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World Energy Projection System Plus: Residential Module

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Update information

This edition of the WEPS+ Residential Model reflects changes made to the model since the previous iteration of this report. These changes include:

- Replaced GDP with disposable personal income

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 2017* (*IEO2017*). 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 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 U.S. Energy Information Administration (EIA) to provide adequate documentation in support of its models (*Public Law 93-275, section 57.b.1*). Third, it facilitates continuity in model development by providing documentation from which energy analysts can undertake and analyze their own model enhancements, data updates, and parameter refinements for future projects.

Model summary

The WEPS+ Residential Model for the *IEO2017* 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 annual residential consumption for nine energy sources in each of the 16 WEPS+ regions. The model primarily uses a dynamic econometric equation for the key energy sources, basing the projection on assumptions about future growth in disposable personal income (income), 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 income and price projections are available to the Residential Model from the WEPS+ Global Activity 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 income and price. These impacts 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 2017* (*IEO2017*).

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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 annual projections of household energy use. 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 Model

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 Non-OECD Americas

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 Global Activity Model and by various transformation and supply models (Table 2).

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

Model Input	Source
Disposable personal income	Global Activity Model
Residential distillate retail price	Refinery Model
Residential kerosene retail price	Refinery Model
Industrial LPG retail price	Refinery Model
Residential natural gas retail price	Natural Gas Model
Residential coal retail price	Coal Model
Residential electricity retail price	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
	Regional by-fuel multiplicative factors applied to GDP and price elasticities
	Total liquids consumption (hard-coded into input file from Reference case run; only used in the High Oil Price case)
	Increment of liquids that must be allocated to natural gas, coal, and electricity to represent substitution effects (this is only used in the High Oil Price case, where fuel substitution away from 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).

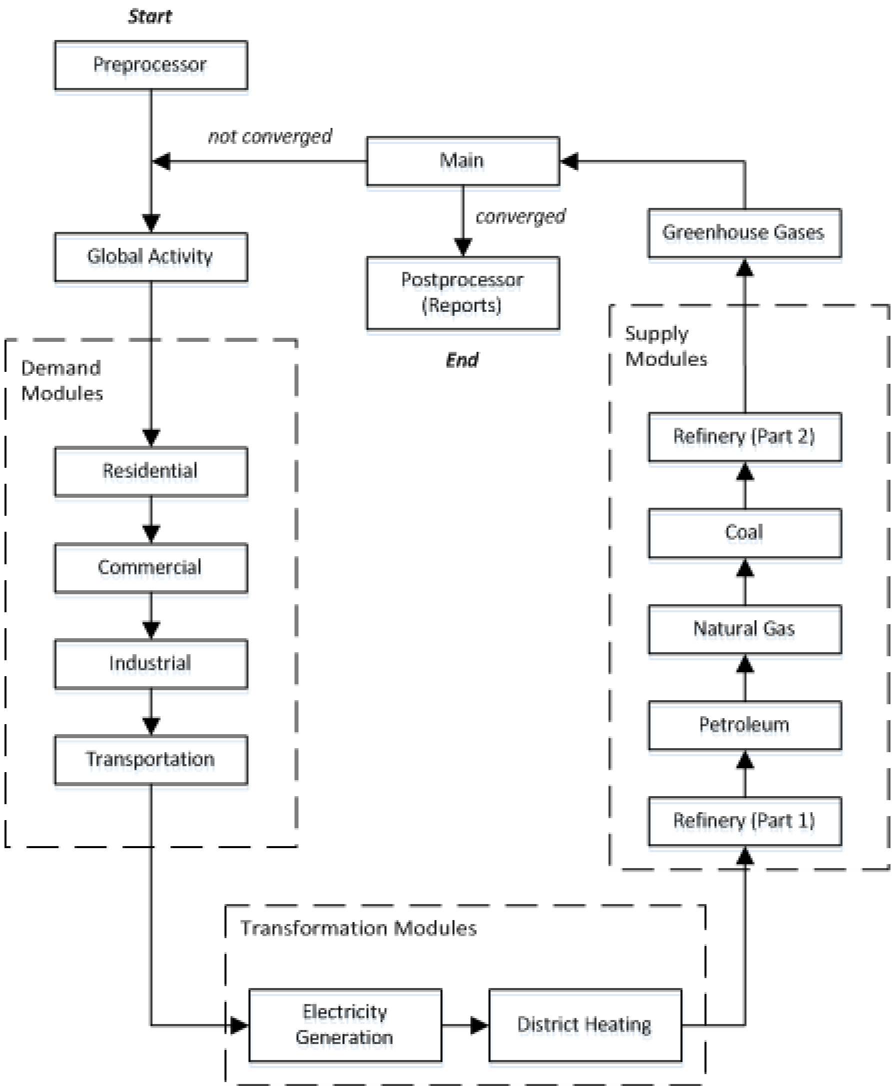
Table 4. Residential Model Outputs and the WEPS+ Models that Use Them

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	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 that 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 *IEO2017* 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 income projections from the Global Activity Model and a variety of residential retail price projections from various supply and transformation models. 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.

