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World Energy Projection System Plus: District Heat Model

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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 2017* (*IEO2017*). 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 seven energy sources: distillate, residual fuel, natural gas, coal, waste, biomass, and geothermal. 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 common database 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 2017* (*IEO2017*).

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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 Organisation for Economic Co-operation 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 and Chile	China
OECD Europe	India
Japan	Other Non-OECD Asia
Australia and New Zealand	Middle East
South Korea	Africa
	Brazil
	Other Non-OECD Americas

Model inputs and outputs

Inputs

The District Heat Model uses heat consumption and retail price projections imported from the WEPS+ common database. 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.xlsx file (Table 3).

Table 3. Major exogenous District Heat Model Input Data Series

Source Input File	Model Input
HeatInput.xlsx	Transmission and distribution loss factors by year
	Regional efficiency index for new capacity (2012 = 1.0)
	Regional discount rate
	Fuel price adder index (2012 = 1.0)
	Load factor by fuel
	Average plant lifetime by fuel
	Learning index for renewable fuels
	Capital cost by fuel and region
	Fixed O&M cost by fuel and region
	Variable O&M cost by fuel and region
	Exogenous generation targets by fuel and region

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+ common database for use by other models (Table 4).

Table 4. District Heat Model outputs and the WEPS+ models that use them

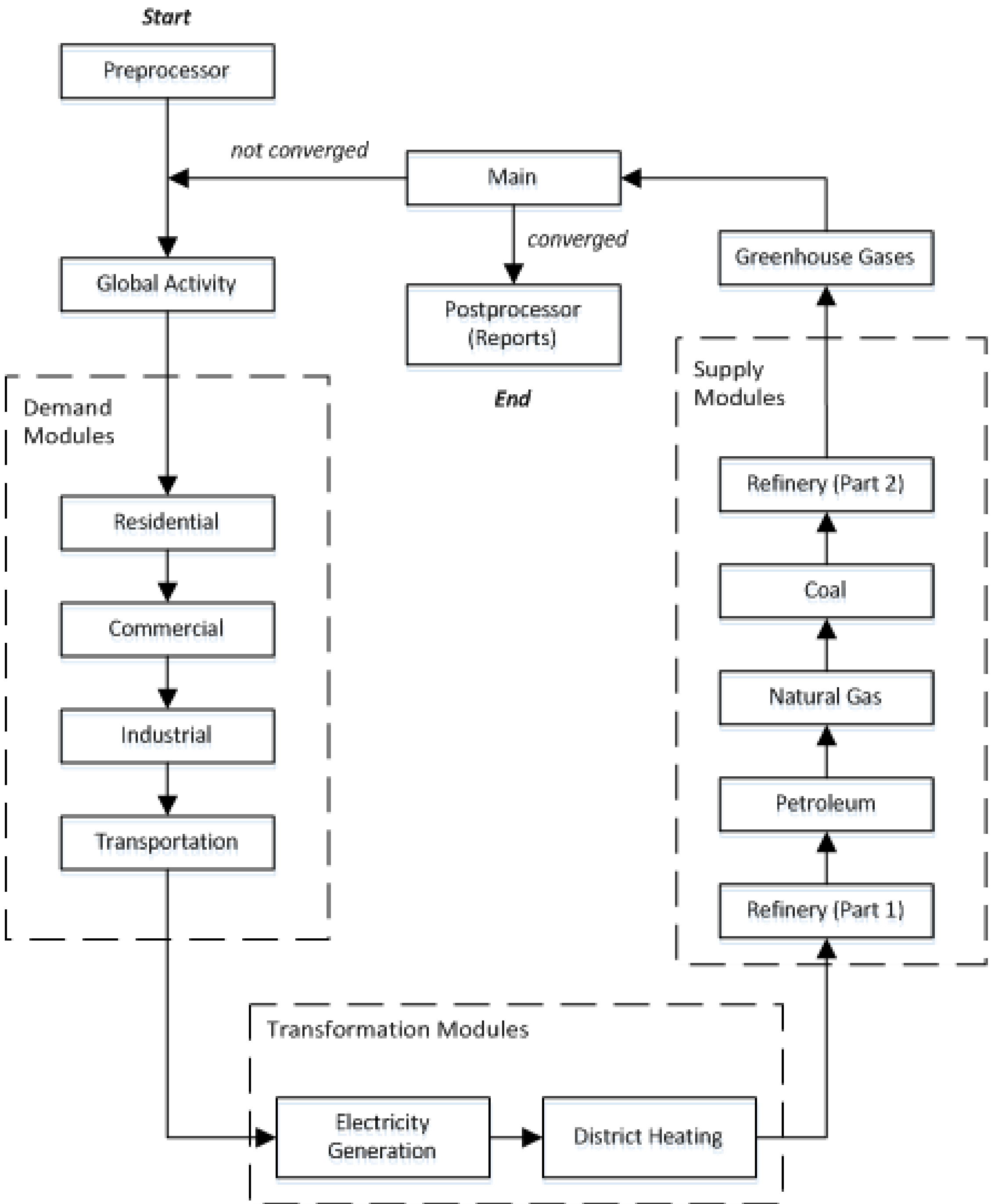
District Heat Model Output	Destination
Distillate consumption	Petroleum Model and Refinery Model
Residual fuel consumption	Petroleum Model and Refinery Model
Crude oil consumption	Petroleum Model and Refinery Model
Natural gas consumption	Natural Gas Model
Coal consumption	Coal Model
Waste consumption	Reporting
Biomass consumption	Reporting
Geothermal consumption	Reporting
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.

