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World Energy Projection System Plus (WEPS+): Overview

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Introduction

The World Energy Projection System Plus (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-demand, -transformation and -supply projection activities.
- A convergence model that determine when an equilibrium between supply and demand has been reached.

WEPS+ is a modular system, consisting of a number of separate energy models joined through a common database, which enables them to communicate and work with each other. These models are each developed independently but are designed with 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 comprise a complete set of models that can simulate the complete 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 models in WEPS+ is

- 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. Each model is run in turn before the system runs the convergence model, which then determines if the system has converged. If the system has not converged, it begins another sequence (iteration). If it does converge, it finishes up 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
- Mexico and Chile
- 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+:

- The U.S. Energy Information Administration's (EIA) International Energy Statistics (IES) database (https://www.eia.gov/beta/international/) 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 IEO countries and 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. The structure of GIM, which calculates gross output in the IEO sectors for each country or region in WEPS+, is based on input-output relationships. It calculates gross output in the IEO sectors for each country or region in WEPS+

Residential and Commercial Demand Models

The WEPS+ Residential Demand Model projects household energy consumption. However, on-road transportation energy demand, such as for motor gasoline, is projected in the Transportation 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 Residential and Commercial Models 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 retail fuel prices for each region over time. Income, service sector gross output, and price projections are available to the Residential and Commercial Models from the Global Activity Model and supply models. The trend factor is meant to represent continuing impacts on energy use not directly represented in household income, GDP, 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 projects the amount of energy that is directly consumed as a fuel or as a feedstock by industrial processes and activities. It includes both manufacturing industries and non-manufacturing industries such as construction, agriculture, and mining. The Industrial Demand Model is a structured, industry-level, stock/flow model that uses gross output from the Global Activity

Model as its primary driver. The model also uses energy prices as an input. These drivers are available to the Industrial Model from the WEPS+ global activity and supply models through the common database.

The Industrial Demand Model projects energy consumption in several different industries identified according to their energy consumption characteristics. The industries model includes: Paper, Basic Chemicals, Refineries, Iron and Steel, Motor Vehicles, and others. For a complete list, see the separate Industrial Model documentation.

The Industrial Demand Model uses a stock/flow modeling approach. The model is initialized with an existing stock of productive capacity for each industry, and that capacity consumes energy based on its energy intensity—energy consumed per dollar of gross output—and fuel shares. For each projection year, the model estimates how the productive capacity has changed in three vintage categories: original existing capacity, previously added capacity from previous projection years, and new capacity. The total energy consumption in each vintage category is calculated as the gross output multiplied by the energy intensity. The energy consumption for each fuel in each vintage category is calculated as the total consumption 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 16 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 Model reads macroeconomic (GDP and population) and energy price projections from the common database. After running, the model provides energy consumption projections to the common database.

Electricity Model

The WEPS+ Electricity Model (IEMM) projects

- Electricity generating capacity additions and retirements
- Electricity generation
- Electricity added 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). Prices are determined and fed into both the upstream and conversion models.

The upstream model uses the new supply price to solve a least-cost optimization problem that determines when an oil/natural gas project is economically viable through its net present value, decides its production profile, and schedules its commencement.

The conversion model uses the crude oil demand price to solve a linear program of maximizing the profit of the refinery by deducing the optimal production of refined petroleum products. The updated quantities from both models are sent back to the logistics model and the entire process iterates until the convergence criteria have been met. The converged prices are sent to WEPS+ for the demand models' use in developing their own demand projections.

Coal Supply Model

The WEPS+Coal Model projects wholesale prices and sectoral retail prices of coal in each region. The regional wholesale prices are based on an exogenous price path and a price elasticity term, which are based on historical prices and analyst judgment. Retail prices are based on fixed sectoral markups from the wholesale prices.

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.