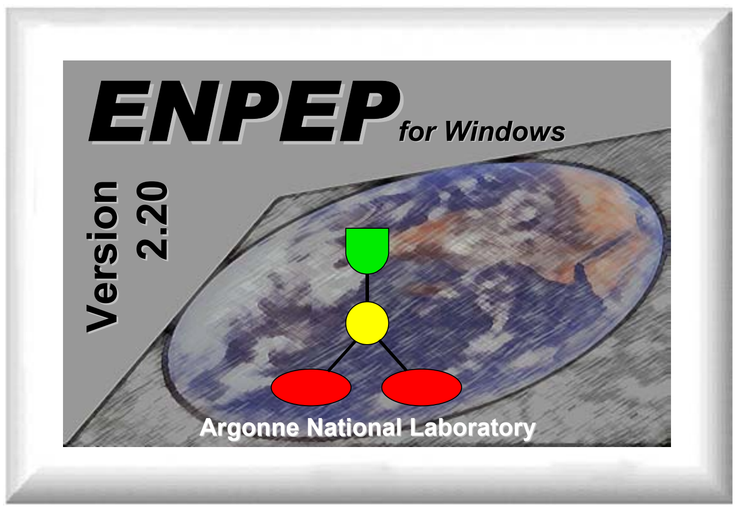
Argonne National Laboratory
Decision and Information Sciences Division

ENergy and Power Evaluation Program (ENPEP)

Brief Model Overview



Center for Energy, Environmental, and Economic Systems Analysis (CEEESA)
Decision and Information Sciences Division
9700 South Cass Avenue
Argonne National Laboratory
Argonne, IL 60439-4832
Email: energycenter@anl.gov
Internet: www.energycenter.anl.gov

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Center for Energy, Environmental, and Economic Systems Analysis (CEEESA)

ENPEP – An Integrated Energy, Economic, and Environmental Model

As shown in Figure 1, the Windows version of the ENergy and Power Evaluation Program (ENPEP) is a set of ten integrated energy, environmental, and economic analysis tools and is the premier energy system analysis software in use in over 80 countries. Each module has automated linkages to other ENPEP modules as well as stand-alone capabilities.

The ***MACRO-E*** module is a new macro-economic analysis tool that helps analyze the feedbacks between the energy sector and the economy as a whole.

The ***MAED*** module (Model for Analysis of Energy Demand) is a strategic, scenario-based, simulation model that performs long-term energy and electricity demand forecasting. Future energy demand is estimated by using a bottom-up approach in which useful energy demand needs for specific activities are projected. Energy consumption levels for individual activities are then aggregated to project total future demand for fossil fuels, electricity, district heating, coke, and feedstocks in each sector/subsector of the economy. Designed to reflect the structural changes in energy demand, MAED performs detailed analyses of social, economic, and technological developments, as well as policy issues. The latest version is spreadsheet-based and offers much more flexibility in defining a country's energy system representation.

The new ***LOAD*** module analyzes and processes hourly electric loads and generates load duration curves and other load parameters for use in other ENPEP modules. LOAD is not a load forecasting model. It simply helps the user to prepare and format load data such that it can be easily used in power systems analysis models like ICARUS, WASP-IV, and GTMax.

The ***PC-VALORAGUA*** module has been used extensively to determine the optimal generating strategy of mixed hydro-thermal electric power systems. The optimal operation strategy is obtained for the system as a whole, with an emphasis on detailed simulation and optimization of the hydro subsystem operation. The model can simulate the operation of all types of hydropower plants (run-of-river, weekly, monthly, seasonal, or multi-annual regulation), including pumped-storage plants and multipurpose hydro projects. The model calculates possible production of hydropower plants based on either a historical series of monthly water inflows or synthetic water inflows with associated probabilities of occurrence. PC-VALORAGUA works with the hydraulic network of a country (or region) and can determine the optimal operation of up to 50 reservoirs in as many as 18 hydrocascades in the system. The most outstanding feature of PC-VALORAGUA is that it can calculate the marginal value of water in reservoirs at all times of the year. The mathematical expectancy of the future value of water is the basis for deciding whether to use the water from the reservoirs now or to retain it for later use.