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. It also receives district heat retail price projections for various fuels from the appropriate supply models. With these inputs, the District Heat Model provides consumption projections, through the system, back to the supply models. The supply models, in turn, provide a breakdown of fuel consumption by end-use sector—Residential, Commercial, and Industrial—according to each sector's share of heat demand. 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 1. World Energy Projection System Plus (WEPS+) Model Sequence



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 common database 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. Fuel shares of new generation capacity are determined through a logit function that uses estimates of the levelized cost of new generation facilities to project market shares. Prices for district heating are calculated based on fuel consumed, which is a function of the calculated fuel shares, historical fuel consumption-generation ratios, and expected efficiency improvements over the model projection period.

Model assumptions

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

1. Total generation in each year is equal to heat demand net of generation from combined heat and power (CHP) facilities, adjusted by a transmission and distribution (T&D) loss factor. New generation capacity is added for each projection year as needed to make up the difference between existing generation capacity and generation required.

2. Choice of new generation capacity fuel is based on a least-cost market-share logit algorithm. Market shares of each fuel are determined based on levelized cost, which is calculated based on fuel prices, load factors, efficiency, and assumed operations and maintenance (O&M) and capital costs. In IEO2017, only one boiler technology choice is assumed to exist per fuel.

3. T&D losses and boiler efficiencies are assumed to improve at a constant rate per year from historical levels toward a target level. The T&D loss target is set at 10% for IEO2017, while the boiler efficiency target is set at 85%. None of the regions are assumed to fully accomplish the target by the target date, but they are assumed to accomplish a certain percentage of the target depending on whether they fall into the *robust policy* category. Regions are sorted into the *robust policy* category if they have recently adopted policies or strategies to improve efficiencies in their district heat sectors, and include China, Europe, Japan, Russia, and South Korea. These regions are assumed to accomplish 75% of the targets for efficiency and T&D losses. Other regions are assumed to accomplish 40% of the targets.

4. For IEO2017, discount rates are assumed to equal 7% for developed regions and 10% for developing regions.

5. The load factor is assumed to be 20% for all boiler technologies and regions.

6. The lifetime of generation plants is assumed to be 35 years for fossil technologies and 20 to 25 years for renewable technologies. The retirement rate for generation stock remaining from the historical period is assumed to be constant from year to year, and is equal to the inverse of the plant lifetime.

7. For renewable technologies, the model assumes modest learning, equivalent to a 1% reduction in non-fuel costs per year.

8. Capital costs and fixed and variable O&M costs are calibrated so that the model accurately predicts fuel consumption in historical years.

9. For IEO2017, the model specifies an exogenous 27% renewables target for OECD Europe by 2020. This target represents a weighted average of individual country renewables targets for the heating and cooling sector.[1]

[1] REN21, 2016. "Renewables 2016: Global Status Report." P. 181, Table R23: Heating and Cooling from Renewable Sources, Targets and 2014 Shares. Available at www.ren21.net/wp-content/uploads/2016/05/GSR_2016_Full_Report_lowres.pdf (accessed on February 23, 2017).

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 seven energy sources (distillate, residual fuel, natural gas, coal, waste, biomass, and geothermal).

The basic structure of the District Heat Model is illustrated in Figure 2. Once called by the WEPS+ interface, the District Heat Model imports values from the common database and the HeatInput.xlsx file and initializes the data structures needed to complete the projection calculations. The District Heat Model then calculates heat consumption, generation, and capacity additions by fuel in all years. Based on calculated fuel consumption and heat generation, it then determines retail heat prices. In its final step, the model exports all projections to the common database for use by other WEPS+ models.

The main District Heat Model creates an Inputs class, which imports and stores heat demand, historical generation and consumption, and fuel prices from the common database. The Inputs class also imports and stores exogenous data series from the HeatInput.xlsx data file, including transmission and distribution (T&D) loss factors, indices denoting changes in fuel consumption over time, discount rates, and technology attributes.

The District Heat Model creates a dictionary of Region objects that store regional attributes. These are either imported from HeatInput.xlsx or the common database, or calculated based on imported values. Values imported from the common database include generation, consumption, CHP generation, heat demand, fuel prices, heat prices, and carbon prices. Imported from the HeatInput.xlsx file are regional transmission and distribution loss factors, yearly efficiency indices for new generation facilities, discount rates, and consumer choice parameters.

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 actual generation, the model sets GenAdj(r) to the requirement divided by actual generation. The factor GenAdj(r), multiplied by the total heat demand, is used in the computations of generation and capacity to ensure that inaccuracies in the historical data cause no unintended deviations in the projections.

The model also creates a dictionary of Technology objects that store attributes for each potential fuel for new district heat generation facilities. For IEO2017, technologies and fuels are analogous to one another, as there is only one potential boiler technology per fuel. Attributes assigned to each Technology object include fuel type, non-fuel costs (capital, fixed O&M, variable O&M), load factors, plant lifetime, and efficiency of new generation plants.

Once region and technology dictionaries are created, the model's *project_con_gen* function projects generation and fuel consumption for each region and year. Heat generation does not include CHP generation, which is calculated by the Electricity Model. For each projection year, the *get_gen_req* function determines how much generation is required by dividing heat demand net of CHP generation by the region's transmission and distribution loss factor, and multiplying by the generation adjustment factor. Then, the model determines how much generation capacity already exists in the projection year. Remaining generation capacity in each fuel category is retired; the retirement rate is assumed to be the inverse of the plant lifetime assigned to each generation fuel. If an exogenous generation target exists for certain fuels in the region, the model calls the *calc_new_exoggen* function, which adds capacity in the target fuels to the existing capacity stock in order to be able to meet this target.

