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Pacific Northwest National Laboratory (USA)
Agency for Rational Energy Use and Ecology (Ukraine)

MODELING AND ANALYSIS OF GREENHOUSE GASES EMISSIONS IN UKRAINE:

Selecting and Adapting the ENPEP Program to Ukrainian Conditions and Test Modeling

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ABBREVIATIONS

CSPEC - Comprehensive State Program of Energy Conservation of Ukraine

GDP – Gross Domestic Product

FER – Fuel and Energy Resources

SER – Secondary Energy Resources

TRPT – Transport Sector in ENPEP Model

RESID – Residential and Communal Sector in ENPEP Model

OTH – Other Sectors in ENPEP Model

IND – Industrial Sector in ENPEP Model

CGN – Sector of Heat and Power Generation in ENPEP Model

AEC – Nuclear Power Station

HPS– Hydropower Station

THPS – Thermal Power Station

CHP – Combined Heat and Power Plant

IPCC – Intergovernmental Panel on Climate Change

1. INTRODUCTION

Ukraine has committed to reducing its greenhouse gas emissions under the Framework Convention on Climate Change (FCCC) and the Kyoto Protocol. Current Ukrainian emissions are significantly below the 1990 base year level as a result of the economic decline in the 1990s. As Ukraine's economy begins to grow in the next few years, policy makers need information on the types of policies and measures that can be undertaken to keep emissions growth below economic growth. Economic models can provide data on likely future emission trajectories; they can also provide information on how costly or cost-effective specific measures are likely to be in Ukraine and they can simulate the impact of joint implementation on the local economy.

Ukraine's economy is the most energy intensive in the world. Numerous cost-effective opportunities exist to reduce greenhouse gas emissions and at the same time benefit the Ukrainian economy as a whole. Providing Ukrainian policymakers with information on these opportunities at the national level will help them design and implement policies that can encourage the private sector to invest in them. The information can also help foreign policy makers better understand the emission reduction (and growth) potential in Ukraine. Ukraine is the 11th largest GHG emitter in the world and has one of the largest "surpluses" of emission reductions compared to its baseline in the FCCC.

The main anthropogenic source of GHG emissions in Ukraine is the energy sector, which according to IPCC Guidelines covers mining, transportation, storage, processing and combustion of organic fuel in stationary and mobile energy sources. GHG emissions in the energy sector of Ukraine account for above three-fourths of all GHG emissions. Therefore, to model and analyze GHG emissions in the economy of Ukraine, it is necessary to develop a model of energy sector.

Through work sponsored by the U.S. Environmental Protection Agency, Pacific Northwest National Laboratory requested the Agency for Rational Energy Use and Ecology to perform modeling and analysis of Greenhouse Gases Emissions in Ukraine.

The goal of the project is to help policy makers better understand future emission scenarios in Ukraine. For reaching this goal, two tasks were established:

- Adapting existing computer programs for GHG emissions modeling to Ukrainian conditions.
- Performing analysis of future GHG emissions in Ukraine.

Results of preliminary estimations showed that:

1. The ENPEP model adequately reflects the level of the existing energy consumption and GHG emissions in the energy sector of Ukraine, and forecasts of energy consumption and GHG emissions under various scenarios of economic development and energy efficiency.
2. The quantity of GHG emissions in the energy sector of Ukraine in 2020 will not reach the 1990 level even under the most optimistic scenario of economic development without consideration of energy efficiency measures.
3. Implementation of energy efficiency measures will provide reductions of:
   - Energy consumption by approximately 36% in 2010 and by 45% in 2020 from the 1990 level.
   - GHG emissions associated with the energy sector by approximately 46% of emissions level without consideration of energy efficiency measures (165 to 213 million tons of CO_2 equivalent depending on the economic development scenario) in 2010 and by 51% (205 to 357 million tons of CO_2 equivalent) in 2020 from the 1990 level.

This report presents:

- The definition and selection of the most appropriate criteria for tailoring a GHG emissions modeling program to Ukrainian conditions.
- A short description of the ENPEP program selected for the analysis.
- A description of the model inputs for the energy sector of Ukraine, and other input data and assumptions made in the model.
- The predicted scenarios of energy consumption and GHG emissions under alternative assumptions of economic growth and implementation of energy efficiency.

2. MODELING TARGET

Greenhouse gases as defined under the UN Framework Convention on Climate Change (UNFCCC) are gas-like substances contained in the atmosphere generated by natural and anthropogenic origin which absorb and re-emit infrared radiation. The scientific community is in general agreement that excess concentrations of greenhouse gases in the atmosphere may lead to negative climate change outcomes.

The Intergovernmental Panel on Climate Change (IPCC), jointly established by the World Meteorological Organization and the UN Program on Environmental Protection in 1988, coordinates methodological issues on climate change in order to:

- Provide all interested parties with information on the statistics and methodology, and outline the main goals and tasks of the studies.
- Provide scientific information related to various aspects of climate change.
- Develop strategies to mitigate climate change.

GHG emissions in Ukraine and the potential for their reduction is determined based on international guidelines that include: Proposals to a Concept of the Ukrainian National GHG; Additional Measures and Amended Results of Executing the State Comprehensive Program for Energy Conservation of Ukraine; Fuel and Energy Sector of Ukraine: Numbers and Facts; Inventory of Methane Emissions from Coal Mining Enterprises in Ukraine: 1990-1999. The guidelines cover direct GHG - CO_2, CH_4 and N_2O as well as indirect GHG gases CO, NO_x NMHC, HFC, PFC, SF_6 and SO_2 as stated in Inventory of Methane Emissions from Coal Mining Enterprises in Ukraine: 1990-1999.

