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World Energy Projection System Plus Model Documentation 2011: Residential Model

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1. Introduction

Purpose of This Report

The Residential Model of the World Energy Projection System Plus (WEPS+) is an energy demand modeling system of the world residential end-use sector at a regional level. This report describes the version of the Residential Model that was used to produce the residential sector projections published in the *International Energy Outlook 2011* (*IEO2011*). The Residential Model is one of 13 components of the WEPS+ system and can also be run as a separate, individual model. The WEPS+ is a modular system, consisting of a number of separate energy models that are communicate and work with each other through an integrated system model. The model components 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 forces convergence of consumption and supply pressures to solve for an equilibrium price.

This report documents the objectives, analytical approach and development of the WEPS+ Residential Model. It also catalogues 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 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+ Residential Model for the *IEO2011* projects the amount of energy that is consumed by households. It does not include the energy consumed in household on-road transportation, which is covered by the WEPS+ Transportation Model. The Residential Model projects residential consumption for nine energy sources in each of the 16 WEPS+ regions, on an annual basis to 2035. The model primarily uses a dynamic econometric equation for the key energy sources, basing the projection on assumptions about future growth in gross domestic product (GDP), residential retail energy prices for seven fuels (although the model includes nine energy sources, the renewable energy sources—solar and biomass—do not have associated price paths), and a trend factor. The dynamic equation uses a lagged dependent variable to imperfectly represent stock accumulation. The GDP and price projections are available to the Residential Model from the WEPS+ Macroeconomic Model and the supply models through the restart file, which is shared by all WEPS+ models. The trend factor is meant to represent continuing impacts on energy use not directly represented in GDP and price, and may include a variety of behavioral, structural, and policy-induced activities. The consumption projections generated by the Residential Model are in turn put into the restart file for use by other models.

Model Archival Citation

This documentation refers to the WEPS+ Residential Model, as archived for the *International Energy Outlook 2011* (*IEO2011*).

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Organization of This Report

Chapter 2 of this report discusses the purpose of the Residential 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 Residential Model design, providing insights into further assumptions utilized 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+ Residential Model is to generate regional projections of household energy use. Annual projections by fuel type and region are computed for 2009 through 2035. As an integral component of the WEPS+ system, the Residential Model provides consumption inputs to the various transformation and supply models of WEPS+ and contributes to the calculation of the overall energy supply and demand balance. The consumption inputs are also used by the Greenhouse Gases Model to calculate energy-related carbon dioxide emissions.

As part of the WEPS+ system, the Residential Model provides projections for the 16 WEPS+ world regions (Table 1). These regions consist of countries and country groupings within the broad divide of the Organization of Economic Cooperation and Development (OECD) membership.

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

OECD Regions	Non-OECD Regions
United States	Russia
Canada	Other Non-OECD Europe and Eurasia
Mexico/Chile	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 Residential Model uses macroeconomic and residential price projections that are imported from the WEPS+ restart file. These inputs have been previously projected by the Macroeconomic Model and by various transformation and supply models (Table 2).

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

Residential Model Input	Source
Gross domestic product	Macroeconomic Model
Residential distillate retail price	Refinery Model
Residential kerosene retail price	Refinery Model
Residential LPG retail price	Refinery Model
Residential natural gas retail price	Natural Gas Model
Residential coal retail price	Coal Model
Residential electricity retail price	World Electricity Model
Residential district heat retail price	District Heat Model

A number of exogenous data series are also imported into the Residential Model from the ResInput.xml file (Table 3).

Table 3. Major Exogenous Residential Model Input Data Series

Source Input File	Model Input
ResInput.xml	GDP elasticities by fuel and region
	GDP lag coefficients by region and fuel
	Regional by-fuel price elasticities
	Regional by-fuel price lag coefficients
	Regional by-fuel growth trend terms
	User adjustment factors (not currently used)
	Regional by-fuel multiplicative factors applied to GDP and price elasticities (currently not used)
	Total liquids consumption (hard-wired into input file from Reference case run; only used in High Oil Price case)
	Increment of liquids that must be allocated to natural gas, coal, and electricity (this is only used in High Oil Price case, where fuel substitution out of liquids occurs under sustained high world oil prices)

Outputs

The Residential Model projects household energy consumption by fuel and region, excluding transportation energy use. Upon completion of a model run, these values are exported to the WEPS+ restart file for use by other models (Table 4).

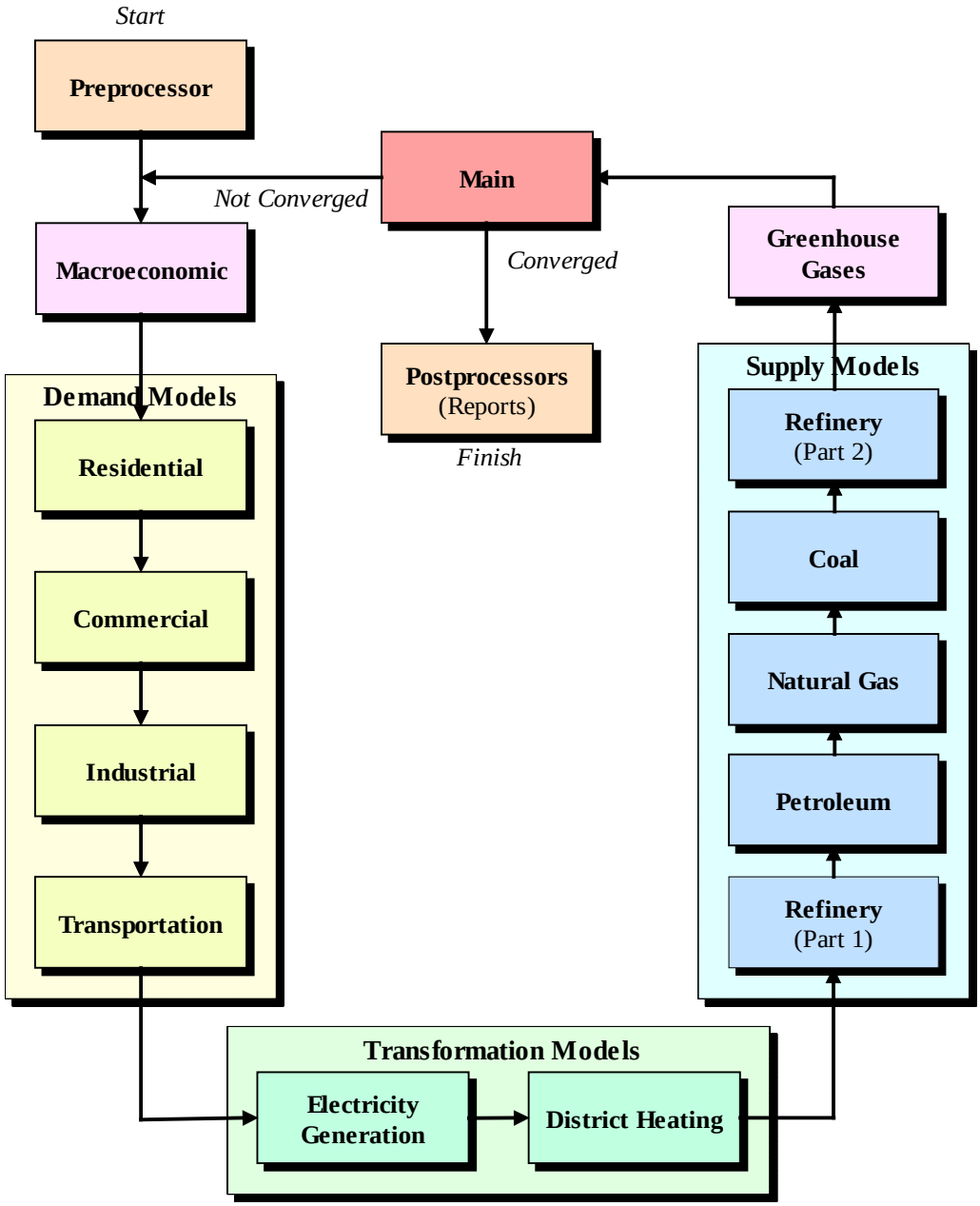
Table 4. Residential Model Outputs and the WEPS+ Models that Use Them

