Concepts, Data Sources, and Techniques
Handbook of Energy Modeling Methods

World Energy Projection System (WEPS): District Heat Module

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1. Introduction

District heat is heat generated in a centralized location and distributed through a pipeline system for residential, commercial, and industrial space heating and water heating. The WEPS District Heat Model projects the amount of district heat generated, by region, to satisfy the district heat demand projected by the WEPS Residential, Commercial, and Industrial Demand Models. The District Heat Model also calculates the total energy and the energy by fuel consumed for district heat generation, and the model also projects regional end-use prices of district heat for the residential, commercial, and industrial sectors. The District Heat Model makes these annual projections for each of the 16 WEPS regions, for heat generated from the following energy sources:

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

Inputs for the model include distillate fuel prices, residual fuel prices, and natural gas prices from the WEPS Hydrocarbon Supply Model, and coal prices from the WEPS Coal Supply Model. Fuel consumption projections serve as inputs to the supply models, and retail district heat prices serve as inputs to the Residential, Commercial, and Industrial Demand Models.

2. Projecting District Heat Generation

The District Heat Model's main purpose is to estimate district heat generation and the amount of fuel consumed for district 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. The model projects fuel use quantities for each WEPS region for seven energy sources: distillate, residual fuel, natural gas, coal, waste, biomass, and geothermal.

The model calculates district heat consumption, generation, and district heat generation capacity additions by fuel for each projection year. Based on projected fuel consumption and heat generation, it then determines retail district heat prices. The model exports its fuel consumption and district heat price projections to a common database for use by other WEPS models.

The model imports and stores data series from outside of WEPS, including discount rates applied to future cash flows, heat generation technology attributes (including fuel type, non-fuel heat generation costs, equipment load factors, district heat plant lifetime, and efficiency of new heat generation plants), and parameters that determine how costs influence utility investors' choices of heat generation technology. Values imported from other WEPS models include heat generation from combined heat and power (CHP) plants, district heat demand, fuel prices, heat prices, and carbon prices.

When district heat is distributed to homes and businesses, some heat is lost in the transmission and distribution process. The model estimates historical transmission and distribution losses by year:

$$\text{Transmission \& Distribution Loss Factor} = \frac{\text{Heat Demand Net of CHP Heat Generation (Btu)}}{\text{Heat Generated (Btu)}}$$

Similarly, the model estimates historical generation efficiencies by fuel and year as follows:

$$\text{Consumption-to-generation ratio (inverse of efficiency)} = \frac{\text{Fuel Consumed for Heat Generation (Btu)}}{\text{Heat Generated (Btu)}}$$

The model uses an iterative exponential smoothing algorithm to project the historical values for the transmission-distribution loss factor and consumption-to-generation ratio forward into the projection years. This forecasting method determines future values using a weighted average of historical observations, weighting recent observations more heavily than those in the distant past. The district heat model uses double exponential smoothing, so if a trend is present in the historical data, it will be projected into the future. Parameters estimated by expert judgment determine how the exponential smoothing algorithm weights observations in the recent past relative to observations in the distant past.

The model then projects generation and fuel consumption for each region and year. The projected heat generation does not include CHP generation, which is projected by the WEPS Electricity Model. For each projection year, we project the required generation by dividing heat demand, net of CHP generation, by the region's transmission and distribution loss factor:

$$\text{Generation Required (Btu)} = \frac{\text{Heat Demand Net of CHP generation (Btu)}}{\text{Transmission-Distribution Loss Factor}}$$

The model then determines how much generation capacity is projected to already exist in the projection year. The model assumes that the rate at which existing generation capacity is retired is the inverse of the plant lifetime assigned to each generation fuel.

3. Simulating Compliance with Renewable Energy Targets

The District Heat model can simulate compliance with analyst-specified targets for heat generation from specific fuels. For each region, if a generation target is specified, the model first determines whether the target is a single-fuel target or a combined renewable energy target. If it 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. A target for a projection year may be specified as a percentage or as an amount in thousand British thermal units (Btu). If the current projection year is before the target year, the model determines the increment that must be added to the previous projection year's generation percentage or the previous projections year's generation amount to progress fast enough to meet 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 below. The new projected generation is then added to the generation capacity stock.

4. Projecting District Heat Capacity and Fuel Consumption

If, after simulating compliance with targets, existing generation capacity is sufficient to meet the current projection year's generation requirements, the District Heat model does not add any new capacity. Rather, it uses two capacity categories to satisfy generation required:

- Remaining capacity, which is capacity added during the historical period and existing in the first projection year
- Additional capacity, which is capacity added during the projection period but before the current projection year

The model assumes that additional capacity, which is more efficient than remaining capacity, is used first; any generation requirement not met by additional capacity is met by remaining capacity. It further assumes that total generation equals required generation and that fuel shares of generation equal the fuel shares of existing capacity.

If the projected existing generation capacity is not sufficient to meet the current projection year's generation requirements, the model adds new capacity. It uses a multinomial logit algorithm to determine fuel shares of new capacity. For each fuel, the model calculates the levelized cost of the corresponding fuel type using non-fuel costs, discount rates, learning indices, and fuel prices. These levelized costs are converted into a *technology weight* using an assumed logit parameter *Lambda*:

$$\text{Technology Weight} = (\text{Levelized Cost})^{-\text{Lambda}}$$

The model projects fuel shares by dividing each technology weight by the total weight for all fuels. To project new generation capacity by fuel, it then multiplies the fuel shares by the total new generation required. New generation capacity is added to the additional capacity stock. In years where new generation capacity is added, the model assumes that both additional and remaining capacity stock are fully utilized, and that total generation is equal to the sum of generation from new and existing capacity for each fuel.

To project fuel consumption, the model uses two sets of fuel consumption-to-generation ratios, known as efficiencies. It multiplies the district heat generation from remaining generating capacity (not added or retired during the projection period) by the historical consumption-to-generation ratio, which we estimate using data from the most recent historical year. This remaining capacity is assumed to be less efficient than the new capacity added during the projection period.

The model projects fuel consumed by the additional generating capacity (added during the projection period) by multiplying the projected consumption-to-generation ratio for new generation in the projection year by the projected amount of district heat generated for the projection year:

$$\text{Fuel Consumption (Btu)} = \text{Consumption-to-Generation Ratio} \times \text{Generation (Btu)}$$

Finally, the model projects retail district heat prices for the residential, commercial, and industrial sectors. It calculates the total fuel cost per Btu by multiplying the fuel price from the a previous WEPS run by the projected fuel consumption, then dividing by total district heat generated. To the fuel cost, the function adds a heat price adder, which is calculated based on historical fuel costs and heat prices.

Heat Price ($/Btu) =

$$\frac{\sum_{\text{Fuels}} (\text{Fuel Consumption to Generate Heat (Btu)} \times \text{Fuel Price (\$/Btu)})}{\text{Heat Generated (Btu)}} + \text{Heat Price Adder (\$/Btu)}$$

After projecting consumption, generation, and prices, the model writes the projections to a 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 of district heat.