Concepts, Data Sources, and Techniques

Handbook of Energy Modeling Methods

World Energy Projection System (WEPS): Overview

Independent Statistics & Analysis

www.eia.gov

U.S. Department of Energy

Washington, DC 20585

Last Updated 2020

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Introduction

The World Energy Projection System (WEPS) generates projections of energy consumption, prices, and production for the *International Energy Outlook* (IEO). This overview presents a brief description of the methodology and scope of each of the component modules of WEPS, along with a brief description of the modeling system. Further details on each of the component modules of WEPS are provided in individual model documentation sections.

The complete WEPS system contains three main parts:

- A common database to track historical energy data and WEPS projections
- Energy models that represent the various sector-level demand, transformation and supply projection activities.
- A convergence model that determines when the system has reached an equilibrium between supply and demand.

WEPS is a modular system, comprising a number of separate energy models joined through a common database, which enables them to communicate and work with each other. EIA develops each of these models independently and incorporates well-defined guidelines or protocols for system communication and interactivity. The overall WEPS system uses an iterative solution technique that works toward converging consumption and price in an equilibrium solution.

The core WEPS models make up a complete set of models that can simulate the international energy system, along with a greenhouse gas emissions and policy model. The system also includes models that perform preprocessing and post-processing, including various final reporting programs.

The core set of WEPS models, in order of execution, is as follows:

- Global Activity Model
- Residential Demand Model
- Commercial Demand Model
- Industrial Demand Model
- Transportation Demand Model
- Electricity Model
- District Heat Model
- Hydrocarbon Supply Model
- Coal Supply Model
- Greenhouse Gas Model
- Convergence Model

Each model is run independently but reads and writes to a common database to communicate with other models. The common database provides *seed* values for macroeconomic quantities, energy prices, and energy consumption. The system runs each model in turn before running the convergence model, which determines if the system has converged. If the system has not converged, it begins another sequence (iteration). If it has converged, it finishes with report writing.

WEPS models 16 world regions that consist of countries and country groupings within the broad divide of the Organization of Economic Cooperation and Development (OECD) and non-OECD:

- OECD regions: United States, Canada, Other OECD Americas (Mexico, Chile, Colombia), OECD Europe, Japan, South Korea, Australia and New Zealand
- Non-OECD regions: Russia, Other non-OECD Europe and Eurasia (non-Russia), China, India, Other non-OECD Asia (non-China, non-India), Middle East, Africa, Brazil, Other non-OECD Americas (non-Brazil)

Individual models can use more detailed regions for internal calculations.

Historical Data

We use several key historical data sources for WEPS:

- EIA's International Energy Statistics (IES) database (https://www.eia.gov/international/data/world) provides country-level data for the following fuels consumed for electricity generation:
    - Liquids
    - Natural gas
    - Coal
    - Nuclear energy
    - Hydroelectric and other renewables

  IES also includes data on electricity generation and installed generating capacity for

- Thermal
- Nuclear
- Hydroelectric
- Other renewables: wind; biomass and waste; geothermal; solar, tide, wave, and fuel cells

- The international data produced and maintained by the International Energy Agency in Paris (referred to as IEA/Paris), as part of its energy balances database, provides country-level consumption data for a wide variety of *flows* (sectors and users) and for a wide variety of *products* (detailed petroleum products, coal types, renewable sources, etc.). EIA uses these detailed data to derive the historical, end-use sector data used in WEPS demand models.

- Historical data and projections for the United States are extracted from the most recent EIA *Annual Energy Outlook*.

The EIA data source provides the overall consumption levels, and the IEA/Paris data provides consumption information at more detailed levels. The IEA/Paris data, therefore, must be calibrated (or *shared*) to agree with the EIA data.

Global Activity Model

The commercially available Oxford Economics Global Economic Model (GEM) and Global Industry Model (GIM) generate projections of gross domestic product (GDP) and gross output for the various WEPS regions and their respective industrial sectors, given energy inputs from WEPS. The theoretical structure of GEM differentiates between the short-term and long-term projections for each country, with extensive coverage of the links among different economies. GEM produces GDP outputs for WEPS and provides drivers for GIM. GIM calculates gross output in various industrial sectors for each WEPS region, based on input-output relationships.

Residential Demand Model

The WEPS Residential Demand Model projects household energy consumption. The Transportation Demand Model, however, projects on-road transportation energy demand, such as demand for motor gasoline.