If, after this upkeep, existing generation capacity is sufficient to meet the current projection year's generation requirements, the model does not add any new capacity. Rather, additional and remaining capacity are used to satisfy generation required. The model assumes that additional capacity, which is more efficient than remaining capacity, is utilized first; any generation requirement not met by additional capacity is met by remaining capacity. Total generation is assumed to be equal to generation required, and fuel shares of generation are assumed to be equal to the fuel shares of existing capacity.

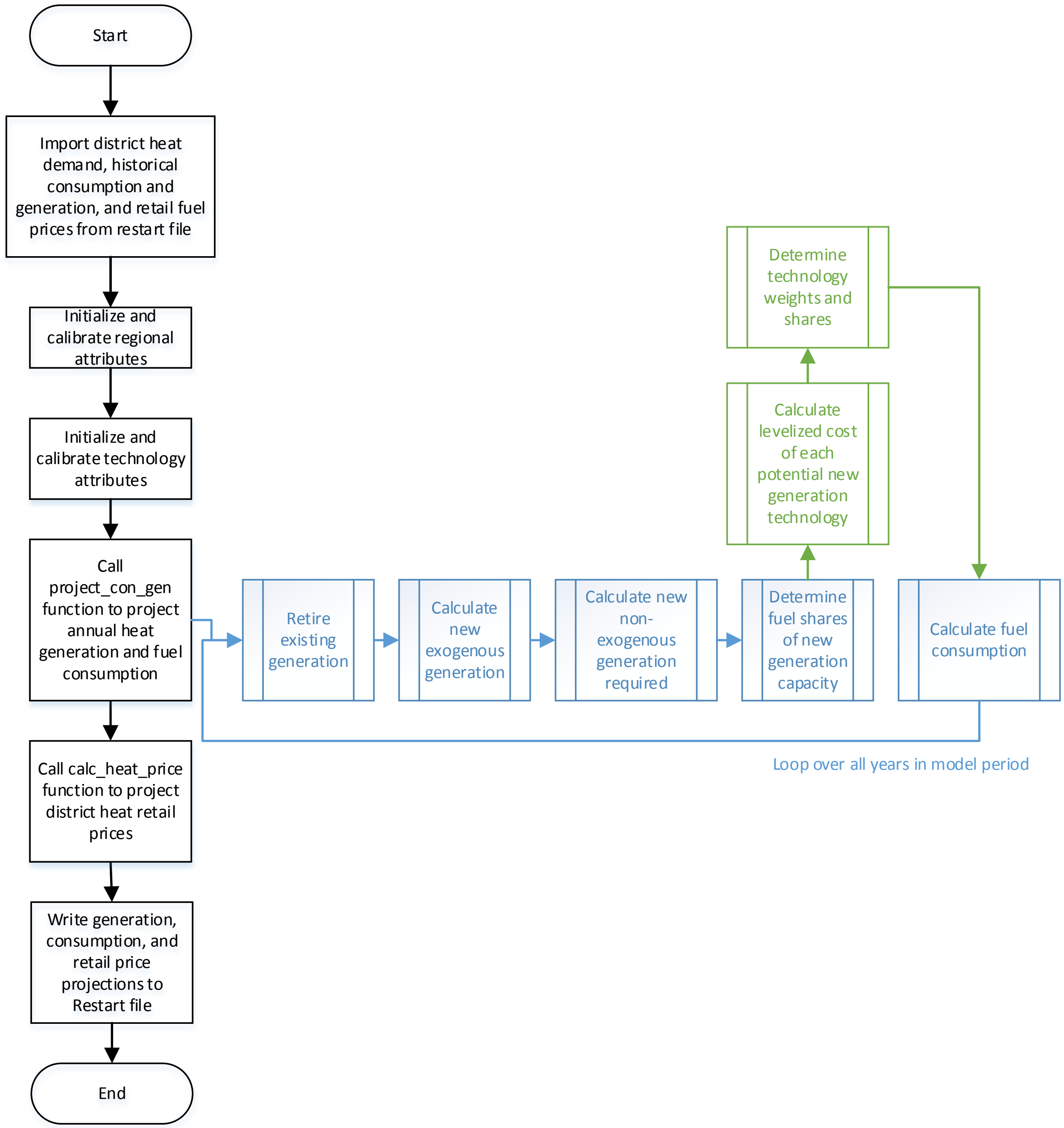
If existing generation capacity is not sufficient to meet the current projection year's generation requirements, the model adds new capacity. The model calls the *calc_tech_weight* function, which uses a multinomial logit algorithm to determine fuel shares of new capacity. For each fuel, the *calc_level_cost* function calculates the levelized cost of the corresponding fuel type, using non-fuel costs, discount rates, learning indices, and fuel prices imported from HeatInput.xlsx and the common database. These levelized costs are converted into a technology weight using the imported logit parameter. Fuel shares are calculated by dividing each technology weight by the total weight for all fuels. Fuel shares are then multiplied by the total new generation required to determine new generation by fuel. New generation is added to the additional capacity stock. Both additional and remaining capacity stock are assumed to be fully utilized in years where new generation is added, and total generation is equal to the sum of generation from new and remaining capacity for each fuel.

To calculate fuel consumption, two sets of efficiencies are used. Generation using remaining capacity is multiplied by the historical consumption/generation ratio, which is calculated during initialization of each Region object. Generation using additional capacity is multiplied by the consumption/generation ratio for new generation, which is calculated during initialization of each Technology object. Finally, the *calc_heat_price* function calculates projections of retail district heat prices for the residential, commercial, and industrial sectors.