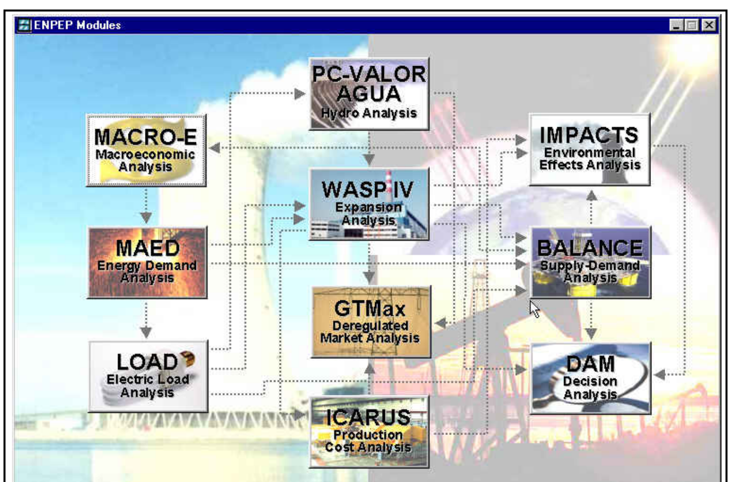


Figure 1: ENPEP Modules

The ***WASP-IV*** module is the latest version of the Wien Automatic System Planning Package (WASP). The module determines an electric system expansion plan that meets the growing demand for electricity at minimum cost while respecting user-specified constraints, such as desired system reliability, fuel limitations, or environmental constraints. The optimum is evaluated in terms of the minimum present worth of total system expansion and operating costs. WASP uses probabilistic simulation of production costs, energy-not-served costs, and system reliability parameters to compare total costs of alternative expansion policies. Each possible sequence of power units added to the system (expansion plan or policy) that meets the constraints specified by the user is evaluated by a cost function (the objective function). The optimal expansion path is then determined using a dynamic programming algorithm. For the analysis of mixed hydro-thermal power systems, WASP is frequently used in combination with the PC-VALORAGUA model. The expansion analysis conducted with the WASP/VALORAGUA methodology provides an enhanced representation of hydro power plants and their operation in the electric power system.

The ***GTMax*** module (Generation and Transmission Maximization) was developed by CEEESA to study the complex marketing and operational issues in today's deregulated power markets. GTMax helps generation companies and utilities maximize the value of their system assets, taking into account firm and non-firm contracts, independent power producer (IPP) agreements, bulk power transaction opportunities, and limitations of energy and transmission resources. GTMax simulates regional or national generation and transmission systems. In simulating multiple systems, GTMax identifies utilities and assets that can successfully compete in the market by tracking hourly energy transactions, costs, and revenues. GTMax employs a user-friendly geographical information system (GIS) interface that allows users to point and click on a map of utility power plants and other system components to modify input data and obtain optimization results (see Figure 2). A map displays hourly energy flows from supply resources such as generators and IPP firm contract purchases to load centers and spot market delivery points. Energy and financial results are also output in easy-to-understand tables and graphs. The model's flexible interface assists the user in building a network representation of any power system of interest. Originally developed for the U.S., the model is rapidly gaining popularity in deregulated markets around the world.

The ***ICARUS*** module (Investigating Costs and Reliability in Utility Systems) is an energy-system analysis tool that assesses the reliability and economic performance of alternative expansion patterns of electric utility generating systems. This detailed dispatch model calculates (1) a system maintenance schedule (if not fully specified), (2) system loss-of-load probability, (3) unserved demand for electric energy, (4) reserve capacity needed to meet a specified reliability criterion, (5) effects of emergency interties, (6) expected energy generation from and cost of each unit and block, (7) total generating system costs, and (8) fuel use. The simplified probabilistic simulation technique provided by ICARUS significantly reduces computational requirements. Its calculations are based on system loads, unit-level generating resources, system operational constraints, and capacity and energy transfers among utility systems.

