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World Energy Projection System Plus: District Heat Module

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1. Introduction

Purpose of this report

The District Heat Model of the World Energy Projection System Plus (WEPS+) is a regional-level energy transformation modeling system. This report describes the version of the District Heat Model that was used to produce the energy projections published in the International Energy Outlook 2016 (IEO2016). It documents the objectives, analytical approach and development of the model and describes critical assumptions, computational methodology, parameter estimation techniques, and model source code.

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

Model summary

The WEPS+ District Heat Model projects the amount of heat generated, by region, to satisfy the heat demand projected by the WEPS+ Residential Model, the Commercial Model, and the Industrial Model. The District Heat Model also calculates the total and by-fuel energy consumed for the purpose of heat generation. In addition, the model projects regional end-use prices of heat for the residential, commercial, and industrial sectors. The District Heat Model makes these annual projections for each of the 16 WEPS+ regions, addressing nine energy sources: distillate, residual fuel, crude oil, natural gas, coal, waste, biomass, geothermal, and nuclear power. Nuclear power is currently a placeholder, however, and was not used in the IEO2016. Inputs for the model include distillate and residual fuel prices from the Petroleum Model, natural gas prices from the Natural Gas Model, and coal prices from the Coal Model.

The District Heat model, in turn, exports its fuel consumption and district heat price projections to the shared restart file for use by other WEPS+ models. Fuel consumption data serves as an input to the Petroleum Model, Refinery Model, Natural Gas Model, and Coal Model, while retail district heat prices serve as an input to the Residential Model, Commercial Model, and Industrial Model.

Model archival citation

This documentation refers to the WEPS+ District Heat Model, as archived for the *International Energy Outlook 2016* (IEO2016).

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Organization of this report

Chapter 2 of this report discusses the purpose of the District Heat 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 District Heat 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+ District Heat Model is to calculate projections, by region and end-use sector, of the following:

- district heat generation
- quantities and types of fuels consumed in generating district heat
- district heat retail prices by fuel

As an integral component of the WEPS+ system, the District Heat Model provides inputs to the WEPS+ Residential Model, the Commercial Model, and the Industrial Model. It also contributes to the calculation of the overall energy supply and demand balance.

The District Heat Model provides projections for each of 16 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 Central and South America

Model inputs and outputs

Inputs

The District Heat Model uses heat consumption and retail price projections imported from the WEPS+ restart file. These inputs have been previously projected by the source models listed in Table 2.

Table 2. WEPS+ Models that provide Inputs to the District Heat Model

District Heat Model Input	Source
Residential heat consumption	Residential Model
Commercial heat consumption	Commercial Model
Industrial heat consumption	Industrial Model
District heat distillate retail price	Refinery Model
District heat residual fuel retail price	Refinery Model
District heat natural gas retail price	Natural Gas Model
District heat coal retail price	Coal Model

The District Heat Model imports several exogenous data series from the HeatInput.xml file (Table 3).

Table 3. Major Exogenous District Heat Model Input Data Series

Source Input File	Model Input
HeatInput.xml	Transmission and distribution loss factors
	Regional retirement rate
	Regional efficiency ratio between new and existing heat capacity
	Regional efficiency index for existing capacity (2006 = 1.0)
	Regional efficiency index for new capacity (2006 = 1.0)

Outputs

The District Heat Model projects energy consumption for district heat by fuel type, end-use sector, and region. The model also calculates retail district heat prices for the residential, commercial, and industrial sectors. Upon completion of a model run, these values are exported to the WEPS+ restart file for use by other models (Table 4).

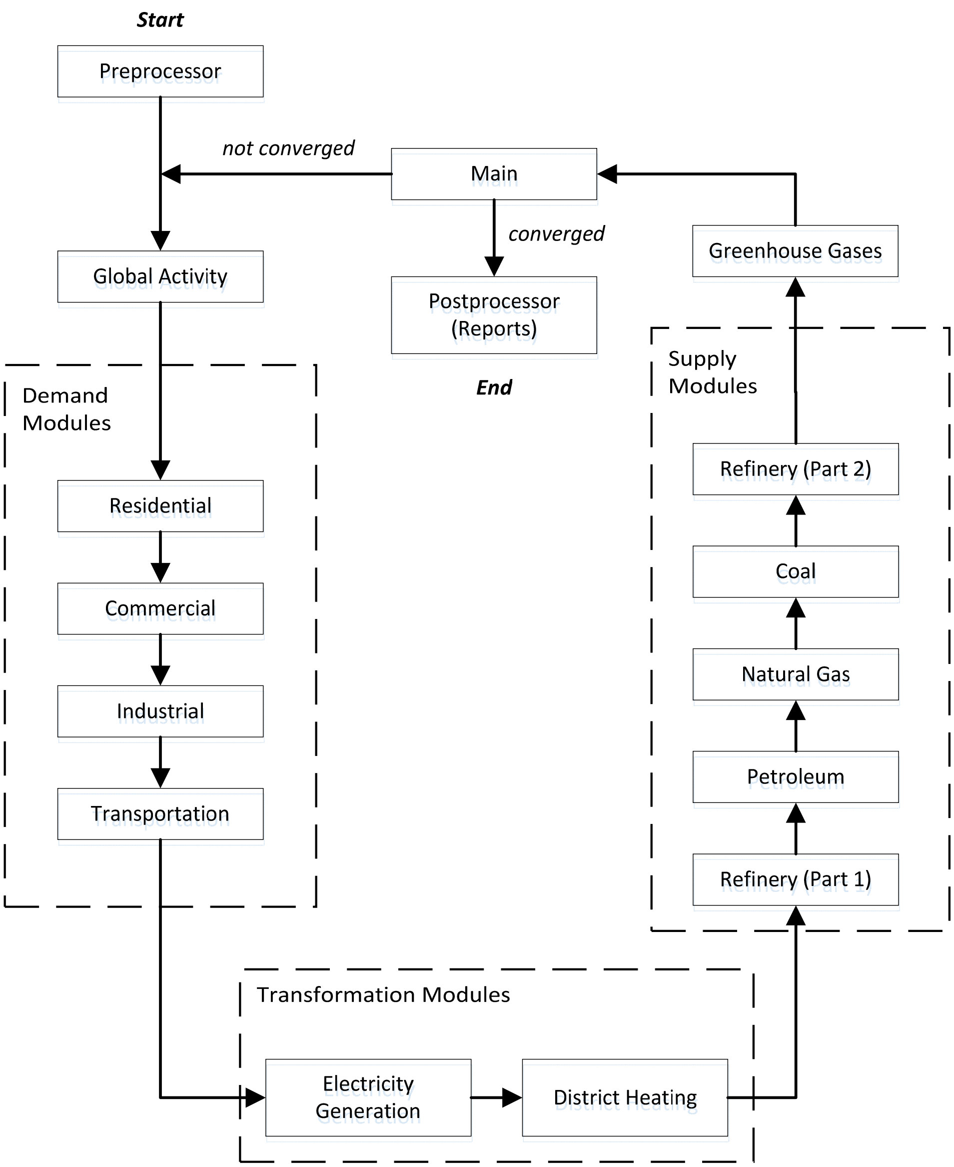
Table 4. District Heat Model Outputs and the WEPS+ Models that use them