The IPCC Guidelines recommend that all sources and sinks be grouped by the following categories:

- Energy sector.
- Industrial processes.
- Solvents.
- Agriculture.
- Land use and forestry.
- Wastes.

The major source of anthropogenic GHG emissions in Ukraine (about 80% of all emissions in 1990 from the Final Report 'The Second National Report on Climate Change' is the energy sector, which under IPCC Guidelines covers mining, transportation, storage, processing and combustion of organic fuel in stationary and mobile energy sources. Therefore, for modeling and analysis of GHG emissions in the economy of Ukraine, it is necessary to develop a model of the energy sector.

Based on existing statistical information, Ukraine's energy sector is composed of the following sub-sectors:

- Heat and electricity generation.
- Fuel combustion in industry.
- Fuel combustion in communal sector.
- Fuel combustion in transport.

- Fuel combustion in agriculture.
- Fuel combustion in the other sectors of the economy.

Fuel combustion in the industry sub-sector includes: coal mining, peat mining, oil mining, natural gas mining, wood combustion, liquefied gas production, and heat and electricity generation.

3. SELECTING A MODELING PROGRAM

3.1. General Information

Under this project a suitable existing model was adapted to model and analyze energy-sector greenhouse gas emissions in Ukraine. A first step was to select the best model for characterizing the development of the economy, energy sector and greenhouse gases emissions in Ukraine. The Agency for Rational Energy Use and Ecology (Ukraine) identified the most appropriate models and sources based on materials from prior studies, application experiences in transition countries (from the workshop in Poland), and investigation for successful adaptation under the current conditions in Ukraine.

3.2. Model selection criterion

The selection of an appropriate model depends on the purpose for which the model will be used, as well as the data, time and other available resources. This selection was based on a multi-criteria approach and trade-offs between the modeling, model formulation, data availability and quality, the implementation perspective, and ability to alternate mitigation strategies.

The project goal is to help Ukrainian policy makers better understand alternate emission scenarios and elaborate an effective mitigation strategy. The first task for achieving the goal is adapting an existing model to Ukraine. It is relevant to use the following criteria for the optimum model selection:

- Compliance with the project objectives.
- Software availability.
- Reputation.
- Availability of consultant guidance.
- Availability of an experienced local model developer.
- Ability to apply to transition economies.
- Opportunity to provide relevant training.

3.3. Description of Models

During the preliminary selection, five models were reviewed: - MARKAL-MACRO, Energy and Power Evaluation Program (ENPEP), SGM (Second Generation Model), VICTORIA, Economic and Environmental Power Planning Software (EEPPS). MARKAL-MACRO, developed at Stanford University and the Brookhaven National Laboratory, provides an integrated representation of macroeconomic relations and energy technology processes. This model, however, contains much greater detail than the others at the end-use and process analysis component. It can address conservation and energy-efficiency changes in end-use devices directly. The objective function in combination with cost-minimization in the liner-programming sub-model ensures that energy demands are at least cost (both on the supply and the demand sides). This model represents the most complete effort to-date to combine the “top-down” and “bottom-up” approaches. MARKAL-MACRO has been applied in the United States and is currently being used in ten countries participating in the International Energy Agency’s Energy Technology Systems Assessment Program.

ENPEP incorporates the dynamics of the market processes related to energy via an explicit representation of market equilibrium, by balancing supply and demand in each time step. ENPEP is used to model a country’s total energy system and does not explicitly include a model of the economy integrated with the energy system model.

SGM is a state-of-the-art computational general equilibrium model of energy, economic activity and greenhouse related emissions. It was designed to run either as a stand-alone model of a national or regional economy, or with a set of models with trade links. The model has nine producing sectors, eleven consuming sectors, energy production detail, twelve regions, vintaged capital stocks, and a suite of anthropogenic greenhouse gases. The model was developed in recognition that energy production and use is the most important set of human activities associated with greenhouse gas emissions.

The “VICTORIA” modeling system includes several levels of mathematical models. The first level is evaluational that includes typical econometric models, which are useful for making preliminary assessments of the chosen scenarios. The second level contains an improved form of the inter-industry model proposed by the Nobel Prize Winner, Professor Vasiliy Leontyev (USA). This enables the System to analyze each scenario for the impact of economic change and associated environmental consequences, and measure inter-sectoral balances, which take into account world market conditions and import/export dynamics. The third level is the dynamic optimization model for calculating energy balances throughout the entire power industry that take into account a broad spectrum of resource restrictions, such as raw material, financial and economic restrictions. The interactive simulation of different situations is also undertaken by the interface on the third level. Experts who are skilled in their own subject areas, but who have little or no experience of mathematical modeling and computer programming, can take full advantage of the VICTORIA System.

EEPPS is an Excel program used to plan regional, national, and multi-national electric power systems. Users can determine the least-cost combination of power supply options needed to meet future demand over 4 time steps while accounting for most environmental externalities. A five-year time step is typical for mid-range studies, allowing for analysis over 20 years. A one-year time step can be used for short-range analysis. A total of 17 different power generation technologies can be modeled as well as 11 different energy sources. The EEPPS model is particularly useful for analyzing environmental policy options such as emission caps or environmental externality taxes on emissions of sulfur dioxide, carbon dioxide, nitrogen oxides, and particulates.

3.4. Approach to Preliminary Selection

The key design features and prioritization of the five models for preliminary selection are presented in tables 3.4.1 and 3.4.2, respectively.