3. Model Rationale

Theoretical approach

The Residential Model makes projections of residential energy consumption based on projected changes in income, 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 income 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 the following:

- Residential consumption, based on the assumption that changes in consumption are related to changes in income
- 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. The residential energy consumption calculations are based on regional estimates of income, residential fuel prices by fuel type, 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, heat, biomass, and solar energy).

The basic structure of the Residential Model is illustrated in (Figure 2). 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 3) is initiated by a call from the main Residential Model. The model requires several *exogenous* data series. The Resd subroutine begins by initiating a call of the RInXML subroutine (Figure 4) to import data from the ResInput.xml data file. The ResInput.xml data file provides the following:

- 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 these data series are imported, the routine recalculates the income and price elasticity factors by incorporating any shape-and-elasticity adjustment factors. The adjustment factors were not used for *IEO2017* model runs.

After the RInXML subroutine has executed, the Resd subroutine begins to compute residential energy consumption projections by fuel. First, income 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 income, 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 to represent consumer substitution away from liquids. 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 calibrated to agree with regional *Short-Term Energy Outlook* projections. Several output files are then 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 2. Flowchart for the Residential Model

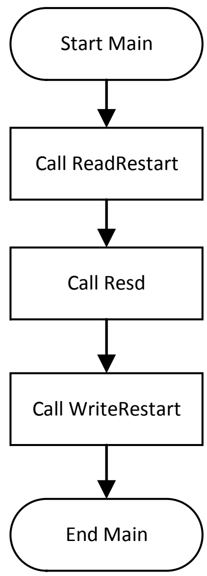


Figure 3. Flowchart for the Resd Subroutine

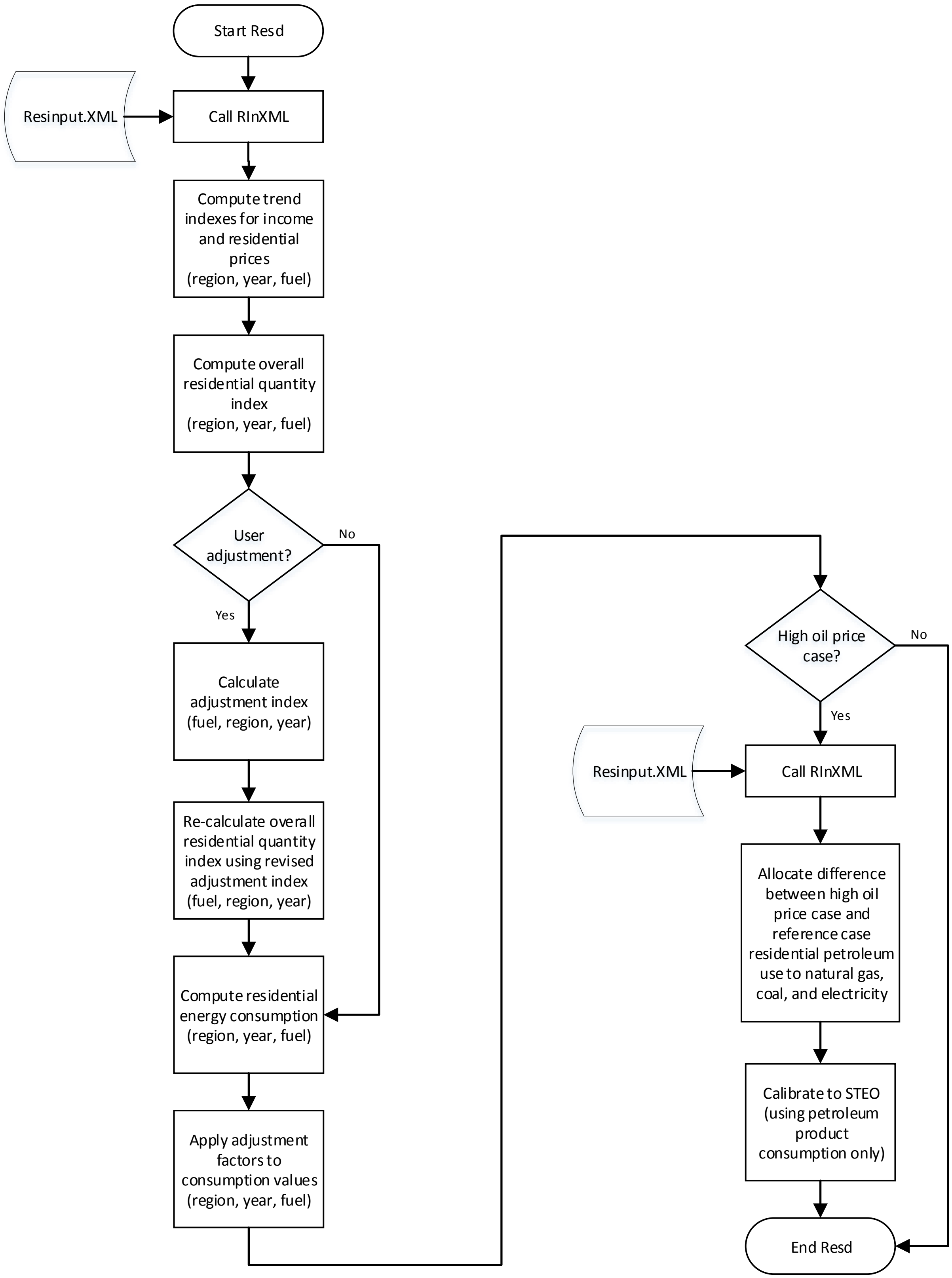
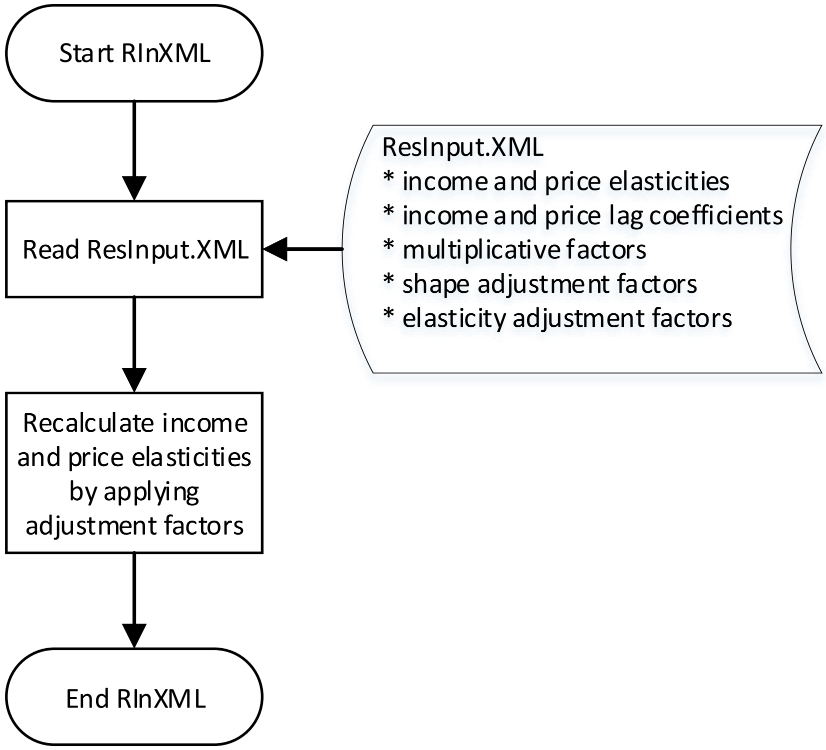


Figure 4. Flowchart for the RInXML Subroutine



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 energy consumption in each of the 16 WEPS+ regions over the projection horizon to 2050 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. The historical data are 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 U.S. Energy Information Administration's International Statistics Database. These data have been processed prior to the execution of the

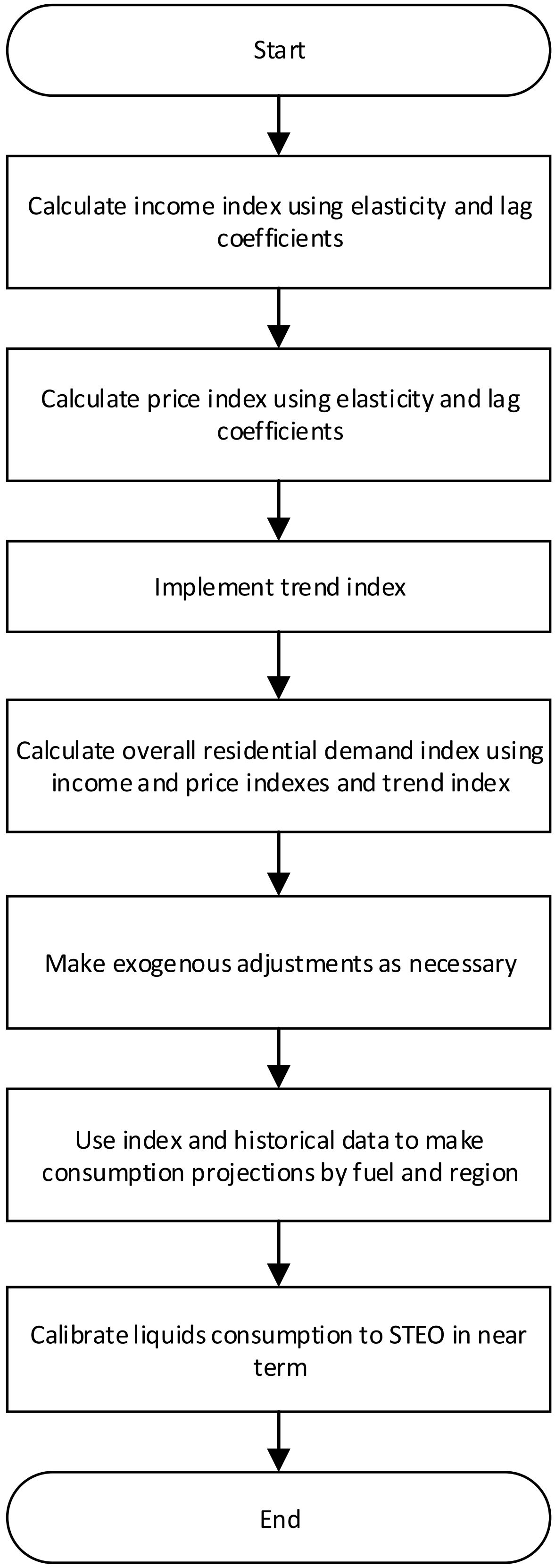
Residential Model and have been stored in the restart file to provide a common starting point for all WEPS+ models. The Residential Model uses the data available to it through the latest historical year (2015 in the case of the *IEO2017*), for each of the 16 regions and nine energy sources.