Residential Model Output	Destination
Distillate consumption	Petroleum Model and Refinery Model
Kerosene consumption	Petroleum Model and Refinery Model
LPG consumption	Petroleum Model and Refinery Model
Natural gas consumption	Natural Gas Model
Coal consumption	Coal Model
Electricity consumption	World Electricity Model
Heat consumption	District Heat Model
Biomass consumption	(Placeholder)
Solar consumption	(Placeholder)

Relationship to Other Models

The Residential Model is an integral component of the WEPS+ system, and it depends upon other models in the system for some of its key inputs. In turn, the Residential Model provides projections of energy consumption which other models in the system depend upon for their key inputs (Figure 1). A summary description of the models, flows, and mechanics of the WEPS+ system used for the *IEO2011* report is available in a separate *Overview* documentation.

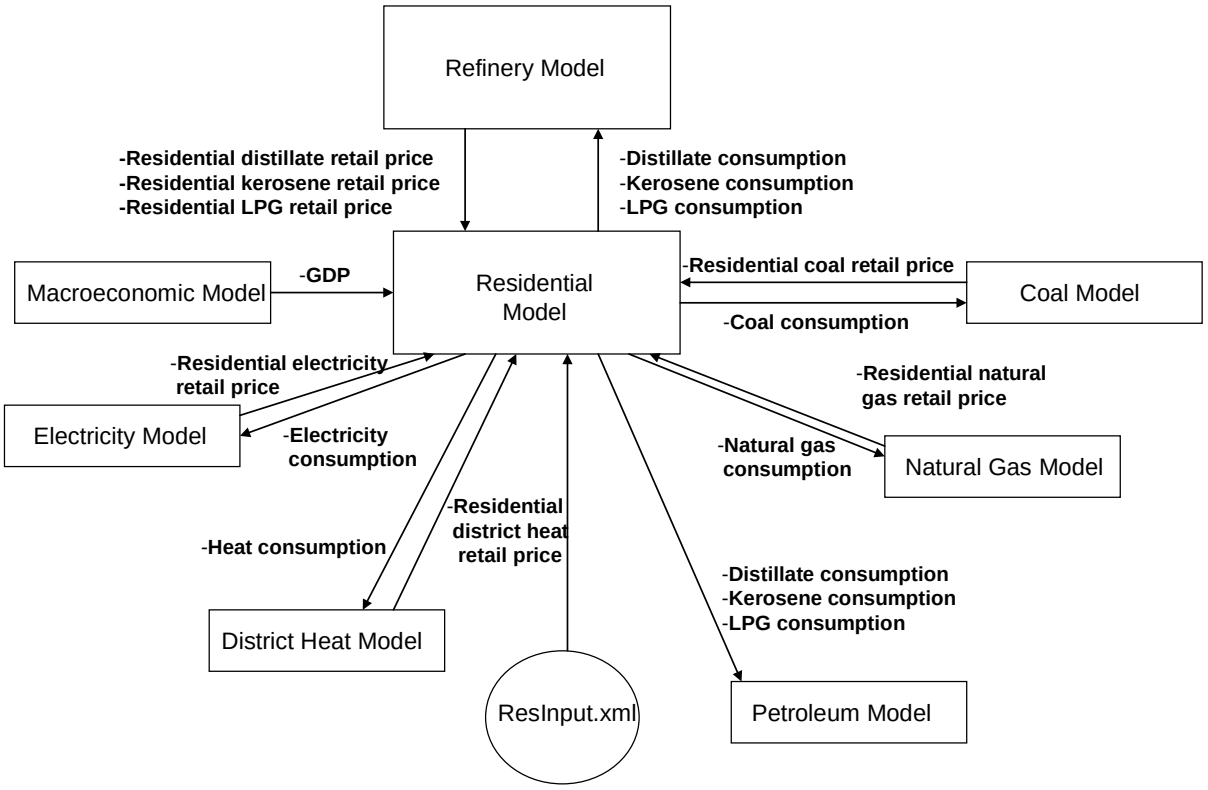
Figure 1 World Energy Projection System Plus (WEPS+) Model Sequence



Through the system, the Residential Model receives GDP projections from the Macroeconomic Model and a variety of residential retail price projections from various supply and transformation models (Figure 2). In turn, the Residential Model provides consumption projections, through the system, back to the various supply models.

Although the Residential Model is an integral part of the WEPS+ system, it can also be easily run as a standalone, outside of the system. In standalone mode, the Residential Model inputs macroeconomic and price projections from the WEPS+ system "restart" file created in a previous full system run.

Figure 2. The Residential Model Relationship to Other WEPS+ Models



3. Model Rationale

Theoretical Approach

The Residential Model makes projections of residential energy consumption based on projected changes in GDP, changes in energy prices, and an assumed trend. The model uses a set of coefficients computed using a dynamic simulation approach described in Appendix B. The estimation method assumes that residential energy consumption follows an overall trend while increasing with GDP and responding inversely to price changes. The overall trend represents behavioral, structural and/or policy-induced activities and is estimated exogenously from historical data.

Model Projections

The Residential Model makes projections of:

- Residential consumption, based on the assumption that changes in consumption are related to changes in GDP

- Residential sector energy prices, based on price elasticity measures that account for residential sector stock adjustments over time

4. Model Structure

Structural Overview

The main purpose of the Residential Model is to estimate annual residential sector energy consumption by region and fuel type from 2009 to 2035. The residential energy consumption calculations are based on regional estimates of GDP, residential fuel type prices, and adjustment trend factors. Consumption is estimated for each of the 16 WEPS+ regions for nine energy sources (distillate fuel, kerosene, liquefied petroleum gas, natural gas, coal, electricity, biomass, and solar energy).

The basic structure of the Residential Model is illustrated in Figure 3. A call from the WEPS+ interface to the Residential Model initiates importation from the restart file of the supporting information needed to complete the projection calculations. The Residential Model then executes the Resd subroutine, which is the major component of the model and the location in which all model computations are made. Finally, the model executes the subroutine to export all projections to the restart file for use by other WEPS+ models.

The Resd subroutine (Figure 4) is initiated by a call from the main Residential Model. There are several exogenous data series that are required in the model. The Resd subroutine begins by initiating a call of the RInXML subroutine (Figure 5) to import data from the ResInput.xml data file. The ResInput.xml data file includes:

- The economic (GDP) and price elasticities and lag coefficients associated with regions, fuels, and years

- Multiplicative and shape and elasticity adjustment factors that are associated with each region and projection year and used if a user-specified adjustment based upon expert judgment is to be incorporated into the projection

Once all of these data series are imported, the routine recalculates the GDP and price elasticity factors by incorporating any shape-and-elasticity adjustment factors. The adjustment factors were not used for *IEO2011* model runs.