Table 3.4.1. Key Design Features of the Five GHG Emission Models

Model	Model Class	Model Type	Energy Supply Representation	Energy Demand Representation	Multi-Period	Solution Algorithm
MARKAL-MACRO	Bottom-up	Hybrid	Process Analysis	Utility Maximization	Yes	Non-linear Optimization
ENPEP	Bottom-up	Iterative Equilibrium	Supply Curves	Exogenous	Yes	Iteration
SGM	Top-down	General equilibrium	Process Analysis	Exogenous	Yes	Input-output Approach, Production Functions
VICTORIA	Top-down	Hybrid	Process Analysis	Exogenous	Yes	Input-output Approach, Linear Optimization
EEPPS	Bottom-up	Engineering Optimization	Process Analysis	Exogenous	Yes	Linear Optimization

Table 3.4.2. Prioritization of Five GHG Emission Models

Model	Compliance With Project Objectives	Software Availability	Reputation	Consultant Guidance	Availability of Experienced Domestic Model-builder	Application to Transition Economies	Ability to Provide Training	Expert Recommendations	Total number of points	Rating
ENPEP	5	5	5	5	4	5	4	5	38	1
MARKAL-MACRO	5	4	5	4	1	5	3	4	31	2
SGM	5	3	4	3	1	5	2	3	26	3-5
VICTORIA	4	2	2	3	3	5	2	5	26	3-5
EEPPS	3	4	3	3	1	4	3	5	26	3-5

On the basis of the scores in Table 3.4.2, the following conclusions can be made:

- ENPEP ranks highest among the five models, leading the others by 20-30%.
- At the pre-selection stage no model has evident advantages, even a 20-30% lead at this stage is not considered convincing.
- It is necessary to carry out additional evaluation for the final model selection.

3.5. The Experience of Models Used in a Transition Country (Poland)

During a training program in Poland on 23-24 April 2001 to model greenhouse gases attention was paid to the models used in Poland for modeling the economy, energy sector and greenhouse gas emissions. During the visit to EnerSys the EFOM, Mini-STRUK and PROSK-E models were demonstrated, and Polish Agency on Energy Market demonstrated the ENPEP and GEM models. All models presented at the seminar were elaborated and can be used for modeling the economy, energy sector and greenhouse gas emissions, while the EFOM and ENPEP models were used for the development of strategies for the development of the fuel and energy complex of Poland.

Of the models presented, EFOM was the most developed, but application required considerable expense and time for implementation to enable collaboration with leading Western European development teams 'Proposals to a Concept of the Ukrainian National GHG Inventory System. - Pacific Northwest National Laboratory, Agency for Rational Energy Use and Ecology, Ukraine. – 2001'

Of the two models presented by the Polish Agency on Energy Market, ENPEP was the most suitable for use in the project. The GEM model is based on the "input-output" matrixes and is not suitable for the "bottom-up" approach accepted for the project.

Thus, the modeling experience of Poland confirmed the advantages of ENPEP model, determined in the preliminary stage of the model selection.

3.6. Opportunities for successful adaptation of the models in Ukraine

When determining the opportunities for successful adaptation of the models to Ukraine, the following factors were taken into account:

- Degree of the model's dissemination and development in Ukraine.
- Availability of Ukrainian specialists who were trained in modeling.
- Opportunities to provide instruction to Ukrainian specialists in the use of these models.
- Ongoing support and improvement of the model by the developers.

As a result of the search, it was established that of the five models examined, only the Victoria and ENPEP models were used fully or partially in Ukraine. The team that developed VICTORIA disbanded last year and at present the model is not maintained. ENPEP is partially used for power industry development modeling.

In Ukraine there are several specialists (including those working in ARENA-ECO) who received training at Argonne National Laboratory to use ENPEP model.

In June 2001 it was determined that IAEA in cooperation with the Ukraine Ministry of Fuel and Energy will conduct the training seminar "ENPEP for Windows" for the specialists from 13 countries of Central and Eastern Europe, who will use an ENPEP modification for modeling the development of the fuel and energy complex in their countries. The Agency of Rational Energy Use and Ecology (Ukraine) has addressed the Ministry of Fuel and Energy with an application for participation of one of its specialists in this seminar, which should receive approval.

The ENPEP program is supported by the developers, and also provided at no charge by the IAEA to organizations for conducting research. Following our request, IAEA has officially provided the Agency of Rational Energy Use and Ecology (Ukraine) with the latest version of the ENPEP program, for use in this project.

3.7. Conclusion

The combined findings of the literature search, experience in other transition countries, and opportunity for adaptation to and use in Ukraine clearly indicate that the ENPEP model (the Energy and Power Evaluation Program), developed at Argonne National Laboratory (USA), is the most appropriate one for using in the given project.

During the preliminary selection of models, five models were reviewed: MARKAL-MACRO, Energy and Power Evaluation Program (ENPEP), SGM (Second Generation Model), VICTORIA, Economic and Environmental Power Planning Software (EEPPS) and computer general equilibrium (CGE) model.

The experience of the models use in Poland has confirmed the preliminary selection of ENPEP as this model best meets the requirements for the development of fuel and energy complex.

ENPEP is supported by the developers, and also delivered at no cost by IAEA to organizations for conducting research. Following our request IAEA has provided the Agency with the latest version of the ENPEP program, for use in this project.

The analysis of the opportunity for successfully adapting the ENPEP model to the existing Ukrainian conditions, has also confirmed the advantages of ENPEP model. Advantages include the degree of the model's dissemination and development in Ukraine, the availability of the specialists in Ukraine trained to use this model, opportunities to provide further instruction for the use of ENPEP, and continuing support and improvement of the model by the developers.

