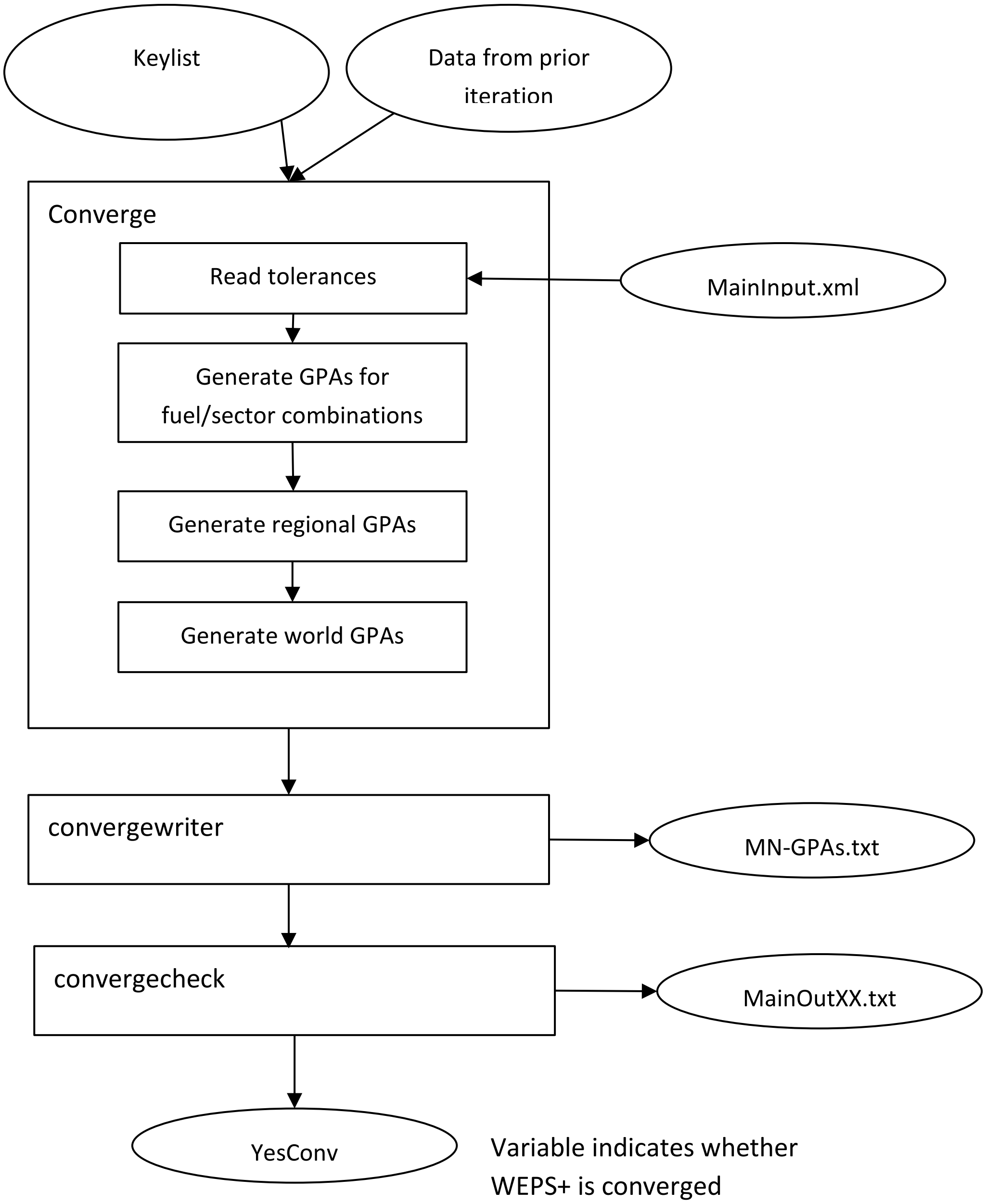


Figure 5: Flowchart for the Convergence functions



Key Computations

Convergence Check

The Main Model is the last model run by the WEPS+ system. A single complete set of model runs 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 model that is run before the iterative process begins is a pre-processor, typically used to set parameters and assumptions before the iterative process begins. A model that is run after the iterative process is a post-processor, typically used for generating reports.

The specific sequence of model execution in WEPS+ is important, because each model uses the results from the models that precede 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, but, as iterations are made, these prices are adjusted based on the results of executing 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 such as the World Electricity Model use both the consumption projected by the demand models and the fuel prices adjusted in the supply models to calculate fuel consumption, which is then used in the supply models. This exchange of data can be characterized as basically a set of demand curves and supply curves that are brought to an equilibrium solution through a series of successive approximations.