After projecting consumption, generation, and prices, the *update_restart* function writes the projections to the WEPS+ common database 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 2. Flowchart for the District Heat Model



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 District Heat Model addresses seven energy sources:

- Distillate
- Residual
- Natural gas
- Coal
- Waste
- Biomass
- Geothermal

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

Data initialization

The model begins by importing the following values from the common database: generation, consumption, CHP generation, heat demand, fuel prices, heat prices, and carbon prices. For generation, consumption, and heat prices, historical values are read in; the model will project these values for model years. CHP generation, heat demand, fuel prices, and carbon prices are read in for both historical and model years. Generation, consumption, CHP generation, fuel prices, and carbon prices are disaggregated by fuel, and heat demand and heat prices are disaggregated by end-use sector. All of these values are stored in Region objects, which are created for each region. Attributes read into the Region objects include

1. Transmission and distribution losses by year, imported from HeatInput.xlsx.
2. Yearly efficiency indices for new generation, which decline over time (representing increasing efficiency). These are imported from HeatInput.xlsx.
3. Regional discount rates, imported from HeatInput.xlsx. In *IEO2017,* these are assumed to be equal to 7% for OECD regions and 10% for non-OECD regions.
4. Logit parameters representing consumer sensitivity to the cost of various fuel choices, imported from HeatInput.xlsx.
5. Regional data imported from the common database, including historical fuel consumption, historical heat generation, and CHP generation.

6. Primary fuel prices, imported from the common database. Imported primary fuel prices are adjusted for any assumed carbon tax by recalculating retail prices (accessed through the common database) for distillate fuel, residual fuel, natural gas, and coal. (No carbon tax adjustment factors were used for *IEO2017* model runs.) Projected fuel prices can fluctuate from year to year and contain some inconsistencies. The model sets any negative fuel prices to match the previous year's value. It also employs an exponential smoothing algorithm to eliminate large single-year jumps.

7. Regional remaining generation capacity, which refers to generation capacity remaining from the historical period, and additional generation capacity, which refers to generation added during the projection period. To start, generation remaining is set to the level of generation in the last historical year, and additional generation is set to zero. As the model projects consumption and generation for each model year, it then subtracts from generation remaining as plants retire and adds to additional generation as required to continue to meet heat demand.

8. Exogenous generation capacity targets, which are imported from HeatInput.xlsx. *IEO2017* features a 27% exogenous capacity target for renewable generation in Europe, to be met by 2020.

Additionally, when Region objects are created, several values are calculated:

Heat demand, which is calculated by adding the consumption estimates projected by the WEPS+ residential, commercial, and industrial demand models:[2]

$$thdem(r,y) = qhtrs(r,y) + qhtcm(r,y) + qhtin(r,y),$$

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 for region r in year y.

[2] Hereafter, all class variables are converted into a simpler notation for the purpose of this report. A lookup table in Appendix E provides the class variable names as found in the model code.

Historical generation required, which is calculated as historical demand divided by regional transmission and distribution losses, net of CHP generation from the Electricity Model:

$$gen\_required(r,y) = \frac{thdem(r,y)}{tdloss(r,y)} - chpgen(r,y)$$
$$\forall\ y \in historical\_period,$$

and where, for a given Region r in year y,

$gen\_required(r,y)$ = generation required;

$thdem(r,y)$ = total heat demand;

$tdloss(r,y)$ = transmission and distribution loss factor; and

$chpgen(r,y)$ = CHP generation calculated by the Electricity Model.

A regional adjustment ratio for heat demand. 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 historical data to calculate an "over-generation ratio": the ratio of total generation to required generation, accounting for distribution loss. This ratio is calculated for the years 2005-2014, and a weighted average (weighting recent years more heavily) is taken to determine an adjustment factor. This adjustment factor, which represents the scale of the inconsistency in the original data, is used to adjust all of the heat demand projections for the region:

$annual\_genadj(r,\mathrm{y}) = \frac{generation(\mathrm{r},y,'TT')}{gen\_required(r,y)}$; and

$genadj(r) = weighted\_average(annual\_genadj(r,y)\ \forall\ y \in [2005, 2014]),$

where *weighted_average* is calculated using the following recursive algorithm:

$$weighted\_average\big(annual\_genadj(r,y)\big) = \alpha * annual\_genadj(r,y) + (1-\alpha) * weighted\_average(annual\_genadj(r,y-1)),$$

initialized as,

$$weighted\_average\big(annual\_genadj(r,2005)\big) = annual\_genadj(r,2005),$$

and where

$annual\_genadj(r,\mathrm{y})$ = the over-generation ratio in a particular historical year;

$genadj(r)$ = the weighted average over-generation ratio across all historical years;

α = a smoothing parameter, set to 0.5; and

$generation(r,y,'TT')$ = total generation in region *r* and year *y.* The subscript *'TT'* refers to the total of all fuels.

Historical consumption/generation ratio by fuel, representing a weighted historical average of fuel consumed to heat generated. This ratio is the inverse of the overall efficiency of heat generation. This ratio is calculated from historical data and used throughout the projection calculations:

$$annual\_historical\_cgratio(r,f,y) = \frac{consumption(r,y,f)}{generation(r,y,f)},$$

where

$annual\_historical\_cgratio(r,f,y)$ = the ratio of consumption to generation in region *r* and a particular historical year *y*;

$consumption(r,y,f)$ = fuel f consumed to generate heat in region *r* and year y; and

$generation(r,y,f)$ = heat generation from fuel f in region *r* and year y.