The Residential Demand Model primarily uses a dynamic econometric equation for the key energy sources, basing the projection on household income, residential retail energy prices, and an assumed future trend. The dynamic equation uses a lagged dependent variable to imperfectly represent fuel stock accumulation in the calculation of fuel prices for each region over time. Income and price projections are available from the Global Activity Model and supply models via the common database. The trend factor is meant to represent continuing impacts on energy use not directly represented in household income and prices and may include the effects of a variety of behavioral, structural, and policy-induced activities.

Commercial Demand Model

The WEPS Commercial Demand Model projects energy consumption that takes place in commercial buildings and activities. It also includes municipal activity, such as street lighting.

The Commercial Demand Model primarily uses a dynamic econometric equation for the key energy sources, basing the projection on service sector gross output, prices, and an assumed future trend. The dynamic equation uses a lagged dependent variable to imperfectly represent fuel stock accumulation in the calculation of fuel prices for each region over time. Service sector gross output and price projections are available from the Global Activity Model and supply models via the common database. The trend factor is meant to represent continuing impacts on energy use not directly represented in service sector gross output and prices and may include the effects of a variety of behavioral, structural, and policy-induced activities.

Industrial Demand Model

The WEPS Industrial Demand Model (also known as the the World Industrial Model, or WIM) projects the amount of energy that is directly consumed as a fuel or as a feedstock by industrial processes and activities. This includes both energy intensive and non-energy intensive manufacturing industries, and non-manufacturing industries.

The WIM uses an array of seven energy intensity (EI) models to find the best fit for each region-industry based on historic trends, statistical measures, and analyst judgement. There are three ordinary least squares (OLS) and three least absolute difference (LAD) models, each type featuring a logarithmic growth, exponential decay, and 'flat' model where LAD models revert to the historic median and OLS models return to historic mean. The seventh model assumes exponential decay in all cases and is linked to the last historical year.

All seven EI models use historic energy intensity data to estimate coefficients which they then apply to compute projections for the projection period. An algorithm then ranks the EI model results using several statistical indicators, the main indicator being the Akaike Information Criterion corrected for small samples (AICc). The top ranked EI model result is selected, unless an analyst has overridden the EI model selection algorithm. The energy consumption for each region-industry is calculated as the gross output multiplied by the projected EI. The energy consumption in each fuel category is calculated as the total consumption in a region-industry multiplied by the fuel shares.

Transportation Demand Model

The WEPS Transportation Demand Model projects the amount of energy consumed to provide passenger and freight transportation services. This projection includes personal household on-road transportation in light duty vehicles (counted here rather than in the Residential Demand Model), fuel consumed by natural gas pipelines, and small amounts of lubricants and waxes. The model projects transportation consumption for 14 energy sources in each of the WEPS regions over the projection horizon. The Transportation Demand Model provides an accounting framework that considers energy service demand and service intensity (efficiency) for the overall stock of vehicles. The service demand is a measure of overall passenger miles for passenger services and overall ton miles for freight services. The service intensity is a measure of passenger miles per unit of energy expended (in Btu) for passenger services and ton miles per unit of energy expended (in Btu) for freight services.

The Transportation Demand Model performs the following functions:

- Uses a bottom-up approach to estimate demand for transportation energy by mode (road, rail, air, and marine) and vehicle type (light-duty vehicles, freight trucks, passenger rail, etc.)
- Estimates transportation energy consumption by fuel and region
- Estimates vehicle stocks by vehicle type and region

The Transportation Demand Model reads macroeconomic (GDP and population) and energy price projections from the common database. After running, the model provides transportation energy consumption projections to the common database.

Electricity Model

The WEPS Electricity Model (IEMM) projects the following:

- Electricity generating capacity additions and retirements
- Electricity generation
- Electricity added to and removed from storage

- Electricity sold and purchased
- Electricity delivered to consumers
- Fuel consumed in electricity generation
- Carbon dioxide emissions
- Electricity prices

The module projects these quantities for each of the 16 WEPS regions by year and *time-slice*. A time-slice is a time period, specified by EIA analysts, as a period of the day during a particular month or season (e.g., January from 6:00 a.m. to 7:00 a.m.). In some cases, some of the quantities listed above are also broken out by other characteristics such as the type of technology used to generate the electricity.

The module projects these quantities by minimizing an objective function subject to several constraints. The objective function represents the total cost for electricity suppliers to meet all electricity demands, by year and time slice, projected by the WEPS demand modules. Examples of constraints include limits on fuel-specific electricity generating equipment, policy constraints (e.g., renewable portfolio standards), and emissions caps. The IEMM uses linear programming to perform the constrained optimization.