The new ***IMPACTS*** module calculates the physical impacts and the associated damage costs for particulate matter, sulfur dioxide, nitrogen oxides, carbon monoxide, and secondary species such as nitrate and sulfate aerosols. A detailed environmental impacts analysis typically requires a very complex, data-intensive multidisciplinary study, including emissions projections, local and regional dispersion analysis, estimation of physical impacts using exposure-response func-

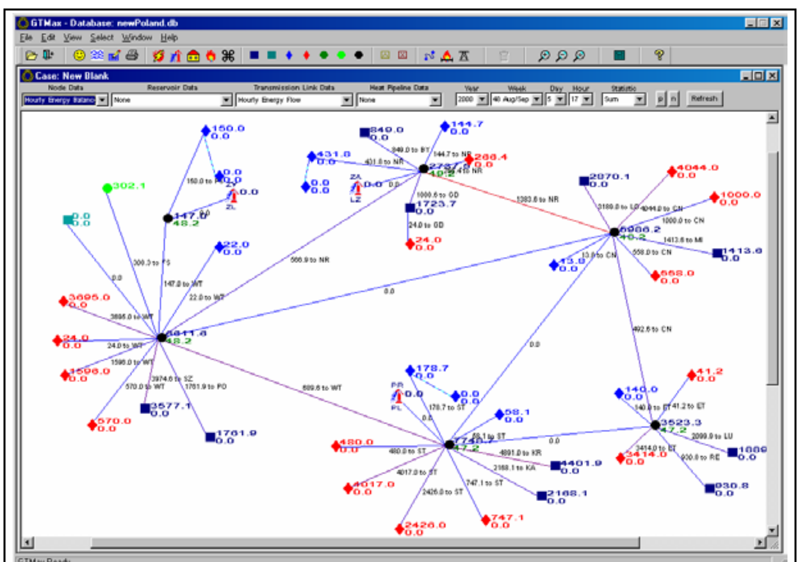


Figure 2: Example for a Power System Representation in GTMax (Poland)

tions, and monetization of impacts. Large uncertainties often occur because required data are either incomplete or missing. AIRPACTS provides a simplified approach that helps analysts develop a first estimate of potential damage from air pollution, both physical and economic. The model is adaptable to data availability because several levels of simplifications have been built in. At the simplest level, it requires only four input variables. As more information becomes available (e.g., local population and meteorological statistics), users can develop a more detailed analysis framework. This design is especially valuable to developing countries that have little data available but over time may acquire more detailed information. AIRPACTS is currently used in more than 20 countries.

The ***DAM*** (Decision Analysis Module) module was developed to aid decision analysts in solving multicriteria decision analysis problems by allowing analysis of trade-offs among technical, economic, and environmental concerns. This Windows-based software allows analysts to view a decision problem and find the best solution from different perspectives; performs standard, but time-consuming, tasks quickly and efficiently; offers a range of decision analysis and trade-off methods that cannot be performed manually; and presents results in convenient graphical and numerical formats. DAM also allows for imprecise or interval trade-offs. Results are displayed intuitively (see Figure 3).

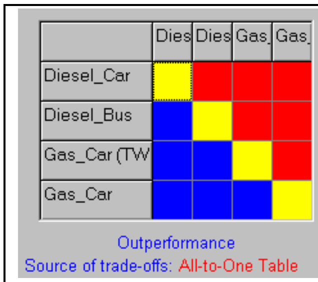


Figure 3: Sample DAM Module Results

The ***BALANCE*** module uses a nonlinear, market-based equilibrium approach to determine the energy supply and demand balance for the entire energy system. The model uses a graphical network representation of the energy system that is designed to trace the flow of all energy forms from primary resource level to final or useful energy demand, that is, transportation gasoline, residential hot water, or industrial process steam. Because this overview is primarily aimed at BALANCE users, the model is described in more detail in the following section.

