



Concepts, Data Sources, and Techniques

Handbook of Energy Modeling Methods

World Energy Projection System (WEPS): Residential Demand Module



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1. Introduction

The WEPS Residential Demand Module projects energy consumption in households, excluding motor vehicle fuel consumption, which is covered in the Transportation Module. The module projects residential energy consumption in each of the WEPS regions for nine fuels:

- Distillate fuel
- Kerosene
- Liquid petroleum gases (for example, propane)
- Natural gas
- Coal
- Electricity
- Heat
- Biomass
- Solar

Our residential solar projections include only solar thermal energy consumed onsite in homes. Solar photovoltaic systems are modeled in the International Electricity Market Module. To project household energy consumption, we assume four factors determine changes in energy consumption over time:

- Changes in disposable income per capita
- Changes in retail residential energy prices
- The sensitivity of energy consumption to changes in income and prices
- A linear trend

Increased income generally leads to higher consumption, and price increases generally support declines in consumption. Energy consumption's sensitivity to changes in income and price varies by region, fuel, and time period and is represented by an elasticity parameter. A linear trend parameter accounts for other factors, such as increases in the availability of electric household goods in developing countries, as well as conservation efforts, policy effects, and energy efficiency improvements.

2. Description of the Projection Method

For each WEPS region and for each fuel and projection year, we calculate an index to find the change in consumption that results from the projected change in household income since the base year. We then compute similar factors to find the effects of changes in residential energy prices and a linear trend. To arrive at a projection for the current year, we multiply the base year's energy consumption estimate by the product of the three factors:

$$\begin{aligned} \text{This Year's Consumption} &= (\text{Base Year's Consumption}) \\ &\quad \times (\text{Index of Change Due to Income Changes}) \\ &\quad \times (\text{Index of Change Due to Price Changes}) \\ &\quad \times (\text{Change Due to a Long-Term Trend}) \end{aligned}$$

To compute *Last Year's Consumption*, we start with an estimate for the *base year*, the most recent historical year for which data are available. We update the estimate sequentially for each year in the projection period. The WEPS Global Activity Module (GLAM) provides the necessary income projections, and various other WEPS modules provide residential fuel price projections.

We calculate an index of change in disposable income relative to the module base year. For each region, fuel, and projection year, we calculate an index value by updating the previous year's value:

$$\text{This Year's Index} = (\text{Last Year's Index})^{\text{Lag Effect Parameter}} \times \left(\frac{\text{This Year's Income}}{\text{Base Year's Income}} \right)^{\text{Income Elasticity}}$$

The *Lag Effect Parameter* indicates the effect of the previous year's index value on the current year's index value (a measure of consistency), and the *Income Elasticity* indicates the impact of income change on the residential consumption of each fuel. For example, a value of 0 for these parameters indicates no effect, and a value of 1 indicates a strong effect. We calculate the values of each of these parameters by analyzing projections from our *National Energy Modeling System* (NEMS) and applying adjustments for the WEPS regions, as discussed in [Section 3](#). The income values represent total disposable income per capita to account for the effects of population change for the region and are adjusted for purchasing power parity.

Similarly, for each fuel, we index the change in fuel price relative to the module base year. Then, for each region and projection year, we calculate an index value by updating the previous year's value:

$$\text{This Year's Index} = (\text{Last Year's Index})^{\text{Lag Effect Parameter}} \times \left(\frac{\text{This Year's Price}}{\text{Base Year's Price}} \right)^{\text{Price Elasticity}}$$

The *Price Elasticity* indicates the effect of price change on residential consumption of the particular fuel.

We also apply a multiplicative growth factor, or an index of change in long-term growth trend relative to the module base year. We set the factor equal to 1 for the base year, and we set it equal to a target value for the final projection year (currently 2050). We then compute the annual growth rate by linear interpolation.

For the reference case, we adjust the residential consumption projections for the first two projection years to match values published in our *Short-Term Energy Outlook*.

3. Deriving the Parameters

The elasticities and the *Lag Effect Parameters* used in the module are largely based on the way the projections from the NEMS *Residential Demand Module* behave, and they are adapted to the WEPS regions. To develop these parameters, we analyze the projections from a previous year's [Annual Energy Outlook](#) Reference case and compare them to those from the corresponding High and Low Economic Growth cases and the corresponding High and Low Oil Price cases.

For example, we estimate the *Income Elasticity* parameters for each year and fuel by examining the differences in projected fuel consumption between the Reference case and the High Economic Growth case relative to the projected income changes. We repeat the process, examining differences between the Reference case and the Low Economic Growth case projections. Because the estimated *Income Elasticity* parameters from the two analyses differ, we generally compute the module parameter by averaging the two values. In cases where the resulting parameter seems inappropriate, we use alternative elasticity estimates (for example, estimates based on data from other fuels or sectors) along with expert judgment to arrive at an acceptable parameter value.

We estimate the price elasticities in essentially the same way. We use different NEMS projections that reflect changes in specific fuel prices and compare the projected changes in fuel consumption to those projected for the Reference case. In general, the elasticity for each fuel is an average of estimated elasticities for that fuel, but our analysts use expert judgment when the NEMS-based elasticities don't seem appropriate.

4. Adjusting the Projection Method for Unusual Conditions

Although the basic method just described provides reasonable projections for most fuels, regions, and WEPS cases, we adjust the method as needed to account for unusual conditions.

4.1 Adjusting the trend factor

Under some conditions, a straight-line trend might not be appropriate for a projection. For example, consumption of a specific fuel in a specific region might have recently grown rapidly and may, therefore, be expected to reach saturation, resulting in a moderation in the trend. The module allows analysts to modify the trend factor by adding an inflection point to the linear trend.

4.2 Accounting for fuel substitution in the High World Oil Price (HWOP) case

When the price of one fuel increases relative to the prices of other fuels, some households switch to the cheaper fuel. Because the basic method described in [Section 2](#) involves no fuel cross-price elasticities, it doesn't generally account for fuel substitution. In the HWOP case, however, we modify the method to ensure that the projected decline in petroleum-based fuel consumption (from the Reference case level) results in increases in the projected consumption of other fuels.

We assume that 50% of the petroleum-based fuel consumption decrease in the HWOP case (relative to the Reference case) will be replaced by increases in consumption of other fuels. We estimate the substitution over the years in the projection period (currently from the base year to 2050) so that it starts at 0 in the base year and gradually increases to its full value five years after the base year. The annual proportion then remains the same through the end of the projection period.

Once we determine the amount of petroleum-based fuel consumption to be replaced by consumption of other fuels for each year, we allocate the total amount to natural gas, coal, and electricity based on the previously projected relative shares of each of these fuels. For example, if 100 trillion British thermal units (Btu) require substitution and the respective fractional shares of natural gas, coal, and electricity are 0.4, 0.0, and 0.6, respectively, then natural gas will increase by 40 trillion Btu, coal will be unchanged, and electricity will increase by 60 trillion Btu.