4. DESCRIPTION OF THE ENPEP

4.1 Description of the ENPEP tools

ENPEP is a powerful integrated software package that allows the energy analyst to conduct complete energy system study (ENPEP for Windows. Version 2.15). The package incorporates a set of energy planning modules, with each module addressing a portion of the energy planning need. These modules can be used either as stand-alone packages or as integral parts of the ENPEP system.

The new Windows version of ENPEP combines the BALANCE and impacts modules into one integrated module.

The BALANCE module enables the analyst to evaluate the energy system configuration that will balance energy supply and demand. BALANCE uses an iterative, non-linear, equilibrium approach to determine the energy supply and demand balance. 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. Energy networks are typically constructed such that demand nodes are located at the top of the network and energy supply resources are at the bottom of the network with conversion process nodes located in the middle. Once the network is constructed and historical energy flows are simulated, the module forecasts future energy demands and prices.

The model employs a market share algorithm using a logit function 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. 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.

As market shares of energy are dependent on energy prices and energy prices are dependent on the quantity of fuel demands, BALANCE uses an iterative process to bring network prices and quantities into equilibrium.

The equilibrium modeling approach used in the BALANCE Module is based on the concept that the energy sector consists of autonomous energy producers and consumers that carry out production and consumption activities, each optimizing individual objectives. In contrast, optimization models of the entire energy sector, such as linear programming formulations, can take on the interpretation of a central planning authority that has control over all energy flows and prices in the entire energy sector. Using the market share algorithm sets BALANCE apart from other modeling techniques.

The BALANCE approach simulates the more complex market behavior of multiple decision-makers that optimization techniques may not be able to capture as they assume a single decision maker. Every sector (electric, industrial, residential, 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.

An energy network represents all energy production, conversion, transport, distribution, and utilization activities in a country or region, as well as the flows of energy and fuels among those activities. The energy network is constructed with a set of submodels or building blocks, called NODES. The nodes of the network represent energy activities or processes, such as petroleum refining or residential space heating. The user connects the nodes with a set of LINKS. The links represent energy and fuel flows and associated costs among the specific energy activities. Links convey this information (i.e., price and quantity) from one node to another. The energy network is developed by defining the energy flows among the different types of nodes for a given base year.

Energy resources are either imported or produced domestically. Fuel conversion occurs, for example, in the oil refinery in the oil and gas supply sector (crude oil is converted to refined products) and in the electricity generation sector (coal, oil, or gas are converted to electricity). The transmission/ distribution sector routes the fuels to the various demand sectors (industry, residential, commercial, transport, and agriculture/fishing). In the demand sectors, final energy is consumed to provide a variety of energy services (residential water heating, industrial steam demand, etc.).

By convention the energy network is constructed such that demand nodes are located at the top of the network and energy supply resources are at the bottom of the network. Conversion process nodes are located in the middle. Once the network is constructed and historical energy flows are simulated, the module forecasts future energy demands and prices.

Each network node type corresponds to a different submodel in BALANCE and is associated with specific equations that relate the prices and energy flows on the input and output links of the node. The following node types are available in BALANCE:

Depletable Resource Node Models the production of a depletable resource that is either imported or domestically produced, such as crude oil, coal, or natural gas.

By convention, a depletable resource node has a single output link and no input links as this represents the starting point of the energy supply system. Depletable resource nodes are used to model the domestic production and/or importation of depletable resources such as crude oil, coal, and petroleum products. A single equation is associated with a depletable resource node. The equation relates the cost (or price, depending upon the use of the resource node) of producing or importing the resource to the total, cumulative (over all periods) amount of the resource produced or imported. Effectively, the equation represents a long-run supply curve for the resource. The price of a depletable resource can be computed from the following simple quadratic equation:

$$P_t = A(Q)\,(1+R_t) + BQ_t + CQ^2_t,$$

where:

Pt = production cost (price) of the resource in period t,

Qt = quantity of the resource produced or imported in period t,

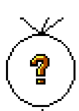
A(Q) = intercept of the supply curve for the resource after having extracted a cumulative amount Q of the resource previous to time t. This value is adjusted at the end of each year in the simulation period based on the amount of the resource produced or imported during the year (the initial value of A(Q) in the base year can be taken as the price of the resource in the base year),

Rt = growth rate in real terms of the cost (price) of the resource,

B = slope of the supply curve for the resource, and

C = a quadratic coefficient for the supply curve.

The base-year value of A(Q) and the values of B and C are user-defined, vary by resource, and are based on an evaluation of the historical performance of the specific resource production.



Decision/Allocation Node: Models the selection of fuels or energy forms from alternative sources of supply.

This node is one of the most important in defining the role that competing energy technologies will play in a future energy system. They represent the market forces at play when choices are made to use a particular type of energy. The approach used in simulating the market decision process is to assume that the market share of an energy source is inversely proportional to its price relative to its competitors.

By convention, a decision node has one or more input links and one or more output links. Decision nodes select the amounts of fuel to be supplied from alternative sources (the input links of the node) at various points in the energy network, and route the energy to satisfy energy flow requirements of the output links of the node. Price and quantity equations are associated with a decision node. The quantity equation equates the total energy flow on the output links of the node to the total energy flow on the input links to the node; energy flow is conserved at a decision node. The price equation relates the prices of the fuels on the input links of the node to the price of fuel on the output links of the node. In addition, several other equations indicate the shares of fuel selected from the input links to the node. Shares are based on the relative prices of fuel from the alternative sources, capacity limits on the supply sources, and government policies. It should be noted that one of the features of the decision node algorithm is that energy requirements may be met by selecting fuels from several supply sources simultaneously rather than from a single source, as would be the case if fuel choices were based strictly on least cost. However, the decision node parameters can also be specified so the node selects fuel only from the least-cost source.