After the RInXML subroutine has executed, the Resd subroutine begins to compute residential energy consumption projections by fuel. First, GDP and residential price and trend indices are computed across the projection period by region and fuel. Next, an overall residential quantity index is calculated as the product of the GDP, price, and trend indices. If additional user-initiated adjustments are required, an adjustment index is calculated, and the overall residential quantity index is recalculated to incorporate the adjustment. Projections of residential energy consumption by fuel, region, and year are calculated using the overall index, and then recalculated again with any user-specified multiplicative factors.

Once regional residential energy consumption is calculated, Resd determines whether a High Oil Price case is being implemented. If so, two additional data series are imported from the ResInput.xml file: total liquids consumption by region and year from the Reference case projections, and a factor that indicates the portion of liquids that will be allocated to natural gas,

coal, and electricity. These amounts are then calculated and allocated to the total residential natural gas, coal, and electricity projections. Finally, residential liquids consumption by region is calculated and then benchmarked to regional *Short-Term Energy Outlook* projections through 2012 (in the case of the *IEO2011*, the March 2011 release was used), and several output files are generated and returned to the main Residential Model routine.

After the Resd subroutine has executed, the WriteRestart subroutine is executed. WriteRestart provides projections to the restart file for use in future iterations of WEPS+, notably in the refinery model. These output data series include projections of regional residential energy use by fuel.

Flow Diagrams

Figure 3. Flowchart for the Residential Model

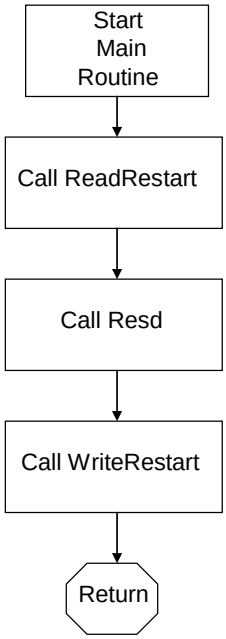


Figure 4. Flowchart for the Resd Subroutine

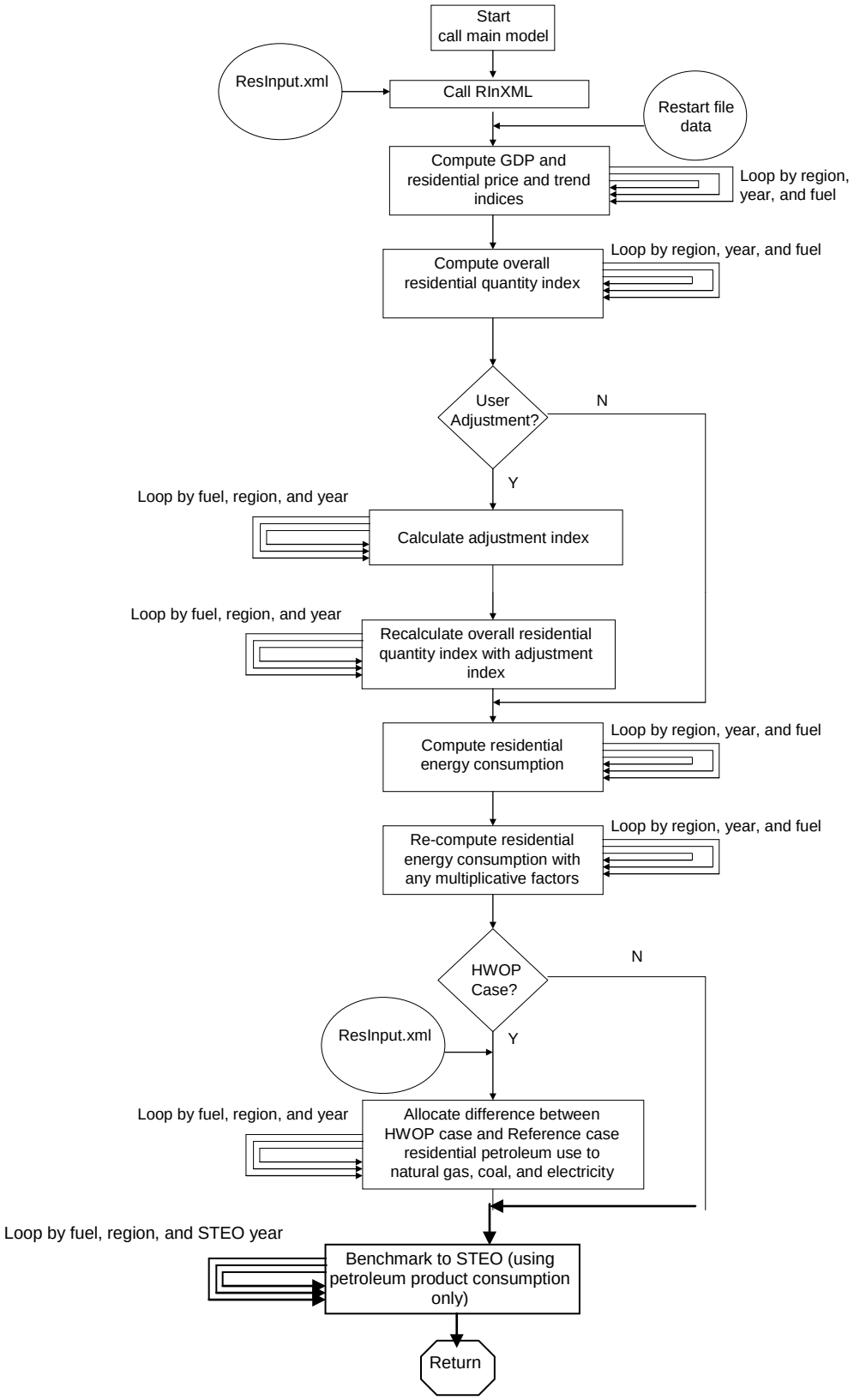
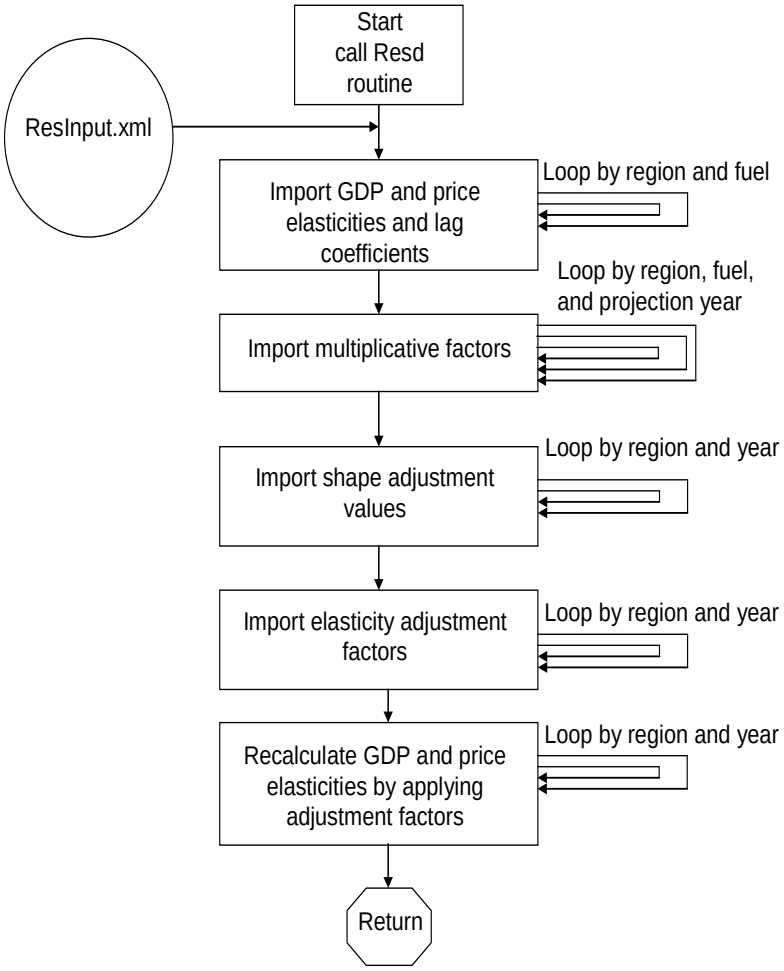