The BALANCE Module of ENPEP

The nonlinear, equilibrium ***BALANCE*** module matches the demand for energy with available resources and technologies. Its market-based simulation approach allows BALANCE to determine the response of various segments of the energy system to changes in energy prices and demand levels. The model relies on a decentralized decision-making process in the energy sector and can be calibrated to the different preferences of energy users and suppliers. Basic input parameters include information on the

Figure 4: BALANCE Module of ENPEP

energy system structure; base year energy statistics, including production and consumption levels, and prices; projected energy demand growth; and any technical and policy constraints (Figure 4).

In this process, an energy network is designed to trace the flow of energy from primary resources to useful energy demands in the end-use sectors. BALANCE networks are constructed using different nodes and links, which represent various energy system components. Nodes in the network represent depletable and renewable resources, various conversion processes, refineries, thermal and hydro power stations, cogeneration units, boilers and furnaces, marketplace competition, taxes and subsidies, and energy demands (Figure 5). Links connect the nodes and transfer information among nodes.

BALANCE is very versatile in that the analyst starts with an empty workspace and builds an energy system configuration of nodes and links. BALANCE's powerful graphical user interface makes it is as easy as "drag and drop" to build networks of regional, national, or multinational scope. Figure 6 displays an example of a typical sectoral energy network, and

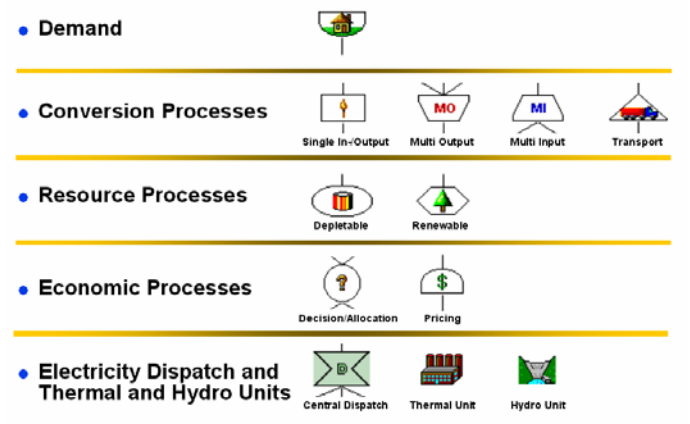


Figure 5: Node Types Available in BALANCE

Figure 7 shows a detailed network for an industrial subsector. Drop-down menus can be used to display model inputs and results directly within the energy network. Double-clicking the nodes allows access to more detailed input and output information.

The model employs a market share algorithm to estimate the penetration of supply alternatives. The market share of a specific commodity is sensitive to the commodity's price relative to the price of alternative commodities as shown in Figure 8. User-defined constraints (e.g., capacity limits), government policies (taxes, subsidies, priority for domestic resource over imported resource, etc.), consumer preferences, and the ability of markets to respond to price signals over time (i.e., due to lag times in capital stock turnover) also affect the market share of a commodity.

Using a market share algorithm distinguishes the equilibrium approach from other modeling techniques. The BALANCE approach simulates more accurately the more complex market behavior of multiple decision makers that optimization techniques may not be able to capture because they assume a single decision maker. Every sector (electric, industrial, residential,