District Heat Model

The WEPS District Heat Model projects the generation of district heat (steam or hot water, from an outside source, used as an energy source in a building) to satisfy the demands projected by the Residential Demand Model, Commercial Demand Model, and Industrial Demand Model for each region. For each fuel, the model estimates the amount of heat generated and the amount consumed, as well as the end-use price of heat for each of the three demand sectors. In addition, the model projects fuel consumed and heat generated in each of the WEPS regions over the projection horizon for eight energy sources. The model uses prices from the supply models for distillate, residual, natural gas, and coal.

The District Heat Model uses a stock/flow approach in which it adds new heat generation capability each year as necessary, based on the heat generation requirement from the end-use demand sectors. The model takes into account the amount of heat that is available from combined heat and power (CHP) plants in the electricity generation sector.

Hydrocarbon Supply Model

The WEPS Global Hydrocarbon Supply Model (GHySMo) comprises three semi-independent submodules: logistics, upstream (oil and natural gas production), and conversion (petroleum refining).

The logistics model solves a transshipment network problem (based on a linear program that minimizes the costs) and determines the best way to direct supplies of various commodities (including natural gas) between a set of producing regions (nodes in the network) on transportation-mode specific routes (arcs on the network) to meet regional demands. Logistical assets included in the model are transportation modes (ships and pipelines) and nodal infrastructure (natural gas liquefaction and regasification facilities). Assets are designated by the commodity type (e.g., crude oil, natural gas, and petroleum products) that they carry or process. (Ships are further categorized by capacity size). The model projects commodity supply and demand prices and passes them to the upstream and conversion models.

The upstream model uses the projected commodity supply prices from the logistics model to solve a least-cost optimization problem: it projects when an oil/natural gas production project is economically viable, through its net present value. It also projects its production profile and the date of its commencement.

The conversion model uses the crude oil demand prices to project (using a linear program(LP)) the optimal quantity of refined petroleum product that refineries should produce. Subject to constraints, the LP of maximizes the profit of the refineries.

The updated quantities from the upstream and conversion models are sent back to the logistics model, and the entire process iterates until the convergence criteria have been met. The GHySMo sends the converged prices to WEPS for the demand models' use in developing their own demand projections.

Coal Supply Model

The WEPS Coal Supply Model (International Coal Markets Model, or ICMM) includes three sub-modules that determine the production, import, export, and price of coal:

- Data processor
- Production module
- Logistics module

Each component is connected to the others to process data from external input files, create and shift coal supply curves, and project the coal trade between each pair of regions.

The data processor starts the ICMM run by creating the input files necessary to run the production module and the logistics module. This includes, for example,

- Separating coal demand data into the four (or more) coal types defined by EIA analysts
- Creating regions, defined in the ICMM, to generate transportation rates based on data about trade routes

At the end of each run, the data processor creates the ICMM outputs for the common WEPS database and for a model-specific diagnostic tool.

The production module creates coal supply curves that the logistics module uses to project the price per unit of coal. Through an interative process, the production module and the logistics module compare and adjust coal supply curve parameters. This process (called the *supply shift*) allows the modules to simulate regional decisions, based on the previous year's projections, to increase or decrease their production in the current projection year. The frequency of the adjustments are used as a convergence criteria: convergence is considered met if the supply shift does not change the coal production projected by the logistics module.

The logistics module projects the quantities of coal shipped from supply regions to demand regions. It uses an LP that maximizes profit. It also projects the prices of different coal commodities (metallurgical, bituminous, subbituminous, and lignite) in the demand regions, the quantities shipped on each trade route, and coal production quantities. The profit maximization LP determines the trade routes with the lowest transportation rates and the supply regions with the lowest supply prices, to meet demand at the lowest possible delivered price. The logistics module passes the projected coal production quantities to the production module, which uses them to create new supply curves for the next iteration.

Greenhouse Gases Model

The WEPS Greenhouse Gases Model projects energy-related carbon dioxide emissions by taking all of the consumption projections of the other models and applying carbon dioxide emissions factors to them. The emissions factors are calibrated to recent historical data from EIA's International Energy Statistics database. The model does not count emissions from fuel used as a feedstock, or *sequestered*, or consumed in a carbon capture and storage technology. The model does not address carbon dioxide emissions from non-energy consumption sources, nor does it account for non-carbon dioxide greenhouse gas emissions.

Convergence Model

The WEPS Convergence Model evaluates and facilitates finding an equilibrium where energy production matches energy consumption. After the other WEPS models have run, the WEPS convergence model checks whether supply and demand are in equilibrium. If not, then other models are executed again, using prices and quantities from the preceding iteration. As needed, the WEPS convergence model adjusts prices up or down to help find an equilibrium.