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 2021

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Contents

Table of Figures

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 module documentation sections.

The complete WEPS system contains three main parts:

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

WEPS is a modular system, that is made up of a number of separate energy modules joined through a common database, which enables them to communicate and work with each other. We develop each of these modules independently and incorporate 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 modules together can simulate the international energy system, along with a greenhouse gas emissions and policy module. The system also includes modules that perform preprocessing and post-processing, including various final reporting programs.

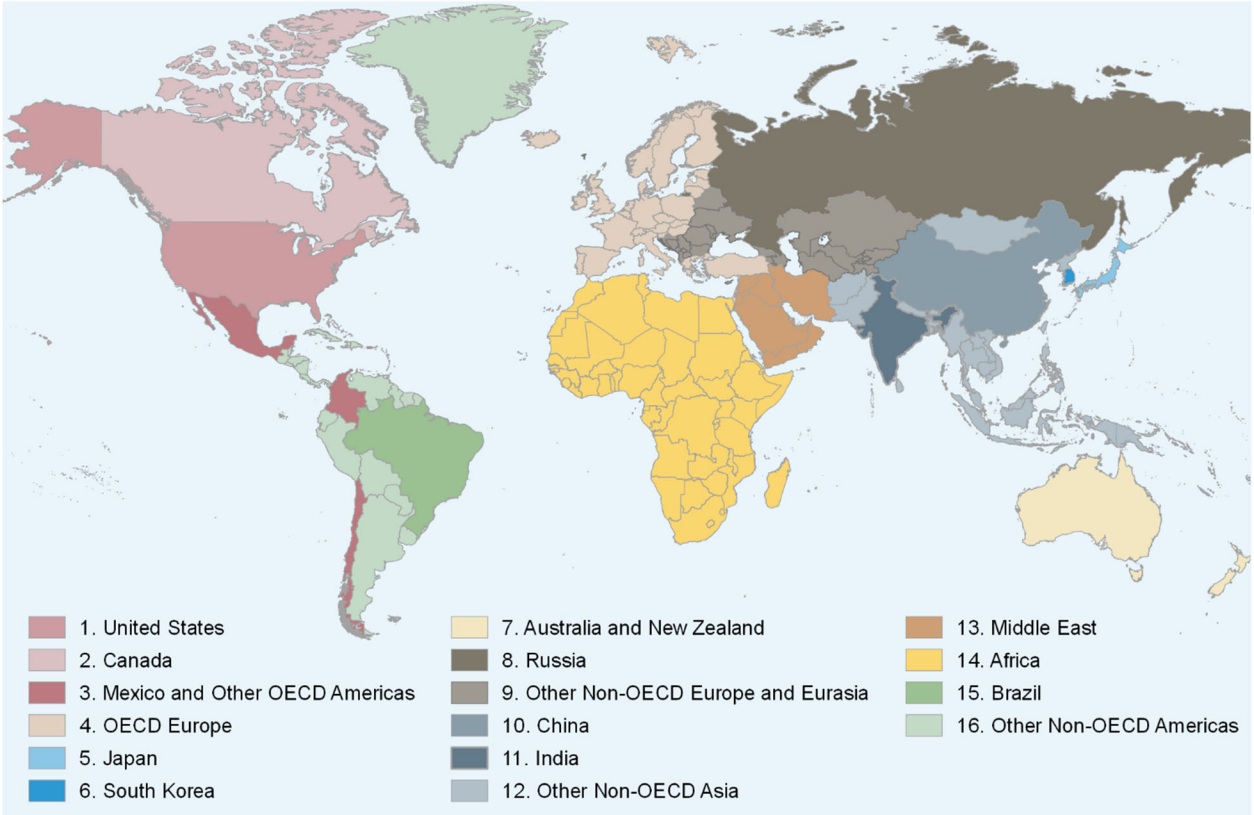
The core set of WEPS modules, in order of execution, includes:

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

Each module is run independently but reads and writes to a common database to communicate with other modules. The common database provides *seed* values for macroeconomic quantities, energy prices, and energy consumption. The system runs each module in turn before running the convergence module, 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 countries.

Figure 1. World Energy Projection System (WEPS) regions



Source: U.S. Energy Information Administration

WEPS results are sometimes reported according to these aggregate regions:

- **OECD Americas:** United States, Canada, Chile, Colombia, Puerto Rico, U.S. Virgin Islands, Mexico
- **OECD Europe:** Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania Luxembourg, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom (Note: Israel is included in OECD Europe for statistical reporting purposes.)
- **OECD Asia:** Australia, American Samoa, Guam, Japan, New Zealand, South Korea
- **Non-OECD Europe and Eurasia:** Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Faroe Islands, Georgia, Gibraltar, Kazakhstan, Kosovo, Macedonia, Malta, Moldova, Montenegro, Romania, Russia, Serbia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan
- **Non-OECD Asia:** Afghanistan, Bangladesh, Bhutan, Brunei, Burma (Myanmar), Cambodia (Kampuchea), China, Cook Islands, Fiji, French Polynesia, Hong Kong, India, Indonesia, Kiribati, Laos, Macau, Malaysia, Maldives, Mongolia, Nauru, Nepal, New Caledonia, Niue, Northern Mariana Islands North Korea, Pakistan, Papua New Guinea, Philippines, Samoa, Singapore,