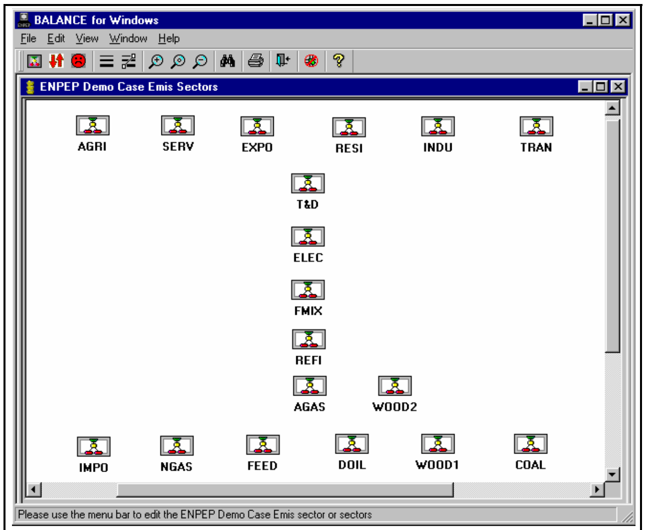


Figure 6: Example for a Sector-Level Energy System Representation in BALANCE

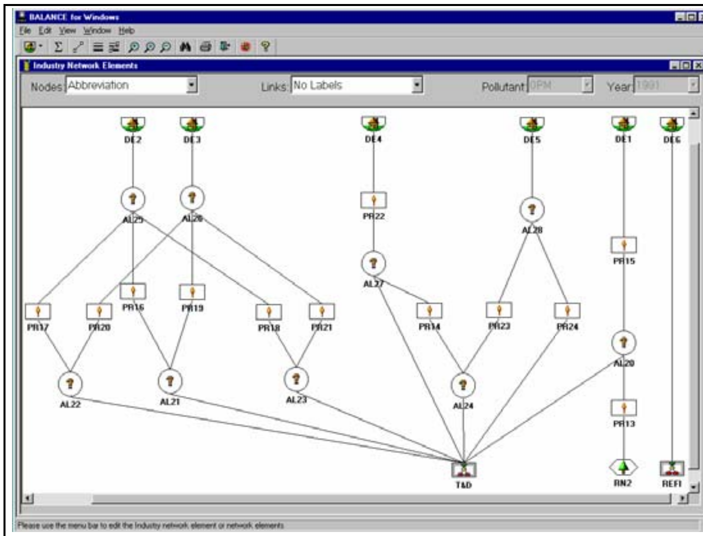
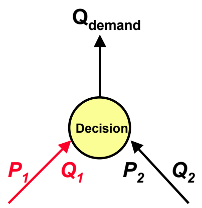


Figure 7: Example for an Industrial Sector Representation in BALANCE

$$MS_1 = \frac{Q_1}{Q_1 + Q_2} = \frac{\left[\frac{1}{P_1 \times PM_1}\right]^{\gamma}}{\left[\frac{1}{P_1 \times PM_1}\right]^{\gamma} + \left[\frac{1}{P_2 \times PM_2}\right]^{\gamma}}$$



γ price sensitivity for this decision process
MS: market share
P: price
PM: premium multiplier
Q: quantity

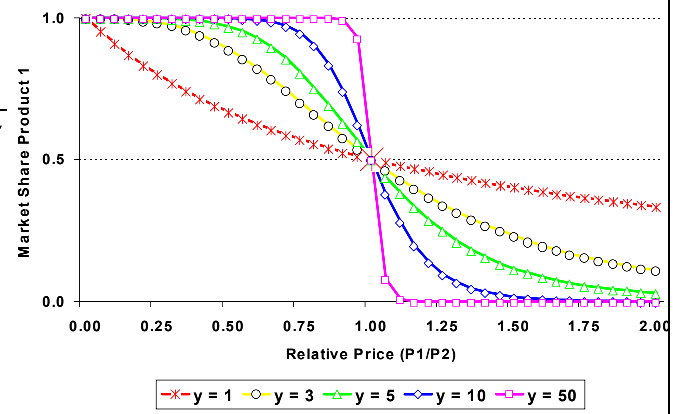


Figure 8: BALANCE Market Share Algorithm

etc.) pursues different objectives and may have very different views of what is "optimum." The equilibrium solution develops an energy system configuration that balances the conflicting demands, objectives, and market forces without optimizing across all sectors of the economy.

BALANCE simultaneously finds the intersection of supply and demand curves for all energy supply forms and all energy uses included in the energy network. Equilibrium is reached when the model finds a set of market clearing prices and quantities that satisfy all relevant equations and inequalities. The model employs the Jacobi iterative technique to find the solution that is within a user-defined convergence tolerance (see Figure 9).