Figure 5. Flowchart for the ResInXML Subroutine



Key Computations

The WEPS+ Residential Model projects the amount of energy that is consumed either in households or in a direct relationship to households. It does not include the energy consumed in household on-road transportation. The model projects residential consumption for a number of energy sources in each of the 16 WEPS+ regions over the projection horizon to 2035. The residential model projects energy consumption for nine energy sources:

1. Distillate fuel

2. Kerosene

3. LPG

4. Natural gas

5. Coal

6. Electricity

7. Heat

8. Biomass

9. Solar

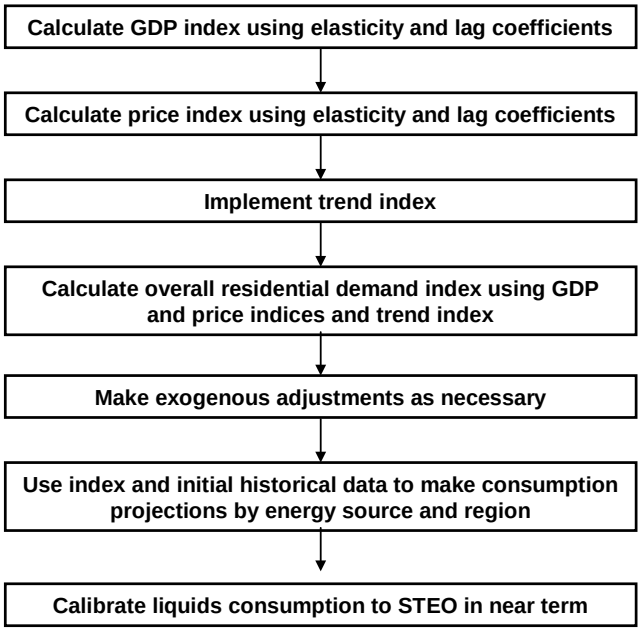
The Residential Model begins by importing the historical data that is available to it in the common, shared restart file. This historical data, compiled from the International Energy Agency's *OECD* and *Non-OECD Statistics and Balances* databases, which have detailed data on energy end-use consumption in the residential sector. The Residential Model calibrates these data to match the more aggregated energy consumption data that are available from the Energy Information Administration's International Statistics Database. These data are processed prior to the execution of the Residential Model, and have been stored in the restart file to provide a common starting point for all WEPS+ models. The Residential Model uses the data available to it to the last historical year (2008 in the case of the *IEO2011*), for each of the 16 regions and nine energy sources.

Macroeconomic and price projections are also imported into the Residential Model from the restart file. These data series are projected in previous system iterations by the Macroeconomic Model and by various transformation and supply models (see Table 2).

Projection Equations

Figure 6 provides a flowchart of the major computations of the Residential Model. Each of these processes is discussed in greater detail in the subsequent text. The Residential Model primarily uses a dynamic econometric-type equation for the key energy sources, basing the projection on a GDP projection, residential retail energy prices for seven fuels (no prices are included for biomass or solar energy sources), and a trend factor. The dynamic equation uses a lagged dependent variable to (imperfectly) represent stock accumulation. The GDP projection is available to the Residential Model from the WEPS+ Macroeconomic Model through the common, shared restart file. The GDP projections are expressed in terms of purchasing power parity in real 2005 dollars. The by-fuel price projections are available to the residential model from the WEPS+ supply models. These too are imported from the common, shared restart file. The prices are all in terms of real 2009 dollars per million Btu. By-fuel prices are not available for biomass or solar energy. The trend factor is meant to represent continuing impacts on energy use not directly represented by GDP and/or price, and may include a variety of behavioral, structural, and policy-induced activities.

Figure 6. WEPS+ Residential Model Basic Flows



The variables used in the projection equations are all expressed in terms of indices representing change relative to the initial residential consumption levels of 2008. This eliminates the need for an intercept in the projection equation. The indexing also allows the model to consider only the changes in the GDP and prices, not their actual levels. The three drivers of the projection, GDP, prices, and the trend term, are each projected forward independently. Then all three indices are applied to the 2008residential consumption levels to make the projections.

GDP Index Equation

An index is created for GDP in each year. This index gives its value relative to the last historical year, LHYr:

$$GDPI(r,y) = \frac{GDP\_PPP(r,y)}{GDP\_PPP(r,y = LHYr)}$$

The GDP index equation is calculated for each fuel and region and is given by:

$$GDPIdx(f, r, y) = \exp(GDPElas(f, r) * \ln(GDPI(r, y)) + GDPLag(f, r) * \ln(GDPIdx(f, r, y-1)))$$

Where: *GDPIdx* is the index relating changes in GDP to changes in residential energy consumption

GDPI is the index for GDP

GDPElas and *GDPLag* are exogenous coefficients for the GDP and for the lag term

The index *GDPIdx* starts with a value of 1.0 in the last historical year (2008). The two coefficients, *GDPElas* and *GDPLag*, are read in from an input file, and both can vary by region and by fuel.

For a cleaner notation, the subscript *r* indicating region is suppressed. For each region, the index representing the effect of GDP changes on the change in residential consumption of fuel *f* for year *y* is calculated as

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Where: = GDP for year *y*, expressed in purchasing power parity;

is a parameter indicating the effect of the lagged value of the parameter for fuel *f* on the current value; and

is an elasticity parameter indicating the impact of the GDP ratio on the residential consumption index for fuel *f*. (For example, indicates no effect of GDP change on residential energy consumption, while indicates a strong effect.)

The index is initialized by setting so can also be written simply as product of the exponentiated GDP ratios:

The parameters and are estimated exogenously from historical data as discussed in Appendix B. In practice, , and . Thus the effect of previous values of on current values is gradually dampened, while the effect of GDP change on the residential energy consumption index varies considerably by fuel and region.

The calculation above is performed within each region, and the index series vary by region.

Price Index Equation

A price ratio is computed for each retail residential price in each year *y*, region *r*, and fuel *f* indicating the change from the last historical year (2008) to year *y*:

Because the oil price spike of 2008 is an outlier to the general price trend, the *RetailPrice* in 2008 is set equal to the average of the *RetailPrices* in 2007 and 2009.

The price index equation for each region and each fuel is given by:

$$PrcIdx(f,r,y) = \exp(PrcElas(f,r) * \ln(RPIdx(f,r,y)) + PrcLag(f,r) * \ln(PrcIdx(f,r,y-1)))$$

Where: *PrcIdx(f,r,y)* is the index for the price-influenced part of the projection

RPIdx(f,r,y) is the ratio above

PrcElas and *PrcLag* are exogenous coefficients for the price and for the lag term, estimated as described in Appendix B.