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 Global Activity Model and by various transformation and supply models (Figure **5**).

Projection equations

(Figure **5**) 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 to project consumption of key energy sources, basing the projections on an income 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 income projection is available to the Residential Model from the WEPS+ Global Activity Model through the common, shared restart file. The income projections are expressed in terms of purchasing power parity in real 2010 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 2013 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 income and/or price; it may account for effects of a variety of behavioral, structural, and policy-induced activities.

Figure 5. 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 in 2015**Error! Reference source not found.**. This use of indices eliminates the need for an intercept term in the projection equation. The indexing also allows the model to consider only the changes in the income and prices, not their actual levels. The three drivers of the projections (income, prices, and the trend term) are each projected forward independently. Then all three indices are applied to the 2015 residential consumption levels to make the projections.

Income index equation

An index $GDPI(r, y)$ is created for income in each year y and region r. This index takes its value relative to the income in the last historical year for which data are available, $LHYr$:

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

where

$GDPI(r, y)$ is the index for income in region r and year y; and

$HH\_Income\_PPP(r, y)$ is the income based on purchasing power parity in region r and year y.

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

$$GDPIdx(f, r, y) = \exp\left[GDPElas(f, r)^{*} \ln\left(GDPI(r, y)\right)\right] + \left[GDPLag(f, r)^{*} \ln\left(GDPIdx(f, r, y-1)\right)\right],$$

where

$GDPIdx(f, r, y)$ is the income-influenced part of the projections, relating changes in income to changes in residential energy consumption; and

$GDPElas(f, r)$ and $GDPLag(f, r)$ are exogenous coefficients for the income and for the lag term, respectively, for fuel f in region r.

The index $GDPIdx(f, r, y)$ starts with a value of 1.0 in the last historical year (2015). The two coefficients, $GDPELAS(f, r)$ and $GDPLag(f, r)$, are read in from an input file.

For a cleaner notation, the subscript r indicating region is suppressed. For each region, the index $\gamma_{f,y}$ representing the effect of income changes on the change in residential consumption of fuel f for year y is calculated as

$$\gamma_{f,y} = \gamma_{f,y-1}^{\beta(f)} \left(\frac{g_y}{g_{2015}}\right)^{\tau(f)},$$

where

g_y = income for year y, expressed in purchasing power parity;

$\beta(f)$ is a parameter indicating the effect of the lagged value of the parameter $\gamma_{f,y-1}$ for fuel f on the current value, $\gamma_{f,y}$.; and

$\tau(f)$ is an elasticity parameter indicating the impact of the income ratio on the residential consumption index for fuel f. (For example, $\tau(f)$ = 0 indicates no effect of income change on residential energy consumption, while $\tau(f)$ = 1 indicates a strong effect.)

The index is initialized by setting $\gamma_{f,2015} = 1$, so $\gamma_{f,y}$ can also be written simply as the product of the exponentiated income ratios:

$$\gamma_{f,y} = \prod_{j=2015}^{y} \left(\frac{g_j}{g_{2015}}\right)^{j\tau(f)+(j-1)\beta(f)}.$$

The parameters $\beta(f)$ and $\tau(f)$ are estimated exogenously from historical data as discussed in Appendix B. Thus the effect of previous values of $\gamma_{f,y}$ on current values is gradually dampened, while the effect of income change on the residential energy consumption index varies considerably by fuel and region.