District Heat Model Output	Destination
Distillate consumption	Petroleum Model and Refinery Model
Residual fuel consumption	Petroleum Model and Refinery Model
Crude oil consumption	Petroleum Model and Refinery Model
Natural gas consumption	Natural Gas Model
Coal consumption	Coal Model
Waste consumption	-
Biomass consumption	-
Geothermal consumption	-
Residential district heat retail price	Residential Model
Commercial district heat retail price	Commercial Model
Industrial district heat retail price	Industrial Model

Relationship to other models

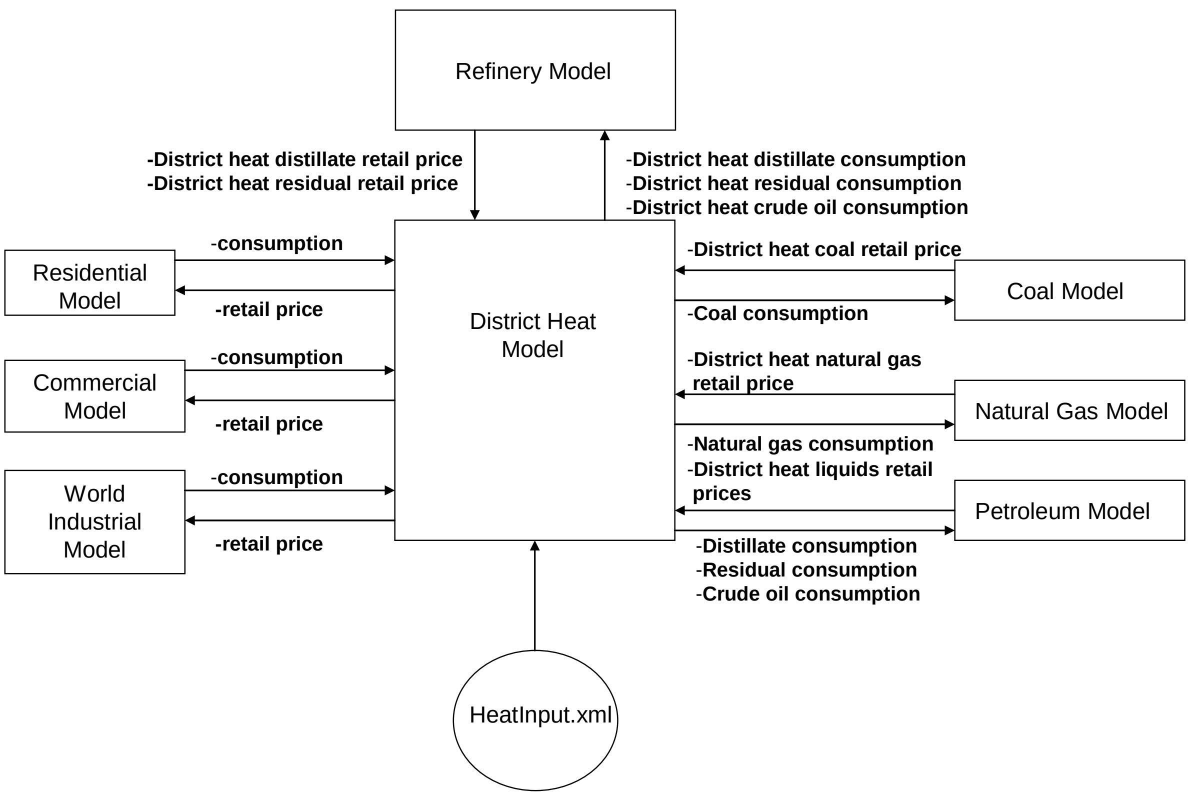
The District Heat Model depends on other models in the WEPS+ system for some of its key inputs. In turn, the District Heat Model provides projections of energy consumption and prices, on which other models in the system depend for their key inputs (Figure 1). A summary description of the models, flows,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

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



Through the system, the District Heat Model receives residential, commercial, and industrial sector district heat consumption projections from the Residential Model, the Commercial Model, and the Industrial Model, respectively (Figure 2). It also receives district heat retail price projections for various fuels from the appropriate supply models. In turn, the District Heat Model provides consumption projections, through the system, back to the supply models. The District Heat Model also recalculates retail price projections related to district heat – broken out by end-use sector and fuel – and provides the data to the appropriate end-use sector demand models.

Figure 2. The District Heat Model Relationship to Other WEPS+ Models



3. Model Rationale

Theoretical approach

The District Heat Model is a component of the WEPS+ energy modeling system. WEPS+ is a modular system, consisting of several separate energy models that communicate and work together through the overall system model. Developed independently, these models 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 price projections to a simultaneous equilibrium solution.