The index *PrcIdx* starts with a value of 1.0 in the last historical year (2008). The two coefficients, *PrcElas* and *PrcLag*, are read in from an input file, and both can vary by region and by fuel. There are prices for all of the fuels except for solar and biomass. The corresponding "own price" is used in the equation for each of the corresponding quantity indices.

Trend Index

The trend "coefficient", TrendGR, is read from an input file as an annual growth rate that is applied beginning in a specific year of the projection period and carried through 2035. Its value can vary by region and by fuel. The growth rate is used to calculate the trend index term for the last model year of 2035 by applying the growth rate over the period from the last historical year (2008) to the last model year (2035). The index begins in 2008 with a value of 1.0. Once the implied value for 2035 has been calculated, the model fills in all the intervening years by using a straight line interpolation. This is given by:

For years from 2008 to 2034:

Overall Projection Index

The overall projection index for each region and fuel is calculated by multiplying each of the GDP, price, and trend indices, and is given by:

$$RQIdx(f,r,y) = GDPIdx(f,r,y) * PrcIdx(f,r,y) * EffIdx(f,r,y)$$

Where: *RQIdx(f,r,y)* is the overall projection index for region *r* and fuel *f* in year *y*.

Exogenous Inflection Algorithm

At this point in the model run, the projection consists of an index that was based upon the GDP projection, the price projection, and a trend. The trend projection was based on a target in 2030 and a straight line interpolation between 2008 and that target. In most cases this represents a reasonable approach to a long-term trend. However in some cases, the straight trend might not be appropriate for the particular projection, and there is some other structural or behavioral trend needed. For example, a specific fuel in a specific region might have been recently growing very rapidly and may therefore be expected to reach saturation, resulting in a moderation in the trend. The model allows the user to modify the projection index by adding an exogenous inflection to the projection index.

To accomplish this, the user specifies the year for the midpoint of the inflection and a fraction indicating the strength of the inflection. The fraction would be a number such as 1.1, indicating that in the specified year the projection index should be 1.1 times its original value. A value of 1.0 has no effect, and a value of 0.9 means it should be 0.9 times its original value. The algorithm then will also modify all the other projection index points so that it is smoothed on each side from the original values in 2005 and 2030. In other words, if the point of inflection is at 2010, then the values from 2006 through 2009 are smoothed based upon the values in 2005 and 2010, and the values from 2011 through 2029 are smoothed based upon the values in 2010 and 2030.

The smoothing uses a simple algorithm based upon the sine function so that the nearer points to the point of inflection are proportionally closer to the amount of inflection and they drop off slowly as the end points are reached. This approach is meant to approximate a spline without the complexity of the calculation.

For the *IEO2011* Reference case, exogenous inflection factors were used for adjusting fuel projections for the following regions, fuels and years:

- Mexico/Chile electricity in 2015, inflection factor = 1.10
- OECD Europe electricity in 2012, inflection factor = 1.10
- Australia/New Zealand electricity in 2012, inflection factor = 1.10
- Russia natural gas in 2020, inflection factor = 0.90
- China electricity in 2010, inflection factor = 1.04
- India distillate in 2013, inflection factor = 1.15
- India kerosene in 2012, inflection factor = 1.15

- India LPG in 2013, inflection factor = 1.15
- India electricity in 2009, inflection factor = 1.30
- Middle East distillate in 2010, inflection factor = 1.10
- Middle East kerosene in 2010, inflection factor = 1.10
- Middle East LPG in 2010, inflection factor = 1.10
- Other Central and South America electricity in 2010, inflection factor = 1.04

Exogenous inflection factors therefore affect 13 out of the 144 *IEO2011* Reference case series (nine fuels multiplied by 16 regions).

Consumption Projection

Finally, the projection indices are used along with the historical starting consumption value to project consumption over the projection horizon.

Where: *RQIdx* is the overall projection index in each region, for each fuel, over the projection horizon

HQty is the historical consumption in 2008 by region and fuel

RQty is the resulting consumption projection over the projection horizon by region and fuel

The above equation is for all fuels except biomass and solar. The consumption of biomass and solar is not part of the equation primarily because there are no prices for solar and biomass, but also because they are very minor in the context of the data being used. Very little solar is being used, and although there are large amounts of biomass being used in some regions, the Energy Information Administration international data which form the basis for the current data do not include estimates of non-marketed biomass.

Adjustment Factors

In order to provide flexibility and allow user control over the projections, the input file has factors that can be used to adjust consumption estimates for any fuel in any region in any year. This algorithm simply multiplies the projected consumption value for the selected fuel, region, and year by the user-specified factor. This function is not generally used, and was not used for the *IEO2011*.

High World Oil Price Fuel Substitution

In the High Oil Price (HWOP) case, the level of petroleum consumption declines significantly. In the model formulation shown above, however, there are no cross-price elasticities so there is

no fuel substitution. This was not considered a particular problem for the original Reference case because the model was "calibrated" through user judgment for each of the individual fuels. However, because high oil prices may cause substantial movement of consumption away from petroleum fuels, a simple algorithm was built into the model to reflect fuel substitution.

In the HWOP case, a portion of the decline in petroleum consumption from the level in the Reference case is replaced by an increase in other fuels. In order to determine how much petroleum consumption has declined from the Reference case, it is first necessary to read in some data that specify the level of petroleum consumption in the Reference case. These data are read in along with some other data that indicate the fraction of the petroleum that will be replaced by other fuels. In the input file, the fraction is set to be 0.5 in all regions, meaning that 50 percent of the petroleum decrease in the HWOP case will be replaced by an increase in other fuels. The model achieves the substitution over the years 2010 to 2030, and modifies the fraction incrementally so that it starts at 0 in 2010 and gradually increases to its full value in 2020. It remains the same to 2030, after which the model solves in the same way as it did in the Reference case.

Once the model determines how much petroleum requires a substitution, it allocates the amounts to natural gas, coal, and electricity based on the current relative shares of each of these fuels. For example, if 100 trillion Btu requires a substitution, and the respective shares of natural gas, coal, and electricity are 0.4, 0.0, and 0.6, then natural gas will increase by 40 trillion Btu, coal will be unchanged, and electricity will increase by 60 trillion Btu.

STEO Calibration

The Energy Information Administration's *Short-Term Energy Outlook* (*STEO*) projects worldwide liquid fuels consumption to 2012. The regions in the *STEO* are somewhat more aggregate than in the WEPS+, and the consumption projections are for total petroleum with no sectoral or product differentiation. Nonetheless, the *IEO2011* projection must replicate these values in the *STEO* projection years. Outside of the Residential Model but within the WEPS+, the Main Model reads the *STEO* data in each iteration. Based upon the results from the current iteration, the Main Model shares the total petroleum consumption to some sub-regions and to all the detail in the end use sectors. The exception to this step is the electric power sector, where liquids-fired generation is not included. The reason for this exception is that electricity generation is a small liquids-consuming sector, and it is much more complicated in terms of its transformation of energy. Instead, the amount of liquids consumed in the electricity generation sector is subtracted from the total *STEO* liquids consumption. After that, the remaining amount of liquids consumption is allocated to the remaining sectors, based upon the remaining share of liquids consumption. These quantities are then exported to the restart file so that they are available to each of the WEPS+ models for calibration to *STEO*. It is worth noting that these sector shares are performed in the Main Model for each WEPS+ iteration so that the actual amounts adapt to the changing shares of sector consumption as the model moves towards the equilibrium solution.