Given the quantity of energy required on each output link of a decision node, the quantity equation equates the total energy flow into the node to the total energy flow out of the node:

$$\sum_{i}^{n} Q_i = \sum_{0}^{p} Q_0 \qquad (1)$$

where:

Qi = quantity on input link i of the decision node,

Qo = quantity on output link o of the decision node, and

n, p = total number of input and output links of the decision node.

If a decision node has a stockpile node associated with it, as large a quantity as possible is taken from the stockpile to supply the quantity demanded on the output links of the decision node. The remaining quantity, the quantity not satisfied by the stockpile reserves, is referred to as the net output quantity and is met by sources that are input links to the decision node. The quantity on any input link i of a decision node is the product of the net output quantity and the share allocated to source i, as the following equation indicates:

$$Q_i = N_Q * S_i \qquad (2)$$

where:

Qi = quantity on input link i,

NQ = net output quantity of the decision node; the value of NQ is the sum of the quantities on all output links minus the amount in the stockpile, if this value is greater than zero; otherwise, NQ is assigned a value of 0, and

Si = fraction (share) of input quantity allocated to input link i (0 ≤ Si ≤1).

The share Si is in general a function of the relative prices on the input links of the decision node. A higher price on an input link results in a smaller share of the quantity allocated to the input link. The share for an input link is given by the formula:

$$S_i = \frac{\frac{1}{(p_i \times p_{mi})^{\nu}}}{\sum_{i}^{n} (\frac{1}{(p_i \times p_{mi})})^{\nu}} \quad (3)$$

where:

Si = market share on input link i,

Pi = price on input link i,

g = price sensitivity coefficient for the decision node,

n = number of input links to the decision node, and

Pm = premium multiplier on input link i.

Note that the above equation ensures that all shares are between 0 and 1, and that shares on all input links sum up to 1.

The price allocation formula is motivated by the empirical observation that all demand is not necessarily allocated to the least-cost source of supply. Rather, the allocation formula models the more general case in which shares depend on relative prices, with the more costly sources receiving relatively smaller shares. Non-price factors often enter into consumption decisions, resulting in a skewed distribution of consumption based on prices. A theoretical justification for the price allocation formula can be found in the energy modeling literature.

The price sensitivity parameter, ν, in the above equation, determines the degree to which differences in relative prices result in differences in market share. In some instances, there is a great deal of sensitivity to price differences. Small changes in relative price will produce fairly large changes in market share. A refinery purchasing crude oil is an example of price sensitive markets. Consumers buying automobiles are an example of relatively price-insensitive markets as other factors influence the decision. The sensitivity parameter ν is used to simulate these different conditions. A value of 0 for ν is an extreme case and indicates the least degree of share sensitivity to prices. A large value for ν, such as 15, indicates a high degree of share sensitivity to relative prices and approximates a situation in which 100% of the quantity is allocated to the single source having the lowest price.

The decision node has several other features that are used to model situations where a particular market cannot readily respond to price changes, even of relatively large magnitude. A lagged adjustment parameter is included in the decision node submodel to represent the lag that often occurs between a change in relative prices and an observed change in the shares of the sources of supply. Existing capital equipment or difficulty in getting access to the cheaper fuel are examples of circumstances that prevent market response. The lag function determines what portion of the market is able to adjust to a change in prices. The value of the lag parameter can be related to the life expectancy of the energy equipment and therefore, to its turnover rate.

$$S_{i,t} = S_{i,t-1} + (S_{i,t^*} - S_{i,t-1}) \times \lambda \quad (4)$$

where:

Si,T = market share on input link i at time t with lag considerations included,

T = current year,

Si,T-1= previous year's market share on input link i,

Si,T* = intermediate value of market share on input link i without lag considerations as determined by the market share equation above,

λ = lag parameter.

The lag parameter value ranges from 0 to 1. A value of 1 indicates there is no lag, and shares respond immediately to current prices. A value of 0 indicates no response to prices; base-year shares will be maintained throughout the study period.

Government policies may exist that override allocation decisions based strictly on relative fuel prices. For example, a government may have a policy in place to use domestically refined petroleum products rather than imported products (usually made to protect local jobs). To model this situation, the decision node submodel can allocate a demand quantity to sources (input links) in a specified order. This priority allocation scheme is done without regard to the relative prices on the input links. A quantity is allocated to an input link up to the capacity of the source, if a capacity exists. This procedure is repeated until the entire net output quantity has been allocated to all input links.

The price assigned to the output links of a decision node is equal to the average price of the inputs to the node, excluding the inputs from stockpiles. The output price is computed from the following:

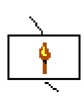
$$P_0 = \sum_{i=l}^{n} (P_i \times S_i) \qquad (5)$$

where:

Po = price assigned to all output links of decision node,

Pi = price on input link i, and

Si = share of net output quantity allocated to input link i.



Conversion or Processing Node: Models the conversion or processing of a resource, fuel, or product to another form.

Examples include a boiler that converts fuel oil to steam, an automobile that converts gasoline to miles traveled. By convention, a conversion node has a single input link and a single output link. Two equations are associated with a conversion node: a quantity equation and a price equation. The quantity equation represents the transformation of the input (usually an energy form) to the output product (also usually an energy form). The price equation represents the value added to the price of the input due to the process. Example illustrates the quantity and price equations for a generator that transforms fuel oil into electricity. The quantity of electricity is related to the quantity of fuel oil input by the following equation:

$$Q_{elec} = Q_{f0} \times \eta \qquad (6)$$

where:

Qelec = quantity of electricity output,

Qfo = quantity of fuel oil input, and

η = process efficiency.