At the end of a model iteration, the Main Model is run. 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. When a system run begins, a preprocessor is used to import consumption and price values from the existing version of the Restart file before any model run occurs. At the end of each iteration, the Main Model creates the “MainOutxx.txt” file, which contains all the current Restart file values, where “xx” denotes the iteration number associated with the current system execution. At the end of a 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 the end of the iteration. These two sets of consumption and price projections are compared as part of the Main Model to determine the extent of the change of an individual value from one model iteration to the next. For each consumption and price value by fuel f, region r, and year y, the proportional changes in consumption and price are calculated. In the variable definitions for the following equations, we suppress the indices f, r, and y.

$$PCQty(f,r,y) = \left(\frac{ConBefore(f,r,y)}{ConAfter(f,r,y)}\right) - 1.0$$

$$PCPr\,c(f,r,y) = \left(\frac{PrcBefore(f,r,y)}{PrcAfter(f,r,y)}\right) - 1.0$$

where $PCQty$ and $PCPrc$ are the proportional changes in consumption and price, respectively;

$ConBefore$ and $ConAfter$ are the consumption values before and after iteration, respectively; and

$PrcBefore$ and $PrcAfter$ are the price values before and after iteration, respectively.

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 *IEO2017* 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 by 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 proportional change is equal to or better than the tolerance, then the GPA for that value is set at 4.0. Otherwise, it is calculated as follows, and bounded to be no greater than 4.0 and no less than 0.0:

$$GPACon(f,r,y) = 5.0 - \left(\frac{PCQty(f,r,y)}{QTol(f,r,y)}\right)$$

$$GPAPrc(f,r,y) = 5.0 - \left(\frac{PCPrc(f,r,y)}{PTol(f,r,y)}\right)$$

where $GPACon$ and $GPAPrc$ are the GPAs for consumption and price, respectively;

$QTol$ and $PTol$ are the tolerances for consumption and price, respectively.

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 determine the degree of the convergence, given the tolerance level. The model calculates aggregate summary GPAs for consumption and for prices (ignoring those categories for which the tolerance is not being considered, like the mostly exogenous renewable energy sources that are determined more by government policy than price changes) that give an overall measure of convergence.

The model uses the GPAs to determine whether convergence has been achieved in the current iteration. For the *IEO2017*, the model 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 model has converged and there will be an additional iteration solely for the purpose of "report writing." If the model 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 an iteration is a final one by exporting the appropriate information to the output file “CtlItr.txt,” which is then read and acted upon by the system.

If the modeling system has not achieved convergence and is going to continue with iterations, an adjustment is applied to facilitate convergence. This is done by the Main Model through a process of “relaxing” the prices, discussed above. Basically, since the model has not reached equilibrium, there is another set of prices that would shift the demand closer to the equilibrium point. The prices are relaxed by re-estimating them to be values halfway between the value at the start of the iteration and the value at the end of the iteration. Although this algorithm is fairly simple, it is very effective:

$$PrcNew(f,r,y) = \frac{PrcBefore\ (f,r,y) + PrcAfter\ (f,r,y)}{2.0}$$

where $PrcBefore$ and $PrcAfter$ are the price values before and after the iteration,

$PrcNew$ is the new relaxed price by fuel, region, and year.

Appendix A. Model Abstract

Model Name:
The 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 model iteration. When convergence is not achieved, convergence in future iterations is facilitated by adjusting price estimates to bring them nearer to the equilibrium prices.

Most Recent Model Update:
2017

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

Model Interfaces:
The Main Model uses 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, facilitates convergence by adjusting retail end use sector prices for the next model cycle.

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Documentation:
Energy Information Administration, U.S. Department of Energy, *Main Model of the World Energy Projection System Plus: Model Documentation 2017*, Washington, DC, October 2017.

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:

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

Coverage:

- Geographic: Sixteen WEPS+ regions: United States, Canada, Mexico/Chile, 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: grade point averages
- Time Unit/Frequency: Annual, through 2050.

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.

Input Sources:

The Main Model has no data sources of its own, and relies upon the WEPS+ restart file.

Independent Expert Reviews:

None

Computing Environment:

Hardware/Operating System: Basic PC with Windows.
Language/Software Used: Python 2.7 64 bit
Run Time/Storage: Standalone model with one iteration runs in about 3-4 seconds, CPU memory is minimal, inputs/executable/outputs require less than 100 MB storage.
Special Features: None.

Appendix B. 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. The documentation details transformations, estimation methodologies, and resulting inputs required to implement the model algorithms in Chapter 4: Model Structure.

Source and Quality of Input Data

Sources of Input Data

- The main model has no data sources specifically imported as part of this model.