The Residential Model reads the *STEO* petroleum allocations for the residential sector from the restart file, and then determines calibration factors for each petroleum product in each region for each of the years from 2009 through 2012. These factors are simply the ratio of the *STEO* residential consumption allocation to the model's projection consumption in those years:

For each year 2009 through 2012:

$$STEOFac(r, y) = \frac{STEOQty(r, y)}{RQty(f = petroleum, r, y)}$$

Where: *STEOQty* is the *STEO* residential consumption allocation

RQty(f=petroleum) is the model's total petroleum consumption

STEOFac is the *STEO* calibration factor

The *STEO* calibration factors are then multiplied against the model petroleum consumption projections in the years 2009 through 2012, so that the model projects the *STEO* consumption levels.

$$QDSRS(r, y) = QDSRS'(r, y) * STEOFac(r, y)$$

$$QKSRS(r, y) = QKSRS'(r, y) * STEOFac(r, y)$$

$$QLGRS(r, y) = QLGRS'(r, y) * STEOFac(r, y)$$

Where: *QDSRS* is the residential distillate consumption

QKSRS is the residential kerosene consumption

QLGRS is the residential LPG consumption

Because the amount of adjustment in 2012 can be significant, it is not appropriate to go directly back to the model consumption level in 2013 (there could be a disconnect). Instead, the 2012 *STEO* calibration factor is carried out over the next 10 years, gradually ramping back to 1.0 during that time. Therefore the transition from 2012 to 2022 is fairly smooth.

Appendix A. Model Abstract

Model Name:

Residential Model of the World Energy Projection System Plus

Model Acronym:

Residential Model

Model Description:

The Residential Model of the World Energy Projection System Plus (WEPS+) is a computer-based energy demand modeling system of the world residential sector at a regional level. For the *IEO2011*, the WEPS+ Residential Model projects the amount of energy that is consumed by households. These projections exclude personal household on-road transportation in light duty vehicles, which is counted in the transportation sector. The model projects residential consumption for nine energy sources (distillate fuel, kerosene, liquid petroleum gas, natural gas, coal, electricity, heat, solar, and biomass) in each of the 16 WEPS regions over the projection period to the year 2035.

Model Purpose:

As a component of the WEPS+ integrated modeling system, the Residential Model generates long-term projections of residential sector energy consumption. The model also provides consumption inputs for a variety of the other WEPS+ models. The model provides a tool for analysis of international residential energy use within the WEPS+ system, and can be run independently as a standalone model.

Most Recent Model Update:

October 2010.

Part of Another Model:

World Energy Projection System Plus (WEPS+).

Model Interfaces:

The Residential Model receives inputs from the Macroeconomic Model, Refinery Model, Natural Gas Model, Coal Model, Electricity Model, and District Heat Model. It provides outputs to all of these models as well as the Petroleum Model, but excluding the Macroeconomic Model. In each case, the inputs and outputs are shared through the common interface file of the WEPS+.

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Documentation:

Energy Information Administration, U.S. Department of Energy, *Residential Model of the World Energy Projection System Plus: Model Documentation 2011*, DOE/EIA-M073(2011) (Washington, DC, August 2011).

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 2011*.

Energy System Described:

International residential sector energy consumption.

Coverage:

- Geographic: Sixteen WEPS+ regions: U.S., 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 Central and South America.

- Mode: total residential consumption.

- Time Unit/Frequency: Annual, 2009 through 2035.

Modeling Features:

The residential model makes projections of residential consumption based upon changes in GDP, energy prices, and a trend term. The model uses a dynamic simulation approach, using elasticities to model the changes over time and a lagged dependent variable to simulate dynamic adjustments.

DOE Input Sources:

Energy Information Administration, International Energy Statistics Database, web site www.gov/emeu/international (as of April 1, 2011).

Energy Information Administration, *Short Term Energy Outlook* (*STEO*), Washington, D.C., (March 2011 release).

Non-DOE Input Sources:

International Energy Agency (IEA), *Energy Balances of OECD Countries*, Paris, 2010.

International Energy Agency (IEA), *Energy Balances of Non-OECD Countries*, Paris, 2010.

IHS Global Insight, *World Overview, Third Quarter 2010* (Lexington, MA, November 2010).

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.

Appendix B. Input Data and Variable Descriptions

The following variables represent data input from the file ResInput.xml.

Classification: Input variable.

GDPElas(f,r):	GDP elasticity by fuel (distillate, kerosene, LPG, natural gas, coal, electricity, and heat; excludes renewable energy sources) and region
GDPLag(f,r):	GDP lag coefficient by region and fuel
PrcElas(f,r):	Regional by-fuel price elasticity
PrcLag(f,r):	Regional by-fuel price lag coefficient
TrendGR(f,r):	Regional growth trend term by fuel
MltFac(f,r,y):	Residential multiplicative factor by region, fuel (distillate, kerosene, LPG, natural gas, coal, electricity, heat, solar, and biomass) and projection year
AdjYr(f,r):	User adjustment term to change shape of residential consumption trend path by fuel and region (note: not currently used in the model)
EGDPFac(f, r):	Regional by-fuel multiplicative factors applied to GDP elasticities (note: currently all set to 1.0)
EPrcFac(f,r):	Regional by-fuel multiplicative factors applied to price elasticities (note: currently all set to 1.0)
PetRef(r,y):	Total liquids consumption in the Reference case by region and year (note: this must be physically updated to current Reference case when user intends to run a High Oil Price scenario)
PetFacA(r):	Increment of additional liquids in the High Oil Price case that must be allocated to natural gas, coal, and electricity by region

The following variables represent data input from the restart file.

Classification: Input variable from the Macroeconomic Model, Refinery Model, and supply models.

GDP_PPP(r,y):	Regional GDP expressed in purchasing power parity by year (note r = 17 is total world GDP)
PDSRS(r,y):	Price of distillate fuel for residential energy use by region and year
PKSRS(r,y):	Price of kerosene for residential energy use by region and year
PLGRS(r,y):	Price of liquefied petroleum gas for residential energy use by region and year

PNGRS(r,y):	Price of natural gas for residential energy use by region and year
PCLRS(r,y):	Price of coal for residential energy use by region and year
PELRS(r,y):	Price of electricity for residential energy use by region and year
PHTRS(r,y):	Price of heat for residential energy use by region and year
ADSRS(r,y):	Carbon price increment to residential sector distillate (diesel) fuel price associated with the carbon allowance price by region and year (dollars per million Btu)
AKSRS(r,y):	Carbon price increment to residential sector kerosene price associated with the carbon allowance price by region and year (dollars per million Btu)
ALGRS(r,y):	Carbon price increment to residential sector liquefied petroleum gas price associated with the carbon allowance price by region and year (dollars per million Btu)
ANGRS(r,y):	Carbon price increment to residential sector natural gas price associated with the carbon allowance price by region and year (dollars per million Btu)
ACLRS(r,y):	Carbon price increment to residential sector coal price associated with the carbon allowance price by region and year (dollars per million Btu)
AELRS(r,y):	Carbon price increment to residential sector electricity price associated with the carbon allowance price by region and year (dollars per million Btu)
AHTRS(r,y):	Carbon price increment to residential sector heat price associated with the carbon allowance price by region and year (dollars per million Btu)
QHDSRS(r,y):	Historical distillate fuel consumption in the residential sector by region and year (years 2004 through 2008)
QHKSRS(r,y):	Historical kerosene consumption in the residential sector by region and year (years 2004 through 2008)
QHLGRS(r,y):	Historical liquefied petroleum gas consumption in the residential sector by region and year (years 2004 through 2008)
QHSPRS(r,y):	Historical sequestered petroleum fuel consumption in the residential sector by region and year (years 2004 through 2008)
QHNGRS(r,y):	Historical natural gas consumption in the residential sector by region and year (years 2005 through 2008)
QHCLRS(r,y):	Historical coal consumption in the residential sector by region and year (years 2005 through 2008)
QHELRS(r,y):	Historical electricity consumption in the residential sector by region and year (years 2005 through 2008)
QHHTRS(r,y):	Historical heat consumption in the residential sector by region and year (years 2005 through 2008)
QHBMRS(r,y):	Historical biomass consumption in the residential sector by region and year (years 2005 through 2008)

QHSLRS(r,y):	Historical solar energy consumption in the residential sector by region and year (years 2005 through 2008)
STEOPTRS(r,y):	Projections of liquids for the residential sector based upon EIA's Short-Term Energy Outlook by region and year (years 2009 through 2012)

The following variables represent data calculated in the subroutine Resd.

