World Energy Projection System Plus (WEPS+): Residential Module

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1. Introduction

The WEPS+ Residential Energy Demand Module projects energy consumption in households, excluding motor vehicle fuel consumption, which is covered in the Transportation Demand Module. The module projects residential energy consumption in each of the 16 WEPS+ regions for nine fuels:

- Distillate fuel
- Kerosene
- Liquid petroleum gases (e.g., propane)
- Natural gas
- Coal
- Electricity
- Heat
- Biomass
- Solar

To project household energy consumption, we assume four factors determine consumption changes over time:

- Changes in household income
- 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 encourage consumption declines. Energy consumption's sensitivity to changes in income and prices varies by region, fuel, and time period and is represented by an *elasticity* parameter. The linear trend 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:

This Year's Consumption = (Base Year's Consumption)

$\times$ (Index of Change Due to Income Changes)

$\times$ (Index of Change Due to Price Changes)

$\times$ (Change Due to a Long-Term Trend)

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 Economic Module provides the necessary income projections, and various other WEPS+ modules provide residential fuel price projections.

We set the Index of Change Due to Income Changes to 1 for the base year. For each region, fuel, and projection year, we calculate an index value by updating the previous year's value:

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

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 zero for these parameters indicates no effect, but a value of one indicates a strong effect. We find the parameter values (Table 1) by analyzing projections from EIA's U.S. National Energy Modeling System (NEMS) and applying adjustments for the WEPS+ regions, as discussed in Section 3. The income values represent total household income for the region and account for the effects of population change.

Similarly, for each fuel, we set the Index of Change Due to Price Changes equal to one for the base year. Then, for each region and projection year, we calculate an index value by updating the previous year's value:

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

The Price Elasticity Indicates the effect of price change on residential consumption of the fuel.

We calculate the Change Due to a Long-term Trend as a simple growth factor. 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.

We adjust the residential consumption projections for the first two projection years to agree with those published in EIA's *Short-Term Energy Outlook*.

3. Finding 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 Module behave, and they are adapted to the WEPS+ international 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, EIA analysts generally compute the model parameter by averaging the two values. In cases where the resulting parameter seems inappropriate, analysts use alternative elasticity estimates, i.e., based on data from other fuels or sectors, along with expert judgment, they arrive at an acceptable parameter value.

We estimate the price elasticities in essentially the same manner. 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 analysts use expert judgment when the NEMS-based elasticities don't seem appropriate.

For IEO2019, the values of the Lag Effect Parameters and the linear trend growth rates were 0, as shown in Table 1.

4. Adjusting the Projection Method for Unusual Conditions

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

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.

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 to 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) requires substitution and the respective fractional shares of natural gas, coal, and electricity

are 0.4, 0.0, and 0.6, then natural gas will increase by 40 trillion Btu, coal will be unchanged, and electricity will increase by 60 trillion Btu.