The District Heat Model uses a stock/flow approach in which new heat generation capacity is added in each projection year, as necessary, to meet demand for heat generation from the residential, commercial, and industrial end-use demand sectors. The heat generation requirement is compared to the amount of existing capacity for heat generation after annual capacity retirements. Before adding new heat capacity to meet generation demand, however, the model accounts for the amount of heat available from combined heat and power (CHP) plants in the electric power sector and applies these amounts to the increased demand. Prices for district heating are calculated based on fuel consumed, which is a function of historical fuel consumption-generation ratios and expected efficiency improvements over the model projection period.

Model assumptions

The District Heat Module assumes that the sector has the following characteristics:

- Transmission and distribution loss factors are equal to 0.85 across all regions and years.
- Retirement rates are equal to 2% across all regions and years.
- The efficiency ratio of new capacity relative to capacity remaining from 2006 is 0.8 for all regions. This ratio is fixed regardless of year.
- The efficiency index for new capacity, defined as the amount of fuel required to generate a given amount of heat in a specific year relative to 2006 values, further declines at a rate of 0.2% per year for all regions.
- The efficiency index for capacity remaining from 2006 declines at a rate of 0.4% per year for all regions.
- Shares of district heat generation and consumption by fuel are assumed to be fixed throughout the projection period and equal to values in the last historical year.
- For Europe, projected amounts of district heat generation and consumption from renewables do not decrease below the amounts observed in the last historical year.
- To calculate district heat prices in the residential, commercial, and industrial sectors, the model assumes a sector-specific adder equal to half of the electricity adder for that sector. This adder is added to the weighted average price of fuels consumed for generation.

4. Model Structure

Structural overview

The main purpose of the District Heat Model is to estimate heat generation and the amount of fuel consumed for heat generation – by region and fuel type – annually over the projection period. The model uses a stock/flow approach in which new heat generation is added each year as necessary, based on the heat generation requirement from the end-use demand sectors. Values are estimated for each of the regions for nine energy sources (distillate, residual fuel, crude oil, natural gas, coal, waste, biomass, geothermal, and nuclear power, which is currently a placeholder and was not used in the IEO2016).

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

The main District Heat Model calls the Heat subroutine (Figure 4), which begins by importing the following exogenous data series from the HeatInput.xml data file:

- Regional estimates of transmission and distribution (t&d) loss factors
- Retirement rates for heat generating capacity
- A ratio of the efficiency of new capacity to the efficiency of existing capacity (TranEff)
- Annual and regional efficiency indices for existing heat generating capacity and new capacity

The subroutine adjusts the imported data for any assumed carbon tax by recalculating retail prices (accessed through the restart file) for distillate fuel, residual fuel, natural gas, and coal. (No carbon tax adjustment factors were used for IEO2016 model runs.)

For some regions, the historical heat generation and heat requirements data are inconsistent. The model therefore checks to determine whether requirements in the historical year exceed actual generation. If the requirements do not exceed generation, the model sets a regional adjustment factor (GenAdj(r)) to 1. If requirements exceed generation, the model sets GenAdj(r) to the total generation divided by a t&d loss factor plus required generation. The factor GenAdj(r) is multiplied by the total heat demand and is used in the computations of generation and capacity to ensure that inaccuracies in the historical data cause no unintended deviations in the projections.

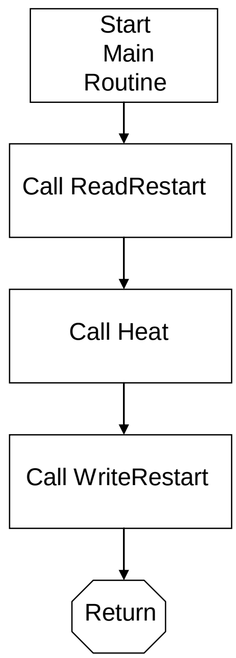
After resolving any inconsistencies in the historical data, the model projects total heat generation by region, based on existing generation, new demand, and annual capacity retirements. It then projects fuel consumption and allocates the total fuel use to the nine sources considered, based on historical proportions. Next, the model projects liquids consumption in the district heat sector for each region and benchmarks the projections to the regional *Short-Term Energy Outlook* (STEO) projections. (For the IEO2016, the August 2015 STEO release was used. STEO benchmarking was switched off for the District

Heat model for the IEO2016.) Finally, the model calculates projections of retail district heat prices for the residential, commercial, and industrial sectors.

After the Heat subroutine has executed, the model calls the WriteRestart subroutine, which writes the projections to the WEPS+ restart file for use in future iterations of WEPS+. These output data series include projections of fuel consumption, by fuel type, in the district heat sector as well as end-use sector retail prices.