In IEO2017, the historical consumption/generation ratio is calculated for the years 2005-2014, and a weighted average is taken to determine a region's historical cgratio. The weighted average is calculated via the same algorithm as used for the adjustment factor; recent years are weighted more heavily, on an exponential basis, than earlier years.

$$historical\_cgratio(r,f) = weighted\_average(annual\_historical\_cgratio(r,f,y)\ \forall\ y \in [2005,2014]),$$

where the *weighted_average* is calculated using the following recursive algorithm,

$$weighted\_average\big(annual\_historical\_cgratio(r,f,y)\big) = \alpha * annual\_historical\_cgratio(r,f,y) + (1-\alpha) * weighted\_average(annual\_historical\_cgratio(r,f,y-1)),$$

initialized as,

$$weighted\_average(annual\_historical\_cgratio(r,f,2005)) = annual\_historical\_cgratio(r,f,2005)$$

and where

$historical\_cgratio(r)$ = the weighted average ratio of consumption to generation in region *r* across all historical years.

Fuel price adders, which are applied to average unit fuel cost in model years to project heat prices, are also calculated based on historical data. For each year in the historical period (in IEO2017, between 2001 and 2014), the model subtracts the unit fuel cost, calculated as the total fuel cost divided by generation, from the heat price. The fuel price adder is a weighted average of these values, with recent years weighted more heavily than past years, and is calculated via the same algorithm as used for the adjustment factor:

$$annual\_hist\_fpadder(r,y) = heatprice(r,y) - \frac{\sum_f consumption(r,y,f) * fuelprice(r,y,f)}{generation(r,y,'TT')};$$
and

$$fpadder(r, first\_model\_year) = weighted\_average(annual\_hist\_fpadder(r,y) \forall\, y \in historical\_period),$$

where the *weighted_average* is calculated using the following recursive algorithm:

$$weighted\_average(annual\_hist\_fpadder(r,y)) = \alpha * (annual\_hist\_fpadder(r,y)) + (1-\alpha) * weighted\_average(annual\_hist\_fpadder(r,y-1)),$$

and where

$annual\_hist\_fpadder(r,y)$ = the difference between the price of heat per BTU and the cost of fuel required to generate it in a particular region *r* and historical year *y;*

$fpadder(r, first\_model\_year)$ = the fuel price adder in the first projection year (in IEO2017, 2015) and region *r,* calculated as a weighted average of $annual\_hist\_fpadder$ across all historical years;

$heatprice(r,y)$ = price of heat in region *r* and year *y* (assumed to be the same for all end-use sectors);

$consumption(r,y,f)$ = consumption of fuel *f* in region *r* and year *y;*

$fuelprice(r,y,f)$ = price of fuel *f* in region *r* and year *y;*

$generation(r,y,'TT')$ = total generation in region *r* and year *y;* and

In each model year, the model then adds on a fuel price increment imported from HeatInput.xlsx, which increases gradually throughout the projection period:

$$fpadder(r,y) = fpadder(r,y-1) + fp\_increment \;\forall\, y \in model\_period,$$

where

$fp\_increment$ = the amount that non-fuel generation costs exogenously rise each year, per MBtu. This is imported from the HeatInput.xlsx file and estimated based on historical trends. (In *IEO2017*, this increment is $0.35/year, or about 1-2% of the heat price in most regions.)

Remaining generation capacity from the historical period, which is initialized for each region and fuel as

$$gen\_remaining(r, last\_historical\_year, f) = generation(r, last\_historical\_year, f),$$

where,

$gen\_remaining(r, last\_historical\_year, f)$ represents generation capacity stock remaining from the historical period in region *r* using fuel f, as of the last historical year; and

$generation(r, last\_historical\_year, f)$ = generation in region r using fuel f in the last historical year.

A second variable, $additional\_gen(r, f)$, represents the stock of capacity added during the projection period. It is initialized to zero in the last historical year.

The model also imports technology attributes for each generation fuel, including plant capital cost, fixed and variable O&M costs, load factors, plant lifetime, and learning indices, and stores them in Technology objects. Attributes stored by the Technology class include the following:

1. Fuel type. In *IEO2017*, exactly one Technology object exists for every fuel represented in the model.
2. Capital cost and fixed and variable O&M costs, which are imported from HeatInput.xlsx. All non-fuel costs are calibrated such that they accurately predict generation and consumption by fuel in historical years.
3. Load factors, which are imported from HeatInput.xlsx. Currently, all load factors are assumed to be 20%.
4. Plant lifetime, which is assumed to fall between 20 years and 35 years, depending on the fuel.
5. A learning index for renewable fuels, which reduces non-fuel costs by a certain percentage each year. Currently, the learning index is assumed to be 1%.
6. A consumption/generation ratio for new generation. For coal and natural gas plants in each region, this ratio is calculated as the product of the historical consumption/generation ratio and the region's yearly efficiency index for new generation:

$$cgnew(r, y, f) = historical\_cgratio(r, f) * neweffindex(r, y),$$

where

$cgnew(r, y, f)$ = consumption/generation ratio for a particular plant fuel category (natural gas plants, coal plants) in year y and region r;

$historical\_cgratio(r, f)$ = weighted average of the consumption/generation ratio for fuel f (either coal or natural gas) in region r in historical years; and

$neweffindex(r, y)$ = an efficiency index for year y and region r that declines over time.

For plants driven by other fuels f, *cgnew* is calculated as

$$cgnew(r, y, f) = historical\_cgratio(r, 'TT') * neweffindex(r, y),$$

where

$historical\_cgratio(r, 'TT')$ = weighted average of the consumption/generation ratio across all fuels in region r in historical years.

In *IEO2017*, it is assumed that new boiler efficiencies start at historical efficiencies and improve over time toward a target of 85% by 2035. (New district heat boilers in many developed countries achieve combustion efficiencies of 85% to 90%.)[3] None of the regions are assumed to fully accomplish the target by the target date, but they are assumed to accomplish a certain percentage of the target depending on whether they fall into the "robust policy" category. Regions are sorted into the "robust policy" category if they have recently adopted policies or strategies to improve efficiencies in their district heat sectors; these include China, Europe, Japan, Russia, and South Korea. These regions are assumed to accomplish 75% of the target efficiency for new boilers. Other regions are assumed to accomplish 40% of the target.