The basic assumption in developing the price equation for the conversion node is that the annual revenue obtained from the output of the process equals the annual costs of the fuel oil and the processing operations. The equation relating annual revenue and cost is:

(Revenue) = (Cost)

$$Q_{elec} \times P_{элек} = Q_{f0} + P_{f0} + OM \times Q_{элек} + TC_i \times CRF_{(i,n)} \qquad (7)$$

where:

Pelec = price of electricity,

Pfo = price of fuel oil,

OM = operating and maintenance cost of distillation process. (This cost excludes the costs of the fuel oil; the fuel oil cost is accounted for in the term Qfo x Pfo.),

TCI = total capital cost of a representative generator process or plant, and

CRF(i,n) = capital recovery factor that amortizes the capital cost over the life of the process, n, at the annual interest rate i.

If both sides of the above equation are divided by Qelec, h is substituted for Qelec/Qfo, and the process is assumed to operate near its annual rated output capacity, then the following equation is obtained relating the required electricity price to the fuel oil price and processing costs:

$$CRF_{(i,n)} = \frac{i \times (1+i)^n}{(1+i)^n - 1} \qquad (8)$$

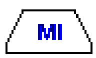
where:

CAP = annual maximum rated output capacity of a representative plant, and

CF = capacity factor for a representative plant (indicating the fraction of the time the plant operates over a one-year period).

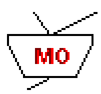
Both equations are used to compute the output quantity and price, respectively, for a conversion node. The capital recovery factor, CRF (i, n), for amortizing the capital cost of a process over a fixed number of discrete time intervals

Using the factor of process efficiency η, data on fuel and energy losses during transportation, storage etc can be obtained. η factor will be given values from 0 to 1 depending on the ratio of losses of fuel and energy. Indicators of capital investments and operational losses in this case are assumed as equal to 0.



Multiple-Input Node: Models special conversion processes that have more than a single form of input fuel, such as a solar heater that uses LPG as a backup fuel.

By convention, a multiple-input-link conversion node has a single output link and two or more input links. Several equations are associated with a multiple input conversion node -- a number of quantity equations equal to the number of input links and a price equation. The quantity equations represent the transformation of the inputs to the node (generally forms of fuel) to the output (generally a form of energy). The price equation represents the value added to the prices of the input fuels by processing.



Multiple Output (Refining) Node: Also called a multiple-output-link node, this node is typically used to model the petroleum refining process in an aggregate form.

By convention, a multiple-output-link (typically a refinery) node has a single input link and two or more output links. Several price and quantity equations are associated with a refinery node. The quantity equations represent the transformation of the input (such as crude oil) to the outputs (such as petroleum products). The price equations represent the value added by the processing to the input, and allocate the processing costs to the outputs. A refinery node can be used to model any process that has a single input and multiple output products. For example, besides a crude oil refinery, a refinery node can be used to model an industrial cogeneration process that produces steam and electricity.

The following example of a refinery node with two output products illustrates the price and quantity equations. The quantity of product 1 is related to the quantity of crude input by the following equation:

$$Q_1 = Q_C \times S_1 \qquad (12)$$

where:

Q1 = quantity of product 1 output,

Qc = quantity of crude input, and

S_1 = slate or ratio of product 1 output per unit of input crude.

An equation similar to the equation above relates the quantity of product 2 produced for each unit of crude input. In the equation, Q_2 and S_2 would be defined similarly to Q_1 and S_1, respectively, for the second product. The parameters S1 and S2 constitute the amount of output product 1 and 2 respectively per unit of crude input.

The basic assumption in developing the price equations for the refinery node is that the annual total revenue obtained from the outputs of the refinery is equal to the annual cost of the crude input plus the associated processing costs. The equation relating annual revenue and cost is:

(Revenue) = (Cost + Profit)

$$Q_1 \times P_1 + Q_2 \times P_2 = \left[Q_C \times P_C + OM \times Q_C + TCi \times CRF\right] \times (1 + PFF) \qquad (13)$$

where:

Q_1, Q_2 = quantities of product 1 and 2, respectively,

P_1, P_2 = prices of product 1 and 2, respectively,

Pc = price of crude input,

OM = operating and maintenance cost of the refinery (this cost includes the costs of labor and materials for operating the refinery but excludes the cost of the input crude),

TCI = total capital cost of the refinery (if the refinery already exists, this value is the present value of the remaining debt),

CRF(i,n) = capital recovery factor that amortizes the capital cost of the refinery over its life n, at annual interest rate i,

PFF = profit factor.

If both sides of the equation (13) above are divided by Qc, S_1 is substituted for (Q_1/Qc) and S_2 for (Q_2/Qc), and the refinery is assumed to operate near its expected capacity, then the following equation relates the price of product 1 to the crude input price, the price of product 2, and the processing costs:

$$P_1 = \left[\frac{P_C}{S_1} + \frac{OM}{S_1} + \frac{TCi \times CFR}{CAP \times CF \times S_1}\right] \times \left(1 + PFF\right) - P_2 \times \frac{S_2}{S_1} \qquad (14)$$

where:

CAP = crude input capacity of the refinery, and

CF = capacity factor (indicating the fraction of time the refinery is expected to operate).