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

Price index equation

In the following, the subscript r indicating region is no longer suppressed. A price ratio is computed for each retail residential price in each year y, region r, and fuel f indicating the change in price from the last historical year (2015) to year y:

$$RPIdx(f,r,y) = \frac{RetailPrice(f,r,y)}{RetailPrice(f,r,y=LHYr)},$$

where

$RetailPrice(f,r,y)$ is the retail price of fuel *f* in region *r* and year *y*;

$RPIdx(f,r,y)$ is the index of change in the retail price of fuel f in region r and year y from the last historical year $LHYr$.

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

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

where

$PrcIdx(f,r,y)$ is the index for the price-influenced part of the projection;

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

$PrcElas(f,r)$ is the price elasticity for fuel f in region r, reflects the extent to which residential energy consumption of fuel f in region r changes in response to changes in price (estimated exogenously as described in Appendix B); and

$PrcLag(f,r)$ is the lag coefficients for the lag term, which is estimated exogenously as described in Appendix B.

The index $PrcIdx(f,r,y)$ starts with a value of 1.0 in the last historical year (2015). The two coefficients, $PrcElas(f,r)$ and $PrcLag(f,r)$, 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.

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 2050. Its value can vary by region and by fuel. The index begins with a value of 1.0 for 2015. The growth rate is used to calculate the trend index term for the last projection year (2050) by applying the growth rate over the period from the last historical year (2015) to the last projection year (2050).

$$EffIdx(f,r,y=2050) = EffIdx(f,r,y=2015) * TrendGR(f,r,y)^{(2050-2015)}.$$

Once the implied value for 2050 has been calculated, the model fills in all the intervening years by using a straight line interpolation. For years from 2015 to 2050,

$$EffIdx(f,r,y) = EffIdx(f,r,y=2015) + \frac{(EffIdx(f,r,y=2050) - EffIdx(f,r,y=2015))}{(y-2015)\big/(2050-2015)}.$$

Overall projection index

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

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

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 income projection, the price projection, and a trend. The trend projection was based on a target in 2050 and a straight line interpolation between 2015 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 for 2015 and 2050. In other words, if the point of inflection is at 2020, then the values for 2016 through 2019 are smoothed based upon the values for 2015 and 2020, and the values from 2021 through 2049 are smoothed based upon the values for 2020 and 2050.

The smoothing uses a simple algorithm based upon the sine function so that the points nearer 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.

Consumption projection

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

$$RQty(f,r,y) = RQIdx(f,r,y) * HQty(f,r,y = 2015),$$

where, for region r, fuel f, and projection year y,

$RQIdx(f,r,y)$ is the overall projection index ;

$HQty(f,r,y)$ is the historical consumption in 2015; and

$RQty(f,r,y)$ is the resulting consumption projection over the projection horizon.

The above equation is for all fuels except biomass and solar. The consumption of biomass and solar is not estimated by the equation, primarily because there are no price estimates available for solar and biomass, but also because they are very minor in the context of the data being used. Although there are large amounts of biomass being used in some regions, the U.S. 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.

High world oil price fuel substitution

In the High Oil Price (HWOP) case, the projected 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 the consumption of other fuels. In order to determine how much petroleum consumption should decline from the Reference case, the model first reads in data that specify the level of petroleum consumption in the Reference case, along with other data that indicate the fraction of the petroleum consumption that will be replaced by consumption of other fuels. In the input file, the fraction is set to be 0.5 in all regions, meaning that 50% of the petroleum decrease in the HWOP case will be replaced by an increases in other fuels. The model estimates the substitution over the years 2015 to 2050, and modifies the fraction incrementally so that it starts at 0 in 2015 and gradually increases to its full value in 2020. It remains the same to 2050, after which the model solves in the same way it did in the Reference case.

Once the model determines how much petroleum consumption should be replaced by consumption of other fuels, it allocates the total amount to natural gas, coal, and electricity, based on the previously projected relative shares of each of these fuels. For example, if 100 trillion Btu requires 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 U.S. Energy Information Administration’s *Short-Term Energy Outlook* (*STEO*) projects worldwide liquid fuels consumption in the near term. The STEO consumption projections are for total petroleum consumption with no sectoral or product differentiation. Nonetheless, the *IEO2017* projections must replicate the STEO projections for 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 detailed 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 uses a small amount of liquids, 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*. 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 year in the STEO forecast. These factors are simply the ratios of the *STEO* residential consumption allocation to the WEPS+ model’s projected consumption in those years:

For each years in the STEO forecast

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

where, for region r and projection year y,

$STEOQty(r,y)$ is the STEO residential consumption allocation;

$RQty\ (f = petroleum, r, y)$ is the model's total petroleum consumption; and

$STEOFac(r,y)$ is the STEO calibration factor.