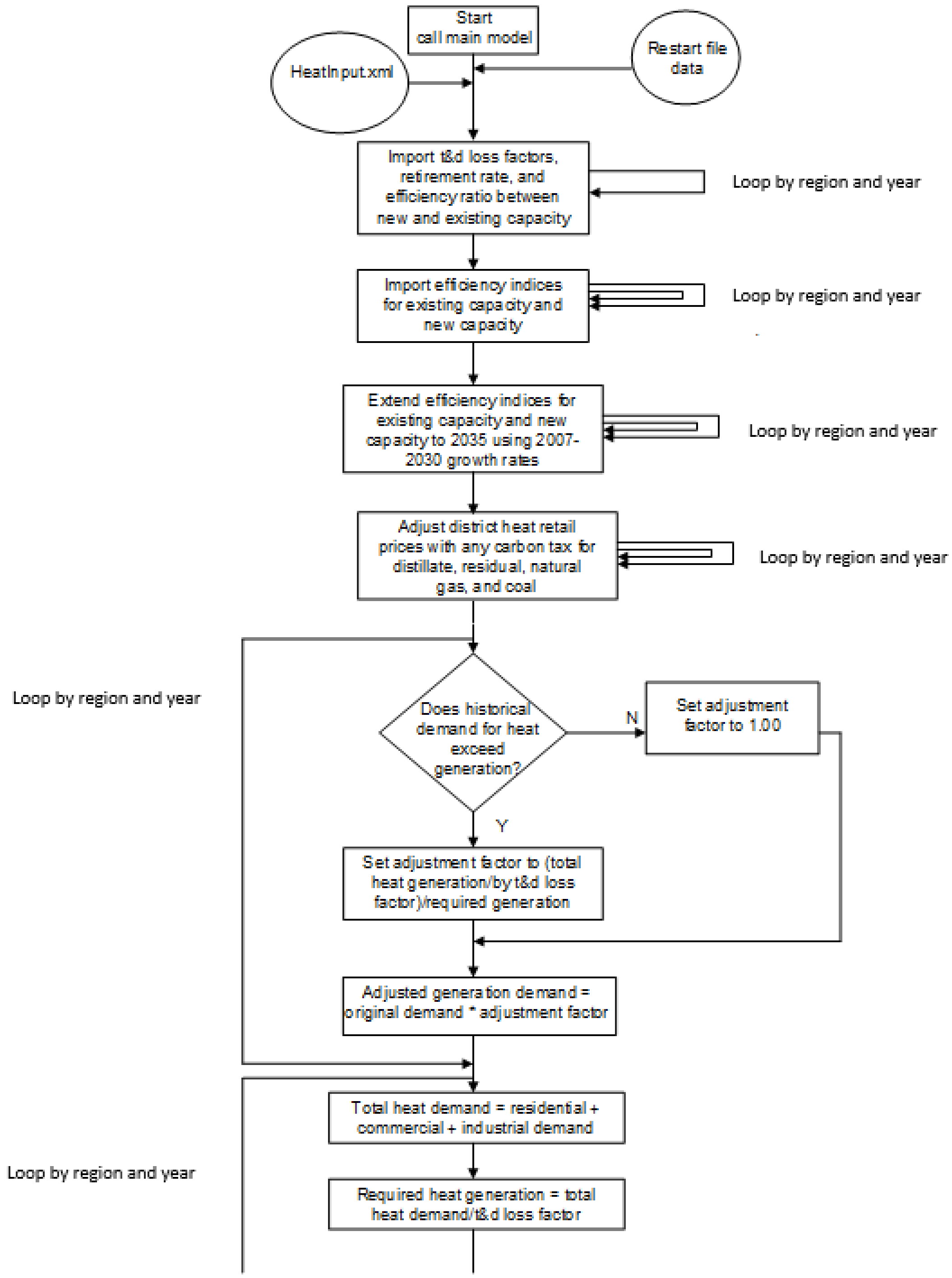
Flow diagrams

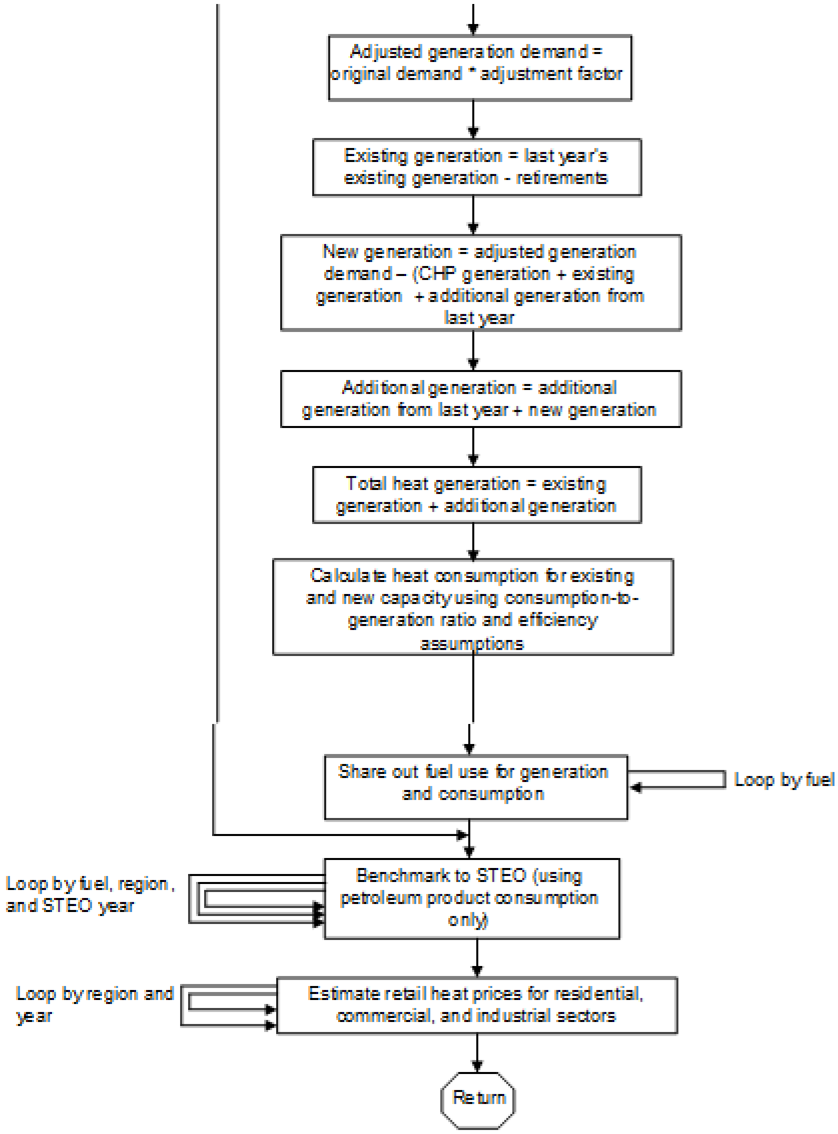
Figure 3. Flowchart for the District Heat Model



Loop by region and year

Figure 4. Flowchart for the Heat Subroutine





Key computations

The District Heat Model uses a stock/flow approach in which it adds new heat generation each year as necessary, based on the heat generation requirement from the end-use demand sectors. The model compares this generation requirement to the amount of existing capability for heat generation, added to the heat that is available from combined heat and power (CHP) plants in the power generation sector. The model does not have an explicit capacity variable. Rather, it implicitly assumes that there is some capacity that provides heat generation, and that the relationship between the generation and implicit capacity—the capacity factor—is always constant. In other words, heat generation is used as a proxy for capacity and the model assumes that no excess capacity exists. The District Heat Model addresses nine energy sources:

- Distillate
- Residual
- Crude oil
- Natural gas
- Coal
- Waste
- Biomass
- Geothermal
- Nuclear power (currently a placeholder and not used in the *IEO2016*)

All fuel and energy quantities in the District Heat Model are expressed in British thermal units (Btu).