Generation and consumption in stock/flow accounting

The District Heat Model is a stock/flow accounting model that uses a simple vintage structure to account for fuel consumption and heat generation.

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

- Remaining – Heat generation from capacity remaining from the last historical year (in *IEO2017*, 2014)
- New – Heat generation from capacity added in the current projection year
- Additional – Heat generation from capacity added between the last historical year (2014) and the end of the projection year
- Total – Total heat generation in the current projection year (sum of remaining and additional)

The *project_con_gen* function projects district heat generation and fuel consumption, iterating over the years in the projection period. The first step for each projection year y is to calculate the district heat-only generation requirement, which is projected as

$$gen\_required(r,y) = \left[\frac{thdem(r,y)}{tdloss(r,y)} - chpgen(r,y)\right] * genadj(r),$$

[3] Roshchanka, V., and M. Evans, "Playing Hot and Cold: How Can Russian Heat Policy Find Its Way Towards Energy Efficiency?" Pacific Northwest National Laboratory, Richland, 2012; Danish Energy Agency and Energinet.dk, "Technology Data for Energy Plants: Updated Chapters," Copenhagen, 2016. Available at https://ens.dk/sites/ens.dk/files/Analyser/update_-_technology_data_catalogue_for_energy_plants_-_aug_2016.pdf (accessed on June 2, 2017); Pöyry Energy, "The Potential and Costs of District Heating Networks," Oxford, 2009. Available at http://webarchive.nationalarchives.gov.uk/20121205174605/http:/decc.gov.uk/assets/decc/what%20we%20do/uk%20energy%20supply/energy%20mix/distributed%20energy%20heat/1467-potential-costs-district-heating-network.pdf (accessed on June 2, 2017).

where

$gen\_required(r, y)$ = annual generation requirement in region *r* and year y

$thdem(r,y)$ = total heat demand in region *r* and year y;

$tdloss(r, y)$ = total distribution loss factor in region r and year y; and

$chpgen(r, y)$ = total CHP generation calculated by the Electricity Model in region *r* and year y.

If the result of the above calculation is negative, gen_required is instead set to 0.

Next, the model retires some of the existing generation capacity. The retirements in each year are assumed to be inversely proportional to the lifetime of the average boiler facility for each fuel: for a given fuel, $retirement\_rate(f) = \frac{1}{plant\_life(f)}$. The remaining generation is calculated as

$$gen\_remaining(r, y, f) = gen\_remaining(r, y - 1, f) * (1 - retirement\_rate(f))$$

Additional generation stock is also retired if sufficient time has passed since it was added:

If $y > first\_model\_yr + plant\_life(f)$,

$$additional\_gen(r, y, f) = additional\_gen(r, y - 1, f) * (1 - retirement\_rate(f)),$$

where, for a given region, fuel type, and year y,

$plant\_life(f)$ = the lifetime of the average boiler facility for a given fuel type *f*;

$gen\_remaining(r, y, f)$ = generation stock for region *r* and fuel f remaining from historical period by year *y*;

$additional\_gen(r, y, f)$ = generation stock added for region *r* and fuel f during the model period by year *y*; and

$first\_model\_yr$ = first projection year.

The model has the capability to represent exogenous generation targets for heat. In *IEO2017*, only one such target is included: a 27% renewable energy target for the European Union. For each region, if an exogenous generation target exists, the model calls the *calc_new_exoggen* function, which first determines whether the target is a single-fuel target or a combined renewable energy target. If the target is a combined renewable energy target, the model assumes that the target may be met by a set of fuels; currently, these include biomass and geothermal. From the input file, the model reads in whether the target is expressed as a percentage or as an amount in tBTU. If the current projection year is before the target year, the model then determines the increment that must be added to the previous projection year's generation percentage or the previous projections year's generation amount in order to progress toward the target. If the current projection year is after the target year, the model determines whether any additional capacity is required to ensure that generation remains greater than or equal to the target level. If the target is a combined renewable energy target, the model determines the share of each renewable fuel that will be used to satisfy the target by employing the multinomial logit algorithm described on pages 23–24. New exogenous generation is then returned to the main generation projection function and added to the $additional\_gen$ capacity stock.

Next, the heat generation requirements are compared to the total heat generation available. If more generation must be added to meet the generation requirements, the model calculates the amount of new non-exogenous generation capacity needed in a given year:

$existing\_gen\_capacity(r, y, 'TT') = gen\_remaining(r, y) + additional\_gen(r, y)$; and

if $gen\_required(r, y) > existing\_gen\_capacity(r, y, 'TT')$,

$$new\_nonexog\_gen(r, y, 'TT') = gen\_required(r, y) - existing\_gen\_capacity(r, y, 'TT'),$$

where

$existing\_gen\_capacity(r, y, 'TT') =$ total existing generation capacity available before the addition of new non-exogenous capacity. 'TT' stands for the total across fuels;

$gen\_required(r, y) =$ heat demand net of CHP (see calculation on page 21); and

$new\_nonexog\_gen(r, y, 'TT')$ = total new non-exogenous capacity across all fuels required to meet demand.