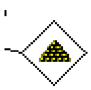
To determine the product prices P1 and P2, an additional equation is required that indicates how the costs of crude and processing are to be allocated between the two products.

The procedure described above can be used to model a refinery node with any number of outputs. Similar equations must be specified for each additional product, such as LPG, gasoline, and residual fuel oil. For example, if a refinery node has four output links, the price for the fourth output product can be related to the price of the input (crude) rather than to the price of the first product, as in the above example.

Demand Node: Models the final demand for a fuel or a form of useful energy such as process steam, and direct heat.

By convention, a demand node has a single input link and no output links. No equations are associated with a demand node. Demand nodes must be positioned in the energy network to indicate the points of final demand, that is, points that terminate energy flows throughout the network. Examples of demand nodes include (1) cement demand in the cement sector; (2) electricity demand in the commercial sector; and (3) space heating demand in the household sector.

The BALANCE Model associates a set of user-specified demand projections over the simulation period with each demand node. The demand node assigns the computed demand quantity in each year to the demand node input link; this quantity is then used as the required output quantity of the node at the input end of the link.

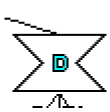


Stockpile Node: Models stockpiling of resources for use at some future time.

By convention, a stockpile node has a single link that functions as both an input link for filling the stockpile and an output link for reducing the stockpile. A stockpile node is used in conjunction with a multiple-output-link node (such as a refinery) and a decision node. The purpose of a stockpile node is to store the quantity of a particular type of a multiple-output-link product that exceeds the demand for that product. An example is a stockpile for residual oil from a specific refinery in the oil sector of the network.

Any excess production of each output product of a multiple-output-link node is added to the existing amount in a corresponding stockpile each year in the simulation period. The logic for computing the amount of the product to be extracted from the stockpile node is explained below.

A convention adopted in the BALANCE program is that the link of a stockpile must be an input link to some decision node of the network. The decision node inspects the amount in the stockpile each year and removes as much of the product as possible to meet the demand requirement on the multiple-output-link process. Any remaining demand requirement is considered the net demand requirement that the process then attempts to meet.



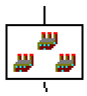
Electricity Dispatch Node:

Models the loading and output of electricity generating units.

This node handles the special requirements for the electric sector. This can be expressed in form of load duration curves. In dispatching generators to meet the load, electric utilities will use their lowest operating cost units (usually large hydropower, coal, or nuclear units) to meet the continuous or base load. Units with higher operating costs are brought on line as the load increases but are reduced in output or shut down as the daily load decreases. Special units (usually gas turbines, pumped storage facilities, smaller hydro units) are used to meet the peak portion of the load. These units are characterized by being able to be switched on and off rapidly but often have higher operating costs than the base load units.

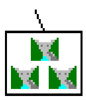
The node will calculate the quantity of electricity generated by each of the available generators, the total cost of electricity, and the average cost of electricity generated per kilowatt-hour. The node will not determine an optimum build schedule for generation facilities. Rather, it uses the input build schedule and utilizes the available plants as needed.

Since energy purchase decisions are not always solely based on price, premium multipliers are used in BALANCE to simulate the preference that consumers have for some commodities over others. Premium multipliers are used to simulate the market behavior when competing resources have different levels of quality or convenience. It can also be used to simulate the market behavior when high capital costs discourage the use of a specific technology or process. In addition, the Model uses a lag parameter to simulate the time that is required for prices and demands to reach an equilibrium or balance.



Thermal Generating Unit

The table of Thermal Generating Unit characteristics contains data on Capacity, in MW; the total capital cost, in $U.S./kilowatt; optional loading order value: (if this field is left blank, the thermal generating unit will be loaded based on its total variable cost); Fixed Operating & Maintenance Cost, in $U.S./kilowatt-year; Variable Operating & Maintenance Cost (this value must be expressed in units of million/kilowatt-hour and should not include the cost of fuel for the unit).



Hydro Generating Unit

The table of Hydro Generating Unit technical characteristics contains five columns representing the average annual energy, in megawatt-years (nodes represent the equivalent plant capacity operating 8,760 hours); load value, in $U.S./megawatt-year (if this field is left blank, the hydroelectric process will be loaded based on a total variable cost); Unplanned Outage Rate (outage rate assigned to this hydroelectric unit); Planned Outage Rate, in days/year; Minimum Annual Utilization Rate, fraction of the total hours in a year (if the plant is loaded but is positioned in the loading order such that it cannot maintain this minimum utilization, the plant will be removed from the loading order and assumed not to operate at all).

The table of Hydro Generating Unit operation economic characteristics, contains four columns representing: Capital Cost, in $U.S./kilowatt; Fixed Operating & Maintenance Cost, $U.S./kilowatt-year); on-line date, which contains the earliest year in which the IDES FORTRAN program will consider the hydroelectric plant's availability (the on-line year in this field can be earlier or later than the base year of the planning study); Plant Total Life (this field indicates the total life (in years) of the hydroelectric plant (this value is used in conjunction with the previous field to provide IDES the last year a plant will be operational. If, for example, the specific plant is needed in the year 2001 and the life in this field is 25 years, the BALANCE Module will assume that the plant operates from Jan. 1, 2001, through Dec. 31, 2025).

5. DESCRIPTION OF THE MODEL ECONOMIC SECTORS OF UKRAINE

5.1. General Description of the Ukraine's Economic Model Based on the ENPEP System

Fig. 5.1 presents the balance scheme of the Ukrainian economy. It is symbolically divided into three stages energy life cycle:

- Extraction and processing (Coal, TURF, OIL, LGAS, GAS, WOOD. REN) (a listing of abbreviations and nodes names is presented in Annex 1);

- Heat and electricity production and processes of fuel and energy distribution among consumers (CGN and D&T respectively);
- Final energy consumption (Ind, InEL, RESID, AGRY, TRP, OTH).