Classification: Computed variable.

XPrc(f,r,y):	By-fuel regional price adjusted according to carbon price
RQIdx(f,r,y):	Residential overall index combining GDP, price, and trend by fuel, region, and year
GDPIdx(f,r,y):	GDP index by fuel, region, and year
PrcIdx(f,r,y):	Price index by fuel, region, and year
EffIdx (f,r,y):	Trend term growth index by fuel, region, and year
AdjIdx(f,r,y):	Adjustment index to apply a user adjustment term to the consumption curves to effect a trend change (not currently used in the model)
QDSRS(r,y):	Consumption of residential distillate fuel by region and year
QKSRS(r,y):	Consumption of residential kerosene by region and year
QLGRS(r,y):	Consumption of residential liquefied petroleum gas by region and year
QNGRS(r,y):	Consumption of residential natural gas by region and year
QCLRS(r,y):	Consumption of residential coal by region and year
QELRS(r,y):	Consumption of residential electricity by region and year
QHTRS(r,y):	Consumption of residential district heat by region and year
QBMRS(r,y):	Consumption of residential biomass by region and year
QSLRS(r,y):	Consumption of residential solar energy by region and year

Coefficient Sources

The elasticities and the parameters for the lagged index values that are used for the Residential Model are largely developed from the behavior of the U.S. National Energy Modeling System (NEMS) Residential Module, and adapted to the WEPS+ international regions. These parameters were created in an Excel spreadsheet through an analysis of the relationship between a previous *Annual Energy Outlook* Reference case, the corresponding High and Low Economic Growth cases, and the corresponding High and Low Oil Price cases. For example, GDP parameters were calculated in each year for each sector and each fuel by looking at the change in the specific demands between the Reference case and the high GDP case relative to the change in the GDP.

This process was then repeated for the relationship between the Reference case and the low GDP case.

Because the GDP elasticities across scenarios were not necessarily the same, some analyst judgments were made. In general, the average of the High and Low Economic Growth cases were selected for the scenarios, but there were also judgments made about whether the elasticities seemed appropriate in the first place. Where they did not seem appropriate, an alternate elasticity was assumed, based upon elasticities for the other fuels and sectors and upon expert judgment.

The price elasticities were calculated in essentially the same manner. For price elasticities, the NEMS runs were for high and low world oil prices, but prices for the other fuels also changed and were used for their sensitivities. When the elasticities were used and placed into the model, the level of the GDP elasticities were increased by a factor of 1.25 for many of the developing or rapidly changing regions. These included Mexico, South Korea, and all of the non-OECD regions.

The Commercial Model coefficients were used in a calibration process to provide a projection for each energy source that is based on the previous Commercial Model projections for the *IEO*. This was accomplished by calculating a trend target that allows the projection to be similar to that in previous *IEO* reports, accounting for subsequent GDP and price changes. This is done in an attempt to capture the extent of future efficiency or usage trends that have been established through accumulated expert judgment and built into previous projections. This final calibration, based upon the trends incorporated in previous projections and upon expert judgment, provides some consistency with previous projections, but is ultimately validated during the run process with newer and more current information or understanding.

Coefficients Used for IEO2011

Table 5 provides the coefficients that were used in the projection equation for the *IEO2011*. These are largely determined in the process described above, but in several cases, various coefficients (typically the trend factor) were changed based upon user judgment. It is worth noting that in most cases the elasticities and lag coefficients are basically the same from region to region (GDP varies somewhat), and among the petroleum products.

Table 5. Residential Model Projection Equation Coefficients

		GDPElas	GDPLag	PrcElas	PrcLag	TrendGR
USA	DS	0.087	0.618	-0.110	0.526	-0.0083
USA	KS	0.087	0.618	-0.110	0.526	-0.0083
USA	LG	0.087	0.618	-0.110	0.526	-0.0083
USA	NG	0.105	0.697	-0.161	0.069	-0.0031
USA	CL	0.100	0.500	-0.100	0.500	-0.0103
USA	EL	0.223	0.498	-0.145	0.110	-0.0002
USA	HT	0.112	0.498	-0.073	0.055	0.0001
CAN	DS	0.087	0.618	-0.110	0.526	-0.0019

		GDPElas	GDPLag	PrcElas	PrcLag	TrendGR
CAN	KS	0.087	0.618	-0.110	0.526	-0.0019
CAN	LG	0.087	0.618	-0.110	0.526	-0.0019
CAN	NG	0.105	0.697	-0.161	0.069	-0.0004
CAN	CL	0.100	0.500	-0.100	0.500	-0.0166
CAN	EL	0.223	0.498	-0.145	0.110	0.0051
CAN	HT	0.112	0.498	-0.073	0.055	0.0003
MEX	DS	0.109	0.618	-0.110	0.526	0.0026
MEX	KS	0.109	0.618	-0.110	0.526	0.0026
MEX	LG	0.109	0.618	-0.110	0.526	0.0026
MEX	NG	0.131	0.697	-0.161	0.069	0.0246
MEX	CL	0.125	0.500	-0.100	0.500	-0.0082
MEX	EL	0.279	0.498	-0.145	0.110	0.0208
MEX	HT	0.139	0.498	-0.073	0.055	-0.0048
EUR	DS	0.087	0.618	-0.110	0.526	-0.0056
EUR	KS	0.087	0.618	-0.110	0.526	-0.0056
EUR	LG	0.087	0.618	-0.110	0.526	-0.0056
EUR	NG	0.105	0.697	-0.161	0.069	-0.0014
EUR	CL	0.100	0.500	-0.100	0.500	-0.0161
EUR	EL	0.223	0.498	-0.145	0.110	0.0062
EUR	HT	0.112	0.498	-0.073	0.055	0.0005
JPN	DS	0.087	0.618	-0.110	0.526	-0.0068
JPN	KS	0.087	0.618	-0.110	0.526	-0.0068
JPN	LG	0.087	0.618	-0.110	0.526	-0.0068
JPN	NG	0.105	0.697	-0.161	0.069	0.0015
JPN	CL	0.100	0.500	-0.100	0.500	-0.0012
JPN	EL	0.223	0.498	-0.145	0.110	0.0030
JPN	HT	0.112	0.498	-0.073	0.055	0.0031
ANZ	DS	0.087	0.618	-0.110	0.526	-0.0009
ANZ	KS	0.087	0.618	-0.110	0.526	-0.0009
ANZ	LG	0.087	0.618	-0.110	0.526	-0.0009
ANZ	NG	0.105	0.697	-0.161	0.069	0.0068
ANZ	CL	0.100	0.500	-0.100	0.500	-0.0118
ANZ	EL	0.223	0.498	-0.145	0.110	0.0005
ANZ	HT	0.112	0.498	-0.073	0.055	-0.0010
SKO	DS	0.109	0.618	-0.110	0.526	-0.0047