If new non-exogenous generation capacity is required, the model calls a choice function, *calc_tech_weight,* which calculates technology weights by fuel. These weights subsequently determine fuel shares. Currently, in *IEO2017*, only one boiler technology is assumed to exist per fuel. The technology weight function first calls the *calc_level_cost* function, which calculates the levelized cost for each boiler fuel, using assumptions imported from the *HeatInput.xlsx* file. First, the present value of the fuel cost is calculated:

$$pv\_fuel(f, y, r) = \sum_v \left[discount\_factor(v) * (load\_factor(f) * 8760) * \left(cgnew(r, y)\right) * fuelprice(y, f)\right],$$

where, for a given fuel type and region,

$pv\_fuel(f, y, r)$ = the present value of fuel costs over the expected generation plant lifetime for fuel *f* in region *r* and decision year (same as projection year) *y*;

$discount\_factor(v)$ = $discount\_rate^{v-1}$ = discount factor for year v during the expected lifetime of the generation plant for fuel type *f*;

$load\_factor(f)$ = the load factor (in *IEO2017*, assumed to be 20% for all fuels). This is multiplied by 8760, the number of hours in a year;

$cgnew(r,y)$ = the consumption/generation ratio for new capacity additions in year y and region r;

$fuelprice(y,f) =$ the fuel price by which the fuel type is being evaluated. In IEO2017, the model assumes myopic foresight of fuel prices, so $fuelprice(y,f)$ refers to the fuel price in the decision year y, when the capacity is being added; and

$\sum_v[\ \ ]$ = the sum over each year v in the expected lifetime of the generation plant for fuel type f.

Next, the present value of fixed and variable O&M cost is calculated:

$$domfix(r,f,v) = discount\_factor(v) * omfix(r,f) * learni(f);$$

$$domvar(r,f,v) = discount\_factor(v) * omvar(r,f) * load\_factor(f) * learni(f);\text{ and}$$

$$pv\_nonfuel(r,f) = \textstyle\sum_v[domfix(r,v) + domvar(r,v)] + capcost(r,f),$$

where, for a given generation fuel f and region r,

$domfix(r,f,v)$ = discounted fixed O&M cost in region *r* and evaluation year v;

$omfix(r,f)$ = fixed annual O&M cost for region r;

$learni(f)$ = technology learning parameter for fuel *f*. In IEO2017, no learning is anticipated for fossil fuel generation systems, while renewable generation becomes 1% less expensive to operate per year;

$domvar(r,f,v)$ = discounted variable O&M cost in evaluation year v;

$omvar(r,f)$ = variable O&M cost for region r;

$pv\_nonfuel(r,f)$ = the present value of non-fuel costs over the expected generation plant lifetime for region *r* ; and

$capcost(r,f)$ = the capital cost of the generation plant for fuel *f* in region *r*.

Finally, levelized cost is calculated:

$$levelcst(r,y,f) = \frac{pv\_fuel(r,y,f) + pv\_nonfuel(r,f)}{load\_factor(f) * 8760 * plant\_life(f)},$$

where $levelcst(r,y,f)$ = the present value of the levelized cost of the generation plant for fuel f per MWh of generation.

Next, the logit algorithm uses the levelized cost to calculate an inverse cost weight for the generation plant for fuel f:

$$techwt(r, y, f) = levelcst(r, y, f)^{-lamb(r)},$$

where, for a given fuel f and region r,

$techwt(r, y, f)$ = the calculated technology weight for the generation plant for fuel f, in region r and decision year y; and

$lamb(r)$ = the logit coefficient assigned to region r, which is imported from the *HeatInput.xlsx* file.

Weights are summed across all fuels, and weights are divided by the sum in order to derive market share:

$$totwt(r, y) = \sum_f techwt(r, y, f);$$ and

$$techshr(r, y, f) = \frac{techwt(r,y,f)}{totwt(r,y)},$$

where $techshr(r, y, f)$ = market share of fuel f.

Fuel shares are then applied to total new non-exogenous generation to determine new generation added by fuel:

$$new\_nonexog\_gen(r, y, f) = techshr(r, y, f) * new\_nonexog\_gen(r, y, 'TT')$$

New non-exogenous generation is added to the additional generation stock, and total generation in year y for each region r and fuel f is set equal to additional generation plus remaining generation:

$$additional\_gen(r, y, f) = additional\_gen(r, y-1, f) + new\_nonexog\_gen(r, y, f);$$ and

$$generation(r, y, f) = additional\_gen(r, y, f) + gen\_remaining(r, y, f).$$

If existing generation in a given year exceeds generation required, the model skips over this choice algorithm. Instead, the model determines which vintage of the existing generation capacity will be used to meet demand. Here, the model assumes that additional generation capacity, being newer and more efficient, will be used first, followed by remaining generation capacity, until the amount of required generation is reached. The model assumes that fuels used for generation are proportional to their representation in each capacity vintage's stock.

The model then projects total fuel consumption based on the calculated total generation and the conversion efficiency ratios as calculated above:

$$con\_from\_remaining\_gen(r, y, f) = gen\_remaining\_used(r, y, f) * historical\_cgratio(r, f);$$

$$con\_from\_additional\_gen(r, y, f) = additional\_gen(r, y, f) * cgnew(r, y, f);$$ and

$$consumption(r,y,f) = con\_from\_remaining\_gen(r,y,f) + con\_from\_additional\_gen(r,y,f),$$

where, for a given region r and fuel f, and in a given year y,

$con\_from\_remaining\_gen(r,y,f)$ = consumption of fuel f by remaining generation capacity;

$gen\_remaining\_used(r,y,f)$ = remaining generation capacity using fuel f that is used to generate heat in region *r* in year *y*. If $gen\_required(r,y) > existing\_gen\_capacity(r,y,'TT')$, then the variable $gen\_remaining(r,y,f)$ is substituted for $gen\_remaining\_used(r,y,f)$ (i.e., it is assumed that all remaining generation capacity is used in this case);

$con\_from\_additional\_gen(r,y,f)$ = consumption of fuel f in region r and year y by additional generation capacity; and

$consumption(r,y,f)$ = total consumption of fuel f in region r and year y in a given region.