Generation and consumption in stock/flow accounting

The model begins by importing the historical values from the restart file. For the *IEO2016,* historical data is imported from 2005 to 2012, the last historical year. For each of the nine fuels listed above, these historical values detail the amount of fuel consumed and the amount of heat generated by each fuel. With regard to total fuel-for-heat consumption, the ratio of the amount of fuel consumed to the amount of heat generated is essentially the inverse of the overall efficiency of heat generation. This ratio is calculated from the last historical year data and used throughout the projection calculations.

$$CGRatio(r, y = LHYr) = \frac{HeatCon(r.y = LHYr)}{HeatGen(r, y = LHYr)},$$

where, for region r,

$CGRatio(r, y = LHYr)$ = ratio of consumption to generation in the last historical year;

$HeatCon(r.y = LHYr)$ = total fuel consumed to generate heat in the last historical year; and

$HeatGen(r, y = LHYr)$ = total heat generated in the last historical year.

For some regions, the original historical heat data are inconsistent. The historical data are used to calculate the total amount of heat generation required to meet demand. This value is equivalent to the end-use consumption of heat divided by the distribution loss factor. Theoretically, this amount should equal the total amount of heat generated, which is the total heat generated either in the district heat sector or by CHP plants (in the electric power sector). For a few regions, the total heat generated exceeds the required generation. For these regions the model uses the last historical year data to calculate an “over-generation ratio”: the ratio of total generation to required generation (accounting for distribution loss). This ratio, which represents the scale of the inconsistency in the original data, is used to adjust all of the heat demand projections for the region. This adjustment, which affects only a few regions, is not shown in the equations in this section.

The District Heat Model is a stock/flow accounting model that uses a simple vintage structure to account for fuel consumption and heat generation. As noted above, there is no direct capacity variable in the model; capacity is implicit, and generation is used as a proxy. Although for the sake of simplicity, much of the discussion in this document refers to capacity, this is actually a reference to the capacity implied by the generation figures, with no excess capacity assumed.

The model uses a simple set of heat generation vintage categories:

- Remaining (existing) –Heat generation from capacity remaining from the last historical year
- New –Heat generation from capacity added in the current projection year
- Added –Heat generation from capacity added between the last historical year and the end of the projection year
- Total – Total heat generation in the current projection year (sum of remaining and added)

Fuel consumption is handled in the same way, and the details are not described in this document.

The first step for each projection year *y* is to retire some of the capacity (generation) remaining from the last historical year. The values for the retirement rates by region are imported from an input file; they are currently all set to 2% per year. The remaining generation is calculated as

$$GenRem(r,y) = GenRem(r,y-1) * \left(1 - RetRate(r)\right),$$

where, for region r and year y,

$GenRem(r,y)$ = generation remaining in year y from the last historical year capacity;

and

$RetRate(r)$ = annual retirement rate for region r (assumed constant across years).

The model first calculates the heat generation available from the district heat sector at the beginning of projection year *y* as the amount of generation still available from the remaining historical capacity *plus* the amount of generation that has been added between the last historical year and the end of year *y*-1:

$$AGenDH(r,y) = GenRem(r,y) + GenAdd(r,y-1),$$

where, for region r,

$GenAdd(r, y)$ = generation added between the last historical year and the beginning of year y; and

$AGenDH(r, y)$ = available generation from district heat at the beginning of year y.

In addition to the district heat sector, CHP plants (in the electric power sector) may also generate heat during the projection year *y*. The World Electricity Model projects generation from CHP plants. The total amount of heat generation already available for year *y* (before any new generation is added) is computed as the sum of the district heat sector generation available from year *y*-1 and the heat generated by CHP plants:

$$AGenTot(r, y) = AGenDH(r, y,) + AGenPG(r, y),$$

where, for region r and year y,

$AGenPG(r, y)$ = generation available from CHP plants in year y; and

$AGenTot(r, y)$ = generation available at the beginning of year y, before adding new generation from district heating.

Next, the amount of the total heat generation requirement is calculated as the total end-use sector heat demand in each region, divided by the distribution loss factor. The District Heat Model adds the consumption estimates projected by the WEPS+ residential, commercial, and industrial demand models:

$$THDem(r, y) = QHTRS(r, y) + QHTCM(r, y) + QHTIN(r, y),$$

where, for region r in year y,

$QHTRS(r, y)$ = residential sector heat demand;

$QHTCM(r, y)$ = commercial sector heat demand;

$QHTIN(r, y)$ = industrial sector heat demand; and

$THDem(r, y)$ = total heat demand in each region and year.

Generation requirements for year y are projected as

$$RGenTot(r, y) = \frac{THDem(r, y)}{TDLoss(r)},$$

where, for region r,

$TDLoss(r)$ = total distribution loss factor; and

$RGenTot(r, y)$ = generation requirements for year y.

The heat generation requirements are compared to the total heat generation available. If more generation must be added to meet the generation requirements, the amount of new generation or capacity needed is calculated:

If $RGenTot(r,y) > AGenTot(r,y)$,

then $GenNew(r,y) = RGenTot(r,y) - AGenTot(r,y)$;

otherwise, $GenNew(r,y) = 0.0$,

where $GenNew(r,y)$ is the amount of new generation added in region r in year y.