		GDPElas	GDPLag	PrcElas	PrcLag	TrendGR
SKO	KS	0.109	0.618	-0.110	0.526	-0.0047
SKO	LG	0.109	0.618	-0.110	0.526	-0.0047
SKO	NG	0.131	0.697	-0.161	0.069	-0.0027
SKO	CL	0.125	0.500	-0.100	0.500	-0.0269
SKO	EL	0.279	0.498	-0.145	0.110	0.0060
SKO	HT	0.139	0.498	-0.073	0.055	-0.0038
RUS	DS	0.109	0.618	-0.110	0.526	-0.0017
RUS	KS	0.109	0.618	-0.110	0.526	-0.0017
RUS	LG	0.109	0.618	-0.110	0.526	-0.0017
RUS	NG	0.131	0.697	-0.161	0.069	0.0038
RUS	CL	0.125	0.500	-0.100	0.500	-0.0207
RUS	EL	0.279	0.498	-0.145	0.110	0.0116
RUS	HT	0.139	0.498	-0.073	0.055	-0.0052
URA	DS	0.109	0.618	-0.110	0.526	-0.0031
URA	KS	0.109	0.618	-0.110	0.526	-0.0031
URA	LG	0.109	0.618	-0.110	0.526	-0.0031
URA	NG	0.131	0.697	-0.161	0.069	-0.0041
URA	CL	0.125	0.500	-0.100	0.500	-0.0213
URA	EL	0.279	0.498	-0.145	0.110	0.0008
URA	HT	0.139	0.498	-0.073	0.055	-0.0073
CHI	DS	0.109	0.618	-0.110	0.526	-0.0173
CHI	KS	0.109	0.618	-0.110	0.526	-0.0173
CHI	LG	0.109	0.618	-0.110	0.526	-0.0173
CHI	NG	0.131	0.697	-0.161	0.069	0.0441
CHI	CL	0.125	0.500	-0.100	0.500	-0.0120
CHI	EL	0.279	0.498	-0.145	0.110	0.0226
CHI	HT	0.139	0.498	-0.073	0.055	-0.0112
IND	DS	0.109	0.618	-0.110	0.526	-0.0093
IND	KS	0.109	0.618	-0.110	0.526	-0.0093
IND	LG	0.109	0.618	-0.110	0.526	-0.0093
IND	NG	0.131	0.697	-0.161	0.069	0.0174
IND	CL	0.125	0.500	-0.100	0.500	0.0113
IND	EL	0.279	0.498	-0.145	0.110	0.0244
IND	HT	0.139	0.498	-0.073	0.055	-0.0098
OAS	DS	0.109	0.618	-0.110	0.526	0.0001

		GDPElas	GDPLag	PrcElas	PrcLag	TrendGR
OAS	KS	0.109	0.618	-0.110	0.526	0.0001
OAS	LG	0.109	0.618	-0.110	0.526	0.0001
OAS	NG	0.131	0.697	-0.161	0.069	0.0216
OAS	CL	0.125	0.500	-0.100	0.500	-0.0036
OAS	EL	0.279	0.498	-0.145	0.110	0.0097
OAS	HT	0.139	0.498	-0.073	0.055	-0.0067
MID	DS	0.109	0.618	-0.110	0.526	-0.0013
MID	KS	0.109	0.618	-0.110	0.526	-0.0013
MID	LG	0.109	0.618	-0.110	0.526	-0.0013
MID	NG	0.131	0.697	-0.161	0.069	-0.0006
MID	CL	0.125	0.500	-0.100	0.500	-0.0244
MID	EL	0.279	0.498	-0.145	0.110	0.0064
MID	HT	0.139	0.498	-0.073	0.055	-0.0052
AFR	DS	0.109	0.618	-0.110	0.526	0.0025
AFR	KS	0.109	0.618	-0.110	0.526	0.0025
AFR	LG	0.109	0.618	-0.110	0.526	0.0025
AFR	NG	0.131	0.697	-0.161	0.069	0.0219
AFR	CL	0.125	0.500	-0.100	0.500	0.0157
AFR	EL	0.279	0.498	-0.145	0.110	0.0108
AFR	HT	0.139	0.498	-0.073	0.055	-0.0064
BRZ	DS	0.109	0.618	-0.110	0.526	0.0022
BRZ	KS	0.109	0.618	-0.110	0.526	0.0022
BRZ	LG	0.109	0.618	-0.110	0.526	0.0022
BRZ	NG	0.131	0.697	-0.161	0.069	0.0599
BRZ	CL	0.125	0.500	-0.100	0.500	-0.0075
BRZ	EL	0.279	0.498	-0.145	0.110	0.0124
BRZ	HT	0.139	0.498	-0.073	0.055	-0.0040
CSA	DS	0.109	0.618	-0.110	0.526	0.0006
CSA	KS	0.109	0.618	-0.110	0.526	0.0006
CSA	LG	0.109	0.618	-0.110	0.526	0.0006
CSA	NG	0.131	0.697	-0.161	0.069	0.0204
CSA	CL	0.125	0.500	-0.100	0.500	-0.0014
CSA	EL	0.279	0.498	-0.145	0.110	0.0016
CSA	HT	0.139	0.498	-0.073	0.055	-0.0057

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. C. Dahl, *International Energy Markets: Understanding Pricing, Policies, and Profits* (PennWell Books, March 2004).

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

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

6. Energy Information Administration, *Model Documentation Report: Residential Sector Demand Module of the National Energy Modeling System 2009*, DOE/EIA-0067(2009) (Washington, DC, May 1, 2009).

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

8. International Energy Agency, *Energy Prices and Taxes* (Paris, France, quarterly: various issues).

9. International Energy Agency, *Energy Technology Perspectives: Strategies and Scenarios to 2050*, (Paris, France 2008).

10. International Energy Agency, *World Energy Outlook 2010 Edition* (Paris, France, November 2010).

Appendix D. Data Quality

Introduction

The WEPS+ Residential Model develops projections of world residential energy use for nine fuels (distillate fuel, kerosene, liquid petroleum gas, natural gas, coal, electricity, heat, solar, and biomass) for 16 regions of the world. These projections are based upon the data elements as detailed in Appendix B of this report. The documentation details transformations, estimation methodologies, and resulting inputs required to implement the model algorithms in Chapter 4: Model Structure. The quality of the principal sources of input data is discussed in Appendix D. Information regarding the quality of parameter estimates and user inputs is provided where available.

Source and Quality of Input Data

Source of Input Data

- *STEO* – Short-term liquid fuel consumption from 2005 to 2012 are provided by region from EIA's *Short-Term Energy Outlook.* The *IEO2011* results are benchmarked to the STEO results from the March 2011 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 *IEO2011*. While the numbers are continuously updated, WEPS+ used a "snapshot" of the database as it existed on April 1, 2011 as the source of its international data.

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

- *NEMS* – Many of the assumptions about price and economic elasticities are based in a large part on those included in the National Energy Modeling System for the United States. Expert judgment has, in some cases, been used to alter assumptions based on analyst knowledge about specific regions in the WEPS+ system.

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. residential fuel consumption, retail prices, and elasticities, based on previous values, responses, and regional and technical knowledge

- Consistency checks

- Technical edits to detect and correct errors, extreme variability