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. The model estimates heat prices from fuel costs, adding approximate non-fuel generation costs and other markups. These markups are represented by the “fuel price adder” calculated endogenously based on historical data during the initialization phase.

The first step is to estimate a weighted average unit fuel cost for each region and year. For a given region,

$$unit\_fuel\_cost(r,y) = \frac{\sum_f [consumption(r,y,f) * fuelprice(r,y,f)]}{generation(r,y,'TT')}.$$

Then, the unit fuel cost is added to the fuel price adder to obtain the retail heat price:

$$heat\_price(r,y) = unit\_fuel\_cost(r,y) + fpadder(r,y).$$

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 *IEO2017,* 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 seven energy sources: distillate, residual fuel, natural gas, coal, waste, biomass, and geothermal. Projections are made for each of the 16 WEPS regions, over the projection period to the year 2050.

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:
April 2017

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+.

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Documentation:

1. U.S. Energy Information Administration, U.S. Department of Energy, *World Energy Projection System Plus: District Heat Model*, DOE/EIA-M077 (2017) (Washington, DC, November 2017).

Archive information:

2. 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:

3. International district heat generation and energy consumption

Coverage:

4. *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.

5. *Mode*: total district heat generation and energy consumption.

6. *Time Unit/Frequency*: Annual, through 2050.

DOE input sources:

7. U.S. Energy Information Administration (EIA), U.S. Department of Energy, *Short-Term Energy Outlook*, Washington, DC, March 2011.

8. U.S. Energy Information Administration (EIA), U.S. Department of Energy, *International Energy Statistics*, Washington, DC, 2015.

Non-DOE input sources:

9. International Energy Agency, Energy Statistics and Balances of OECD Countries, website www.iea.org (subscription site).

10. REN21, "Renewables 2016: Global Status Report," Paris, 2010. Available at www.ren21.net/wp-content/uploads/2016/05/GSR_2016_Full_Report_lowres.pdf (accessed on February 23, 2017).

11. Euroheat and Power, "European District Heating Price Series," Brussels, 2016. Available at https://www.euroheat.org/publications/reports-and-studies/european-district-heating-price-series/ (accessed on June 2, 2016).

12. Danish Energy Agency and Energinet.dk, "Technology Data for Energy Plants: Updated Chapters," Copenhagen, 2016. Available at https://ens.dk/sites/ens.dk/files/Analyser/update_-_technology_data_catalogue_for_energy_plants_-_aug_2016.pdf (accessed on June 2, 2016).

Independent expert reviews:

13. None

Computing environment:

14. Hardware/Operating System: Basic PC with Windows

Appendix B. Input Data and Variable Descriptions

The following variables represent data input from the file HeatInput.xlsx.

Classification: Input variable.

tdloss(r, y):	Transmission and distribution loss factors by region and year
neweffindex(r, y):	Efficiency index for new generation plants by region and year
discount_rate(r):	Discount rate by region
fpincrement(r):	The increment that the non-fuel component of the heat price (the fuel price adder) increases per year
lambda(r)	Logit parameter, by region
exog_target:	Exogenous generation targets by fuel and region, expressed as a dictionary object containing the region, fuel, year, value, and unit of each target generation amount
load_factor(f):	Load factor by fuel
plant_life (f):	Plant lifetime by fuel
learni(f)	Technology learning parameter, applied to non-fuel cost of generation. In IEO2017, no learning is anticipated for fossil fuel technologies, while renewable technologies become 1% less expensive to operate per year.
capcost(f,r)	Capital cost of new generation, by fuel and region
omfix(f, r)	Fixed O&M cost of new generation, by fuel and region
omvar(f, r)	Variable O&M cost of new generation, by fuel and region

The following variables represent data imported from the common database.

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 residual (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(n,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(n,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

SHCNNG(n,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(n,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(n,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(n,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(n,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

SHGNDS(n,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(n,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

SHGNNG(n,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(n,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(n,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(n,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(n,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

SHUCNDS(n,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(n,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

SHUCNNG(n,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(n,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(n,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(n,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(n,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(n,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(n,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(n,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

SUGNDS(n,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(n,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

SUGNNG(n,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(n,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(n,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(n,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(n,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(n,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(n,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(n,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

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

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): Consumption 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

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

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

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

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

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

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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 U.S. 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 *IEO2017*.
- *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

Appendix E. Class Variable Cross-Reference Table

Model documentation variable notation	Model code variable notation
thdem(r, y)	Region.thdem(y)
gen_required(r, y)	Region.gen_required(y)
tdloss(r, y)	Region.tdloss(y)
chpgen(r, y)	Region.chpgen(y)
genadj(r)	Region.genadj
generation(r, y, f)	Region.generation(y, f)
consumption(r, y, f)	Region.consumption(y, f)
historical_cgratio(r)	Region.historical_cgratio
fuelprice(r, y, f)	Region.fuelprice(y, f)
fpadder(r, y)	Region.fpadder(y)
gen_remaining(r, y, f)	Region.gen_remaining(f)
additional_gen(r, y, f)	Region.additional_gen(f)
lamb(r)	Region.lamb
heatprice(r, y)	Region.heatprice(y)
cgnew(r, y, f)	Technology.cgnew(y, r)
plant_life(f)	Technology.plant_life
load_factor(f)	Technology.load_factor
omfix(r, f)	Technology.omfix(r)
omvar(r, f)	Technology.omvar(r)
learni(f)	Technology.learni
load_factor(f)	Technology.load_factor
capcost(r, f)	Technology.capcost(r)