The model updates the added generation value for year y and adds this amount to the generation remaining from the historical capacity:

$$GenAdd(r,y) = GenAdd(r,y-1) + GenNew(r,y),$$

$$GenTot(r,y) = GenRem(r,y) + GenAdd(r,y),$$

where $GenTot(r,y)$ = total district heating generation in region r and year y

The model projects total fuel consumption based on the calculated total generation and assumed conversion efficiency ratios. First, the ratio of heat consumption to heat generation in the last historical year is computed for each region, (*CGRatio(r,y=LHYr))*, as an estimate of historical conversion efficiency. The model assumes that efficiency for the newly added generation capacity exceeds the historical efficiency, as represented by *CGRatio(r,y=LHYr).* The user provides a regional adjustment factor, *TranEff(r)*, which represents the efficiency of the newly added capacity relative to historical capacity for region r. Finally, the efficiency for the remaining capacity and the efficiency for the new capacity are both assumed to improve over time. The efficiency gains for the remaining and new capacity in year *y* are represented by adjustment factors *RemEff(r,y)* and *NewEff(r,y),* respectively; these factors are also user-specified.

The model calculates the consumption from the remaining historical stock:

$$ConRem(r,y) = GenRem(r,y) * CGRatio(r,y = LHYr) * RemEff(r,y),$$

where, for region r in year y,

$ConRem(r,y)$ = amount of fuel consumed for remaining generation capacity from the last historical year;

$RemEff(r,y)$ = efficiency adjustment factor for existing (remaining after retirement) capacity (2006=1); and

$CGRatio(r,y = LHYr)$ = ratio of heat consumption to generation in the last historical year.

The resulting consumption for the new generation in year y is given by

$$ConNew(r, y) = GenNew(r, y) * CGRatio(r, y = LHYr) * NewEff(r, y),$$

where, for region r,

> $TranEff(r)$ = efficiency ratio of newly added capacity to remaining historical capacity, assumed constant across years;
>
> $NewEff(r, y)$ = efficiency ratio of new capacity in projection year y to remaining capacity (2006=1), assumed to vary by year; and
>
> $ConNew(r, y)$ = amount of fuel consumed for new generation in year y.

The consumption vintage accounting for year *y* is given by

$$ConAdd(r, y) = ConAdd(r, y - 1) + ConNew(r, y); \text{ and}$$

$$ConTot(r, y) = ConRem(r, y) + ConAdd(r, y),$$

where, for region r in year y,

> $ConAdd(r, y)$ = fuel consumed for generation added between the last historical year and the end of year y; and
>
> $ConTot(r, y)$ = total fuel consumed for district heating generation in year y.

The model then allocates the fuel consumption to individual energy sources, with the shares assumed to be the same as the fuel shares from the last historical year. This is a simplified assumption that implies that the mix of fuels consumed does not change over the projection period.

STEO Calibration

The EIA *Short-Term Energy Outlook* (STEO) projects worldwide liquid fuels consumption in the near term by region. The STEO regions are more aggregate than those in the WEPS+, and there is no sectoral or product detail included. Nonetheless, the projections must replicate the STEO projections for the STEO projection years. The WEPS+ Main Model reads the STEO data in each iteration. Based upon the results of the current iteration, the Main Model shares the total regional liquids consumption to the WEPS+ regions and all the detailed end-use sectors. (The power generation sector is not included in the allocation routine, because its consumption of liquid fuels is very small and because the World Electricity Model is much more complex in terms of energy transformation.) The regional and sectoral allocations are calculated within the Main Model and exported to the restart file for use by the WEPS+ demand models and the District Heat Model. The IEO2016 uses the August 2015 STEO, which forecasts liquids consumption through 2020; however, STEO benchmarking was switched off for the District Heat Model for the IEO2016.

The District Heat Model imports the STEO liquids allocations for the district heat sector from the restart file and computes calibration factors for each petroleum product by region for each year in the STEO forecast. These factors are simply the ratio of the allocated STEO district heat consumption to the model's projected consumption, by region and year:

For each year in the STEO forecast,

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

where, for region r in year y,

$STEOQty(r,y)$ = STEO liquids consumption allocation for district heat;

$DHQty(f = petroleum, r, y)$ = District Heat Model's total petroleum consumption for district heat; and

$STEOFac(r,y)$ = STEO calibration factor.

The liquids consumption projections from the District Heat Model for *STEO* forecast years are multiplied by the *STEO* calibration factors to force consistency with the STEO consumption projections:

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

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

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

where, for region r in year y,

$QDSDH(r,y)$ = STEO-calibrated district heat distillate consumption;

$QDSDH'(r,y)$ = uncalibrated district heat distillate consumption;

$QRSDH(r,y)$ = STEO-calibrated district heat residual consumption;

$QRSDH'(r,y)$ = uncalibrated district heat residual consumption;

$QCDDH(r,y)$ = STEO-calibrated district heat crude (directly used) consumption; and

$QCDDH'(r,y)$ = uncalibrated district heat crude (directly used) consumption.

Because the magnitude of the *STEO* adjustment in the last *STEO* forecast year can be significant, a break in series would result from use of the direct model-calculated consumption in the next projection year. Modified *STEO* calibration factors are therefore applied to the estimates for the next 10 projection years. The modified factors gradually approach 1 over these years, smoothing the transition between *STEO* forecast and *IEO* projection.

Retail District Heat Price Projections

The next step is to project end-use retail prices for district heat for each of the end-use sectors, so that district heat consumption can be related to price. Because there is currently no historical information on retail district heat prices, the model estimates heat prices from fuel costs, adding approximate generation costs and sector-level markups. The district heat prices are largely adapted from prices used in the World Electricity Model, which are based on the cost of the fuel consumed, capital costs, and other costs associated with the electricity generation, transmission, and distribution. The District Heat Model assumes that the capital costs for heat generation are less than those for power generation, and the model only accounts for distribution capital costs. The cost of district heat generation is assumed to be roughly half that of electricity generation. The cost of electricity generation is based on the weighted average price of fuels consumed for electricity generation compared to the final end-use electricity price in EIA's *Annual Energy Outlook 2016*.