Solomon Islands, Sri Lanka, Taiwan, Thailand, Timor-Leste (East Timor), Tonga, Vanuatu, Vietnam, Wake Islands

- **Middle East:** Bahrain, Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Palestinian Territories, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen
- **Africa:** Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo (Brazzaville), Congo (Kinshasa), Côte d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Eswatini, Ethiopia, Gabon, The Gambia, Ghana, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, South Sudan, St. Helena, Sudan, Tanzania, Togo, Tunisia, Uganda, Western Sahara, Zambia, Zimbabwe
- **Non-OECD Americas:** Antarctica, Antigua and Barbuda, Argentina, Aruba, The Bahamas, Barbados, Belize, Bermuda, Bolivia, Brazil, British Virgin Islands, Cayman Islands, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Falkland Islands, French Guiana, Greenland, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Montserrat, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, St. Kitts and Nevis, St. Lucia, St. Pierre and Miquelon, St. Vincent/Grenadines, Suriname, Trinidad and Tobago, Turks and Caicos Islands, Uruguay, Venezuela

Individual modules 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
  - 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.). We use these detailed data to derive the historical, end-use sector data used in WEPS demand modules.

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

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

Global Activity Module

The commercially available Oxford Economics Global Economic Module (GEM) and Global Industry Module (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 and extensively covers the links between 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 Module

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

The Residential Demand Module 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 Module and supply modules 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 it may include the effects of a variety of behavioral, structural, and policy-induced activities.

Commercial Demand Module

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

The Commercial Demand Module 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 Module and supply modules 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 it may include the effects of a variety of behavioral, structural, and policy-induced activities.

Industrial Demand Module

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

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

All seven EI modules use historical energy intensity data to estimate the coefficients that they apply to compute projections for the projection period. An algorithm ranks the EI module results using several statistical indicators; the main indicator is the Akaike Information Criterion corrected for small samples (AICc). The top ranked EI module result is selected, unless an analyst overrides the EI module selection algorithm. The energy consumption for each region and industry sector 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.

Exceptions to the above are feedstocks in basic chemicals and other industrial and the iron and steel industry. Feedstocks are not subject to efficiency improvements and have energy intensity levels frozen at the last historical year level for each region. Iron and steel industry projections are based on historical trends in physical production levels, production methods (primary versus secondary), and fuel consumption by region.

Transportation Demand Module

The WEPS Transportation Demand Module 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 Module), fuel consumed by natural gas pipelines, and small amounts of lubricants and waxes. The module projects transportation consumption for 14 energy sources in each of the WEPS regions over the projection period. The Transportation Demand Module 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 British thermal units (Btu)) for passenger services and ton miles per unit of energy expended (in Btu) for freight services.

The Transportation Demand Module:

- 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 Module reads macroeconomic (GDP and population) and energy price projections from the common database. After running, the module provides transportation energy consumption projections to the common database.

Electricity Module

The WEPS Electricity Module (IEMM) projects:

- 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

This 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 (for example, 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 (for example, renewable portfolio standards), and emissions caps. The IEMM uses linear programming to perform the constrained optimization.

District Heat Module

The WEPS District Heat Module 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 Module, Commercial Demand Module, and Industrial Demand Module for each region. For each fuel, the module 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 module projects fuel consumed and heat generated in each of the WEPS regions over the projection period for eight energy sources. The module uses prices from the supply modules for distillate, residual, natural gas, and coal.

The District Heat Module 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 module takes into account the amount of heat that is available from combined heat and power (CHP) plants in the electricity generation sector.

Hydrocarbon Supply Module

The WEPS Hydrocarbon Suppy Module (Oil and Natural Gas Tool) adjusts initial supply projections of liquid fuels and natural gas to meet total global consumption. It also provides WEPS with projections of:

- Energy used in oil and natural gas exploration
- Refining consumption
- Energy use related to natural gas transmission
- End-use sector prices by WEPS region and commodity
- Spot prices for crude oil and natural gas in select markets

Coal Supply Module

The WEPS Coal Supply Module (International Coal Markets Module, 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, to create and to shift coal supply curves, and to 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. For example, it:

- Separates coal demand data into the four (or more) coal types defined by EIA analysts
- Creates 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 module-specific diagnostic tool.

The production module creates the coal supply curves that the logistics module uses to project the price per unit of coal. Through an iterative 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 Module

The WEPS Greenhouse Gases Module projects energy-related carbon dioxide emissions by taking all of the consumption projections of the other modules 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 module does not count emissions from fuel used as a feedstock, or *sequestered fuel*, or fuel consumed in a carbon capture and storage technology. The module does not address carbon dioxide emissions from non-energy consumption sources, nor does it account for non-carbon dioxide greenhouse gas emissions.

Convergence Module

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