The *STEO* calibration factors are then multiplied by the model's petroleum consumption projections, 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, for region r and projection year y,

$QDSRS(r,y)$ is the residential distillate consumption;

$QKSRS(r,y)$ is the residential kerosene consumption; and

$QLGRS(r,y)$ is the residential LPG consumption.

Because the magnitude of the adjustment in the last *STEO* forecast year can be significant, it is not appropriate to go directly back to the model consumption level in the next year (there could be a break in the series). Instead, the *STEO* calibration factor is carried out over the next 10 projection years, gradually ramping back to 1.0 over the period. This adjustment makes the transition from *STEO* forecast to *IEO* projection 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 *IEO2017*, 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.

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:

May 2017.

Part of another model:

World Energy Projection System Plus (WEPS+)

Model interfaces:

The Residential Model receives inputs from the Global Activity 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 Global Activity Model. In each case, the inputs and outputs are shared through the common interface file of the WEPS+.

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Documentation:

U.S. Energy Information Administration, U.S. Department of Energy, *World Energy Projection System Plus: Residential Module*, DOE/EIA-M073 (2017) (Washington, DC, November 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:

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

Modeling features:

The residential model makes projections of residential consumption based upon changes in income, 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

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

Non-DOE input sources:

International Energy Agency (IEA), *Energy Balances of OECD Countries*, Paris, 2016.

International Energy Agency (IEA), *Energy Balances of Non-OECD Countries*, Paris, 2016.

Oxford Economics, *Global Economic Model* (March 2017), www.oxfordeconomics.com (subscription site).

Independent expert reviews:

None

Computing environment:

Hardware/Operating System: Basic PC with Windows
Language/Software Used: Fortran 90/95
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.

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 Global Activity Model, Refinery Model, and supply models.

HH_Income_PPP(r,y): Regional disposable personal income expressed in purchasing power parity by year (note r = 17 is total world disposable personal income)

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
QHKSRS(r,y):	Historical kerosene consumption in the residential sector by region and year
QHLGRS(r,y):	Historical liquefied petroleum gas consumption in the residential sector by region and year
QHSPRS(r,y):	Historical sequestered petroleum fuel consumption in the residential sector by region and year
QHNGRS(r,y):	Historical natural gas consumption in the residential sector by region and year
QHCLRS(r,y):	Historical coal consumption in the residential sector by region and year
QHELRS(r,y):	Historical electricity consumption in the residential sector by region and year
QHHTRS(r,y):	Historical heat consumption in the residential sector by region and year
QHBMRS(r,y):	Historical biomass consumption in the residential sector by region and year
QHSLRS(r,y):	Historical solar energy consumption in the residential sector by region and year

STEOPTRS(r,y): Projections of liquids for the residential sector based upon EIA's *Short-Term Energy Outlook* by region and year

The following variables represent data calculated in the subroutine Resd.

XPrc(f,r,y): By-fuel regional price adjusted according to carbon price

RQIdx(f,r,y): Residential overall index combining income, price, and trend by fuel, region, and year

GDPIdx(f,r,y): Income 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 for each year, by sector and fuel, by looking at the changes 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 values from the High and Low Economic Growth cases were selected for the scenarios, but there were also judgments made about whether the original NEMS-based elasticities seemed appropriate. 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, using different NEMS runs where specific fuel prices were changed and the changes in fuel consumption were compared to the Reference case run. In general, the elasticity for each fuel is the average value of the first three year elasticities for that fuel, but there were also judgments made when the NEMS-based elasticities did not seem appropriate. In these runs, prices for the other fuels also changed and the changes were used for sensitivity analysis. When the elasticities were used in the model, the levels of the GDP elasticities were adjusted for many of the regions.

For the *IEO2017* Reference case, income adjustment factors were used for adjusting fuel projections for the following regions and fuels:

- Mexico/Chile electricity, income factor = 1.50
- Mexico/Chile natural gas , income factor = 1.50
- Russia electricity, income factor = 1.50
- China electricity, income factor = 1.25
- China natural gas, income factor = 1.50
- India electricity, income factor = 1.25
- India natural gas, income factor = 1.50
- Middle East electricity, income factor = 1.25
- Africa electricity, income factor = 1.50
- Africa natural gas, income factor = 1.50
- Brazil electricity, income factor = 1.25
- Brazil natural gas, income factor = 1.50
- Other Central and South America natural gas, income factor = 1.50

The Residential Model coefficients were used in a calibration process to provide a projection for each energy source, based on the previous Residential Model projections for the *IEO*. This process was accomplished by calculating a trend target that allowed the projections to be similar to those in previous *IEO* reports, accounting for subsequent income and price changes. This step is an attempt to capture the extent of future efficiency or usage trends that have been anticipated 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 IEO2017

Table 5 provides the coefficients that were used in the projection equations for the *IEO2017*. These coefficients are largely determined in the process described above. It is worth noting that in most cases the elasticities and lag coefficients are basically the same from region to region and among the petroleum products.