The first step is to estimate a weighted average fuel cost for each region and year:

$$AFCost(r,y) = \frac{\sum_f [ConFuel(f,r,y) * PrcFuel(f,r,y)]}{\sum_f ConFuel(f,r,y)},$$

where, for region r in year y,

$ConFuel(f,r,y)$ = consumption of fuel f;

$PrcFuel(f,r,y)$ = price of fuel f; and

$AFCost(r,y)$ = weighted average fuel cost.

Next, the price (expressed as real dollars per million Btu) is adjusted by adding markups for each sector given by

$PHTRS(r,y) = AFCost(r,y) + 12;$

$PHTCM(r,y) = AFCost(r,y) + 11;$ and

$PHTIN(r,y) = AFCost(r,y) + 7,$

where, for region r in year y,

$PHTRS(r,y) =$ residential retail heat price;

$PHTCM(r,y) =$ commercial retail heat price; and

$PHTIN(r,y) =$ industrial retail heat price.

Appendix A: Model Abstract

Model name:

District Heat Model of the World Energy Projection System Plus

Model acronym:

District Heat Model

Model description:

The District Heat Model of the World Energy Projection System Plus (WEPS+) is a computer-based energy transformation modeling system at a regional level. For the IEO2016, the District Heat Model projects the amount of heat generated to satisfy the heat demands projected in the WEPS+ Residential Model, the Commercial Model, and the Industrial Model. The model also projects the amount of fuel consumed for heat generation, and the end-use price of heat for the residential, commercial, and industrial sectors. The model addresses nine energy sources: distillate, residual fuel, crude oil, natural gas, coal, waste, biomass, geothermal, and nuclear power, which is currently a placeholder and not used in the IEO2016. Projections are made for each of the 16 WEPS regions, over the projection period to the year 2040.

Model purpose:

As a component of the WEPS+ integrated modeling system, the District Heat Model generates long-term projections of heat generation, fuels consumed for the purpose of district heat generation, and end-use prices for heat. As part of the system, the model provides inputs to the WEPS+ Residential Model, the Commercial Model, and the Industrial Model, as well as the Refinery Model, Natural Gas Model, and Coal Model. It also contributes to the calculation of the overall energy supply and demand balance. The model provides a tool for analysis of international heat generation within the WEPS+ system, and can also run independently as a standalone model.

Most recent model update:

December 2009

Part of another model:

World Energy Projection System Plus (WEPS+)

Model interfaces:

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

Official model representative:

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Documentation: Energy Information Administration, U.S. Department of Energy, District Heat Model of the World Energy Projection System Plus: Model Documentation, DOE/EIA-M077 (2016) (Washington, DC, December 2016).

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 2016.

Energy system described: International district heat generation and energy consumption

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

Mode: total district heat generation and energy consumption.

Time unit/frequency: Annual, through 2040.

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

Independent expert reviews: None

Computing environment:

Hardware/Operating System: Basic PC with Windows
Language/Software Used: Python, 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 HeatInput-2010_07_25.xml.

Classification: Input variable.

TDLoss(r): Transmission and distribution loss factors by region

RetRate(r): Retirement rate by region

TranEff(r): Efficiency ratio between new and existing (remaining after retirement) capacity by region

RemEff(r,y): Efficiency index for existing (remaining after retirement) capacity (2006=1.0) by region and year

NewEff(r,y): Efficiency index for new capacity (2006=1.0) by region and year

The following variables represent data imported from the restart file.

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

PDSDH(r,y): Retail price of distillate fuel for district heat generation by region and year

PRSDH(r,y): Retail price of residual fuel for district heat generation by region and year

PNGDH(r,y): Retail price of natural gas for district heat generation by region and year

PCLDH(r,y): Retail price of coal for district heat generation by region and year

ADSDH(r,y): Carbon price increment to the district heat distillate (diesel) fuel price associated with the carbon allowance price by region and year (dollars per million Btu)

ARSDH(r,y): Carbon price increment to the district heat distillate (diesel) fuel price associated with the carbon allowance price by region and year (dollars per million Btu)

ANGDH(r,y): Carbon price increment to the district heat natural gas price associated with the carbon allowance price by region and year (dollars per million Btu)

ACLDH(r,y): Carbon price increment to the district heat coal price associated with the carbon allowance price by region and year (dollars per million Btu)

SHCNDS(t,r,y): Historical district heat sector consumption of distillate fuel by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHCNRS(t,r,y): Historical district heat sector consumption of residual fuel by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHCNCD(t,r,y): Historical district heat sector consumption of crude oil by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHCNNG(t,r,y): Historical district heat sector consumption of natural gas by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHCNCL(t,r,y): Historical district heat sector consumption of coal by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHCNWS(t,r,y): Historical district heat sector consumption of waste by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHCNBM(t,r,y): Historical district heat sector consumption of biomass by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHCNGT(t,r,y): Historical district heat sector consumption of geothermal energy by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHCNNU(t,r,y): Historical district heat sector consumption of nuclear by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year (years 2005 through 2012). This was not used for *IEO2016*.

SHGNDS(t,r,y): Historical district heat sector generation of distillate fuel by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHGNRS(t,r,y): Historical district heat sector generation of residual fuel by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHGNCD(t,r,y): Historical district heat sector generation of crude oil by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHGNNG(t,r,y): Historical district heat sector generation of natural gas by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHGNCL(t,r,y): Historical district heat sector generation of coal by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHGNWS(t,r,y): Historical district heat sector generation of waste by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHGNBM(t,r,y): Historical district heat sector generation of biomass by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHGNGT(t,r,y): Historical district heat sector generation of geothermal energy by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHGNNU(t,r,y): Historical district heat sector generation of nuclear by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year. This was not used for *IEO2016*.

SHUCNDS(t,r,y): Historical utility consumption of distillate fuel by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHUCNRS(t,r,y): Historical utility consumption of residual fuel by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHUCNCD(t,r,y): Historical utility consumption of crude oil by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHUCNNG(t,r,y): Historical utility consumption of natural gas by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHUCNCL(t,r,y): Historical utility consumption of coal by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHUCNWS(t,r,y): Historical utility consumption of waste by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHUCNBM(t,r,y): Historical utility consumption of biomass by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHUCNGT(t,r,y): Historical utility consumption of geothermal energy by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHUCNSL(t,r,y): Historical utility consumption of solar energy by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHUCNWN(t,r,y): Historical utility consumption of wind power by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHUCNOR(t,r,y): Historical utility consumption of other renewable energy resources by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SHUCNNU(t,r,y): Historical utility consumption of nuclear by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year. This was not used for *IEO2016*.