Concurrently with the energy calculations, the model computes the environmental residuals associated with a given energy system configuration. In addition to greenhouse gases and standard criteria air pollutants, such as particulates, SO_X, NO_X, CO, CO_2, methane, volatile organic compounds, lead, etc., these residuals may include waste generation, water pollution, and land use. Greenhouse gas emissions can be reported in a format that is compatible with the Intergovernmental Panel on Climate Change.

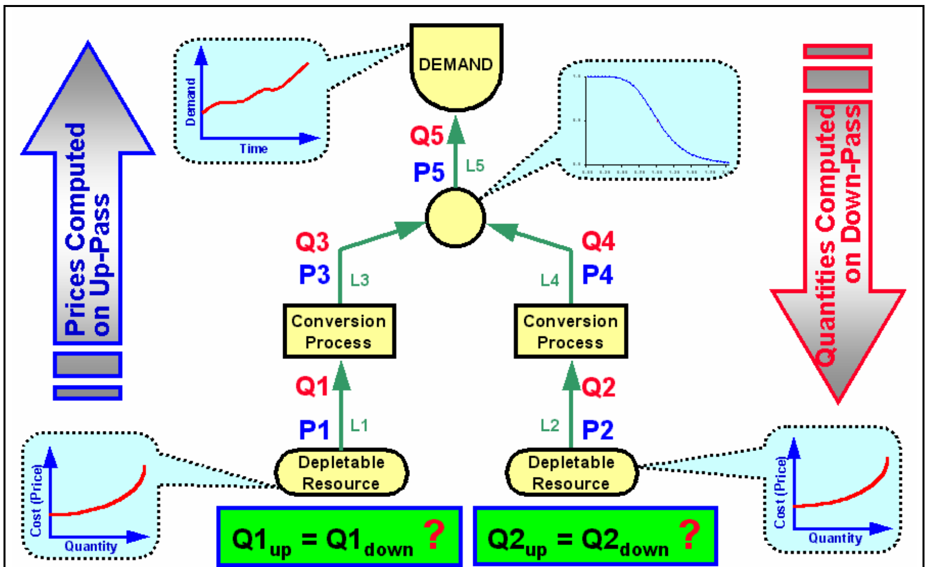


Figure 9: BALANCE Uses an Iterative Technique to Find the Solution within a Specified Convergence Tolerance

ENPEP is Used Worldwide to Analyze Priority Issues

ENPEP is used extensively in the global community to analyze today's priority energy and environmental issues. ENPEP clients include energy and environmental ministries, electric utilities, power merchants, transmission companies, consulting companies, lending agencies, and research institutions. Model applications cover the entire spectrum of issues found in today's complex energy markets, such as:

- Energy policy analysis;
- Energy market projections;
- Energy and electricity demand forecasting;
- Analysis of power sector development options;
- Analysis of production costs, marginal costs, and spot-market electricity prices;
- Operation and management of hydro power plants and reservoirs;
- Economic evaluation and timing of new investments in the power sector;
- Energy-environmental trade-offs and decision analysis;
- Natural gas market analysis;
- Carbon emissions projections;
- Projections and emission control strategies for criteria pollutants (PM, SO_2, NO_X, etc.);
- GHG mitigation studies;
- Power market and design studies;
- Interconnection studies; and
- Market deregulation issues.

Recent examples of ENPEP applications include the following:

- A Mexican team of experts is applying ENPEP to develop various energy projections and evaluate different carbon mitigation options. The team consists of experts from the power company (CFE), the oil company (PEMEX), the Ministry of Energy (SE), the National University (UNAM), the Petroleum Institute (IMP), the National Ecology Institute (INE), and the Energy Management Commission (CONAE).

- Under a regional European project, 10 countries are currently using ENPEP to evaluate various GHG mitigation options, including Bulgaria, Croatia, Czech Republic, Latvia, Lithuania, Poland, Russia, Slovenia, Turkey, and Ukraine (Figure 10).