Table 5. Residential Model Projection Equation Coefficients

Region[1]	Fuel[1]	GDPElas	GDPLag	PrcElas	PrcLag	TrendGR
USA	DS	0.049	0.000	-0.183	0.000	0.000
USA	KS	0.049	0.000	-0.183	0.000	0.000
USA	LG	0.049	0.000	-0.183	0.000	0.000
USA	NG	0.508	0.000	-0.218	0.000	0.000
USA	CL	0.033	0.000	-0.150	0.000	0.000
USA	EL	0.796	0.000	-0.303	0.000	0.000
USA	HT	0.037	0.000	-0.100	0.000	0.000
CAN	DS	0.049	0.000	-0.183	0.000	0.000
CAN	KS	0.049	0.000	-0.183	0.000	0.000
CAN	LG	0.049	0.000	-0.183	0.000	0.000
CAN	NG	0.508	0.000	-0.218	0.000	0.000
CAN	CL	0.033	0.000	-0.150	0.000	0.000
CAN	EL	0.796	0.000	-0.303	0.000	0.000
CAN	HT	0.037	0.000	-0.100	0.000	0.000
MEX	DS	0.049	0.000	-0.183	0.000	0.000
MEX	KS	0.049	0.000	-0.183	0.000	0.000
MEX	LG	0.049	0.000	-0.183	0.000	0.000
MEX	NG	0.508	0.000	-0.218	0.000	0.000
MEX	CL	0.011	0.000	-0.150	0.000	0.000
MEX	EL	0.796	0.000	-0.303	0.000	0.000
MEX	HT	0.037	0.000	-0.100	0.000	0.000
EUR	DS	0.049	0.000	-0.183	0.000	0.000
EUR	KS	0.049	0.000	-0.183	0.000	0.000
EUR	LG	0.049	0.000	-0.183	0.000	0.000
EUR	NG	0.508	0.000	-0.218	0.000	0.000
EUR	CL	0.033	0.000	-0.150	0.000	0.000
EUR	EL	0.796	0.000	-0.303	0.000	0.000
EUR	HT	0.037	0.000	-0.100	0.000	0.000
JPN	DS	0.049	0.000	-0.183	0.000	0.000
JPN	KS	0.049	0.000	-0.183	0.000	0.000
JPN	LG	0.049	0.000	-0.183	0.000	0.000
JPN	NG	0.508	0.000	-0.218	0.000	0.000
JPN	CL	0.033	0.000	-0.150	0.000	0.000
JPN	EL	0.796	0.000	-0.303	0.000	0.000
JPN	HT	0.037	0.000	-0.100	0.000	0.000
ANZ	DS	0.049	0.000	-0.183	0.000	0.000
ANZ	KS	0.049	0.000	-0.183	0.000	0.000

Table 5. Residential Model Projection Equation Coefficients (cont.)

Region[1]	Fuel[1]	GDPElas	GDPLag	PrcElas	PrcLag	TrendGR
ANZ	LG	0.049	0.000	-0.183	0.000	0.000
ANZ	NG	0.508	0.000	-0.218	0.000	0.000
ANZ	CL	0.033	0.000	-0.150	0.000	0.000
ANZ	EL	0.796	0.000	-0.303	0.000	0.000
ANZ	HT	0.037	0.000	-0.100	0.000	0.000
SKO	DS	0.049	0.000	-0.183	0.000	0.000
SKO	KS	0.049	0.000	-0.183	0.000	0.000
SKO	LG	0.049	0.000	-0.183	0.000	0.000
SKO	NG	0.508	0.000	-0.218	0.000	0.000
SKO	CL	0.033	0.000	-0.150	0.000	0.000
SKO	EL	0.796	0.000	-0.303	0.000	0.000
SKO	HT	0.037	0.000	-0.100	0.000	0.000
RUS	DS	0.049	0.000	-0.183	0.000	0.000
RUS	KS	0.049	0.000	-0.183	0.000	0.000
RUS	LG	0.049	0.000	-0.183	0.000	0.000
RUS	NG	0.508	0.000	-0.218	0.000	0.000
RUS	CL	0.033	0.000	-0.150	0.000	0.000
RUS	EL	0.796	0.000	-0.303	0.000	0.000
RUS	HT	0.037	0.000	-0.100	0.000	0.000
URA	DS	0.049	0.000	-0.183	0.000	0.000
URA	KS	0.049	0.000	-0.183	0.000	0.000
URA	LG	0.049	0.000	-0.183	0.000	0.000
URA	NG	0.508	0.000	-0.218	0.000	0.000
URA	CL	0.033	0.000	-0.150	0.000	0.000
URA	EL	0.796	0.000	-0.303	0.000	0.000
URA	HT	0.037	0.000	-0.100	0.000	0.000
CHI	DS	0.049	0.000	-0.183	0.000	0.000
CHI	KS	0.049	0.000	-0.183	0.000	0.000
CHI	LG	0.049	0.000	-0.183	0.000	0.000
CHI	NG	0.508	0.000	-0.218	0.000	0.000
CHI	CL	0.033	0.000	-0.150	0.000	0.000
CHI	EL	0.796	0.000	-0.303	0.000	0.000
CHI	HT	0.037	0.000	-0.100	0.000	0.000
IND	DS	0.049	0.000	-0.183	0.000	0.000
IND	KS	0.049	0.000	-0.183	0.000	0.000
IND	LG	0.049	0.000	-0.183	0.000	0.000
IND	NG	0.508	0.000	-0.218	0.000	0.000
IND	CL	0.033	0.000	-0.150	0.000	0.000