SUGNDS(t,r,y): Historical utility generation from distillate fuel by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SUGNRS(t,r,y): Historical utility generation from residual fuel by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SUGNCD(t,r,y): Historical utility generation from crude oil by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SUGNNG(t,r,y): Historical utility generation from natural gas by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SUGNCL(t,r,y): Historical utility generation from coal by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SUGNWS(t,r,y): Historical utility generation from waste by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SUGNBM(t,r,y): Historical utility generation from biomass by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SUGNGT(t,r,y): Historical utility generation from geothermal energy by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SUGNSL(t,r,y): Historical utility generation from solar energy by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SUGNWN(t,r,y): Historical utility generation from wind power by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SUGNOR(t,r,y): Historical utility generation from other renewable energy resources by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year

SUGNNU(t,r,y): Historical utility generation from nuclear reactors by type (t=1 for heat generation only, =2 for CHP, and =3 for total generation), region, and year. This was not used for *IEO2016*.

QHHTRS(r,y): Historical district heat consumption in the residential sector by region and year

QHHTCM(r,y): Historical district heat consumption in the commercial sector by region and year

QHHTIN(r,y): Historical district heat consumption in the industrial sector by region and year

QHDSDH(r,y): Historical distillate fuel consumption in the district heat sector by region and year

QHRSDH(r,y): Historical residual fuel consumption in the district heat sector by region and year

QHCRDH(r,y): Historical crude oil consumption in the district heat sector by region and year

QHNGDH(r,y): Historical natural gas consumption in the district heat sector by region and year

QHCLDH(r,y): Historical coal consumption in the district heat sector by region and year

QHWSDH(r,y): Historical waste consumption in the district heat sector by region and year

QHBMDH(r,y): Historical biomass consumption in the district heat sector by region and year

QHTRS(r,y): Quantity of district heat consumed in the residential sector by region and year

QHTCM(r,y): Quantity of district heat consumed in the commercial sector by region and year

QHTIN(r,y): Quantity of district heat consumed in the industrial sector by region and year

STEOPTDH(r,y): Projections of liquids consumption for the district heat sector based on EIA's *Short-Term Energy Outlook* by region and year

The following variables represent data calculated in the subroutine Heat.

Classification: Computed variable.

SHCNDS(1,r,y): *C*onsumption of distillate fuel for heat generation alone (type=1) by region and year

SHCNRS(1,r,y): Consumption of residual fuel for heat generation alone (type=1) by region and year

SHCNCD(1,r,y): Consumption of crude oil for heat generation alone (type=1) by region and year

SHCNNG(1,r,y): Consumption of natural gas for heat generation alone (type=1) by region and year

SHCNCL(1,r,y): Consumption of coal for heat generation alone (type=1) by region and year

SHCNWS(1,r,y): Consumption of waste for heat generation alone (type=1) by region and year

SHCNBM(1,r,y): Consumption of biomass for heat generation alone (type=1) by region and year

SHCNGT(1,r,y): Consumption of geothermal for heat generation alone (type=1) by region and year

SHCNNU(1,r,y): Consumption of nuclear generation for heat generation alone (type=1) by region and year. For *IEO2016* this is a placeholder

SHGNDS(1,r,y): Heat generation associated with distillate fuel by region and year

SHGNRS(1,r,y): Heat generation associated with residual fuel by region and year

SHGNCD(1,r,y): Heat generation associated with crude oil by region and year

SHGNNG(1,r,y): Heat generation associated with natural gas by region and year

SHGNCL(1,r,y): Heat generation associated with coal by region and year

SHGNWS(1,r,y): Heat generation associated with waste by region and year

SHGNBM(1,r,y): Heat generation associated with biomass by region and year

SHGNGT(1,r,y): Heat generation associated with geothermal by region and year

SHGNNU(1,r,y): Heat generation associated with nuclear power by region and year. For *IEO2016* this is a placeholder

QDSDH(r,y): Consumption of distillate fuel used for district heat generation by region and year

QRSDH(r,y): Consumption of residual fuel used for district heat generation by region and year

QCDDH(r,y): Consumption of crude oil used for district heat generation by region and year

QNGDH(r,y): Consumption of natural gas used for district heat generation by region and year

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

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

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

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

PHTRS(r,y): Retail price of residential sector district heat by region and year

PHTCM(r,y): Retail price of commercial sector district heat by region and year

PHTIN(r,y): Retail price of industrial sector district heat by region and year

Appendix C. References

1. Walter Nicholson, *Microeconomic Theory: Basic Principles and Extensions* (Harcourt College Publishers, Fort Worth: Texas, 1972).
2. Alpha C. Chiang, *Fundamental Methods of Mathematical Economics* (McGraw-Hill Book Company, NY: NY, 1967).
3. Wayne L. Winston, *Operations Research: Applications and Algorithms* (Brooks/Cole—Thomson Learning, Belmont, CA, 2004).
4. International Energy Agency, *Energy Statistics and Balances of OECD Countries*, web site www.iea.org (subscription site).
5. International Energy Agency, *Energy Statistics and Balances of Non-OECD Countries*, web site www.iea.org (subscription site).
6. International Energy Agency, *World Energy Outlook 2010 Edition* (Paris, France, November 2010).

Appendix D. Data Quality

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 Energy Information Administration provides historical data on international primary energy consumption by fuel type for historical years These data are used as the historical basis for all regional projections that appear in the IEO2016.
- International Energy Agency – The subscription site www.iea.org provides historical data by energy product, end-use sector, and country from the OECD and non-OECD balances and statistics databases. These data are benchmarked to the historical aggregate energy consumption data in EIA's international statistical data base.

Data quality verification

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

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