- Under a regional Asian project, 11 countries are currently using ENPEP to analyze different carbon mitigation policies, including Bangladesh, China, India, Indonesia, Malaysia, Mongolia, Pakistan, Philippines, South Korea, Sri Lanka, and Vietnam (Figure 11).

- The World Bank (2001) used several ENPEP Modules (MACRO, DEMAND, WASP, BALANCE, and IMPACTS) to conduct an Energy and Environmental Review for Bulgaria. The study was carried out with the objective to better inte-

Figure 10: GHG Mitigation Studies under Current Regional Europe Project

Figure 11: GHG Mitigation Studies under Current Regional Asia Project

grate energy sector development and investment plans with the country's environmental goals.

- Harza Engineering Co. and CEEESA staff used ENPEP-WASP, PC-VALORAGUA and GTMax models to analyze the financial viability of 2 transmission lines in the Balkans (ESM 2001). The study was financed by the U.S. Trade and Development Agency and ENRON EUROPE Ltd. (http://www.adica.com/main/index.asp).

- Balajka (2001) used the model to analyze a joint implementation (JI) project that included the repowering of an industrial heating plant with a new natural gas-fired combined-cycle cogeneration unit in Slovakia (http://www.rec.org/climate/calendar/04182001/BalajkaPaper.html).

- Pasierb et al. (2001) used ENPEP to estimate the amount of carbon allowances Poland may be able to sell under seven different scenarios and projected the expected revenue streams assuming a likely range of carbon prices (http://www.pnl.gov/aisu/pubs/PolishET.pdf).

- A recent ENPEP study was conducted by Harza Engineering Co. and CEEESA staff for the electric power system of Macedonia (ESM 2000). In this World Bank-financed study, the WASP/VALORAGUA methodology was applied to analyze long-term development options for the Macedonian electric power system.

- The Ministry of Environment of the Slovak Republic (2001) used ENPEP to analyze energy sector mitigation options for its 3. National Communication (www.enviro.gov.sk/minis/ovzdusie/tns/prehladtns.htm).

- Jamaica Public Service Company (JPSCo) used ENPEP-WASP to develop a least-cost expansion plan for their system. CEEESA staff reviewed this plan in a project sponsored by the National Investment Bank of Jamaica (Koritarov et al. 2000).

- Using the ENPEP-WASP model, CEEESA staff developed a methodology for the evaluation of bids for the IPP projects in Hungary and served as technical auditor for the Hungarian Power Companies in the bid evaluation process (Conzelmann et al. 1999)

- CEEESA staff, in association with the Romanian Institute of Power Studies and Design (ISPE), used ENPEP to develop a long-term energy strategy for Romania. The study was sponsored by The World Bank with the aim to help the Government of Romania in developing an appropriate energy and fuel policy for the period until 2020 (Koritarov et al. 1998).

- The World Bank (1998) used ENPEP in a study for the Slovak Republic to project carbon credits that the country could potentially have available for sale (http://www.admin.ch/swissaij/pdf/cb_nss_skreport.pdf).

- CEEESA staff are using ENPEP to analyze carbon mitigation policies in Turkey for The World Bank (www.adica.com/main/index.asp).

- The Colombian Ministry of Energy uses ENPEP for their annual gas and electricity market projections (http://www.upme.gov.co/docume.htm).

- Poland's Energy Market Agency used ENPEP-GTMax to evaluate the potential for distributed generation in the deregulated Polish electricity market (www.adica.com/main/index.asp).

For more details and additional information on the ENPEP software and the BALANCE module, the reader is referred to Jusko et al. (1994), Koritarov et al. (2001), Veselka and Thimmapuram (2001), and Conzelmann (2002).

For non-commercial purposes, ENPEP is distributed by CEEESA (energycenter@anl.gov), the U.S. Department of Energy, The World Bank, and the International Atomic Energy Agency.

Commercial licenses for the GTMax and BALANCE modules are available through ADICA Consulting LLC at www.adica.com.

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