Table 5. Residential Model Projection Equation Coefficients (cont.)

Region[1]	Fuel[1]	GDPElas	GDPLag	PrcElas	PrcLag	TrendGR
IND	EL	0.796	0.000	-0.303	0.000	0.000
IND	HT	0.037	0.000	-0.100	0.000	0.000
OAS	DS	0.049	0.000	-0.183	0.000	0.000
OAS	KS	0.049	0.000	-0.183	0.000	0.000
OAS	LG	0.049	0.000	-0.183	0.000	0.000
OAS	NG	0.508	0.000	-0.218	0.000	0.000
OAS	CL	0.033	0.000	-0.150	0.000	0.000
OAS	EL	0.796	0.000	-0.303	0.000	0.000
OAS	HT	0.037	0.000	-0.100	0.000	0.000
MID	DS	0.049	0.000	-0.183	0.000	0.000
MID	KS	0.049	0.000	-0.183	0.000	0.000
MID	LG	0.049	0.000	-0.183	0.000	0.000
MID	NG	0.508	0.000	-0.218	0.000	0.000
MID	CL	0.033	0.000	-0.150	0.000	0.000
MID	EL	0.796	0.000	-0.303	0.000	0.000
MID	HT	0.037	0.000	-0.100	0.000	0.000
AFR	DS	0.049	0.000	-0.183	0.000	0.000
AFR	KS	0.049	0.000	-0.183	0.000	0.000
AFR	LG	0.049	0.000	-0.183	0.000	0.000
AFR	NG	0.508	0.000	-0.218	0.000	0.000
AFR	CL	0.033	0.000	-0.150	0.000	0.000
AFR	EL	0.796	0.000	-0.303	0.000	0.000
AFR	HT	0.037	0.000	-0.100	0.000	0.000
BRZ	DS	0.049	0.000	-0.183	0.000	0.000
BRZ	KS	0.049	0.000	-0.183	0.000	0.000
BRZ	LG	0.049	0.000	-0.183	0.000	0.000
BRZ	NG	0.508	0.000	-0.218	0.000	0.000
BRZ	CL	0.033	0.000	-0.150	0.000	0.000
BRZ	EL	0.796	0.000	-0.303	0.000	0.000
BRZ	HT	0.037	0.000	-0.100	0.000	0.000
CSA	DS	0.049	0.000	-0.183	0.000	0.000
CSA	KS	0.049	0.000	-0.183	0.000	0.000
CSA	LG	0.049	0.000	-0.183	0.000	0.000
CSA	NG	0.508	0.000	-0.218	0.000	0.000
CSA	CL	0.033	0.000	-0.150	0.000	0.000
CSA	EL	0.796	0.000	-0.303	0.000	0.000
CSA	HT	0.037	0.000	-0.100	0.000	0.000

[1] See Appendix C for a key to region and fuel abbreviations.

Appendix C. Key to Abbreviations Used in Table 5

USA:	United States
CAN:	Canada
MEX:	Mexico/Chile
EUR:	OECD Europe
JAN:	Japan
ANZ:	Australia/New Zealand
SKO:	South Korea
RUS:	Russia
URA:	Other non-OECD Europe and Eurasia
CHI:	China
IND:	India
OAS:	Other non-OECD Asia
MID:	Middle East
AFR:	Africa
BRZ:	Brazil
CSA:	Other non-OECD Americas
DS:	Distillate
KS:	Kerosene
LG:	Liquefied Petroleum Gas
NG:	Natural Gas
CL:	Coal
EL:	Electricity
HT:	Heat

Appendix D. References

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

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10. International Energy Agency, *World Energy Outlook 2015 Edition*, Paris, France, (November 2015).

Appendix E. 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 covers 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 forecasts are provided by region from EIA's *Short-Term Energy Outlook.*
- *International Statistics Database* – The U.S. Energy Information Administration provides historical data on international energy consumption by fuel type. These data are used as the historical basis for all regional projections that appear in the *IEO2017*.

International Energy Agency – The by 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 U.S. Energy Information Administration's international statistical data base.

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 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 and extreme variability