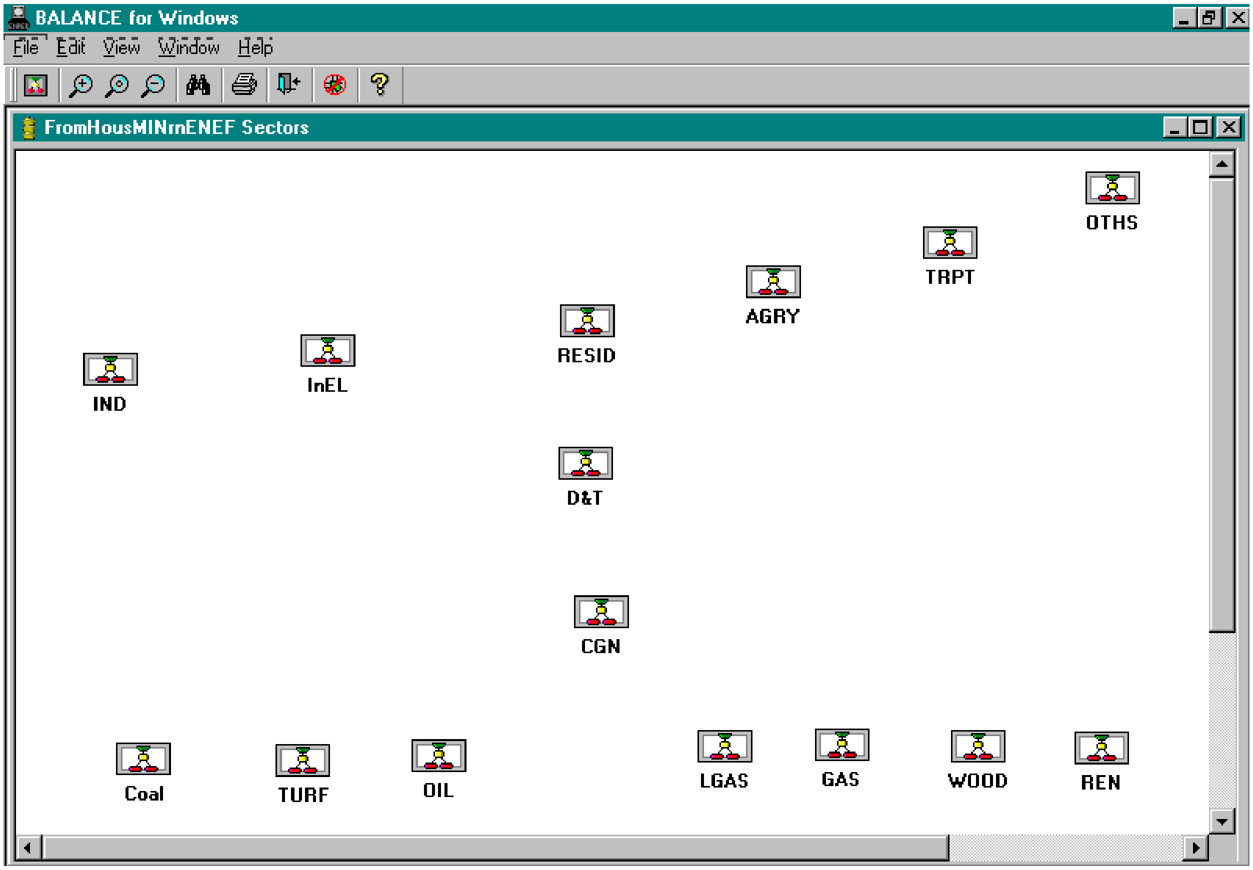


Fig. 5.1 Balance Study Sectors Network

The primary supply energy resources are presented as sectors Coal (Coal), TURF (turf), LGAS (liquefied natural gas) GAS (Natural Gas), Oil (Crude Oil), WOOD (forestry), REN (non-traditional energy). The conversion energy sector is presented as CGN (cogeneration process) and the energy distribution process as D&T. The final demand sectors are presented as IND (industry sector), InEL (consumption of heat and power for own needs of electric stations), RSD (residential sector), AGRY (agriculture), TRP (transportation) and OTH (other branches not included into the previous sectors). Raw materials processing is contained in the respective supply sectors.

The economic model of Ukraine is based on the assumption that the nodes and their links mean the relative processes on energy production, processing, transporting and consumption are available in the economy. Thus, for example, the refinery node means that a refinery comprises the aggregated characteristics of all six refineries operating in Ukraine. The input link to this node characterizes all the available processes of delivering crude oil to the refineries in Ukraine.

The model was developed with the assumption that there are no limits for transporting and processing primary energy. This assumption doesn't contradict actual economic conditions because manufacturing facilities are just partially utilized.

Energy consumption is assumed to increase gradually in the near term based upon the assumed reduced level of economic activity.

1997 was selected as a base year as the most objective and complete statistical information is available for this year. Also, this is the most recent year for which the official full and objective statistics are available.

5.2 Sector of renewable energy

Sector of renewable energy indicates modeled processes of application in the Ukrainian economy of geothermal, solar, wind energy and biogas. Biogas is supplied for direct consumption to the residential and communal sector and remaining renewable enter into competition with heat and electricity, generated traditionally through burning fuel. Figure 5.2. shows the renewable sector of the model.

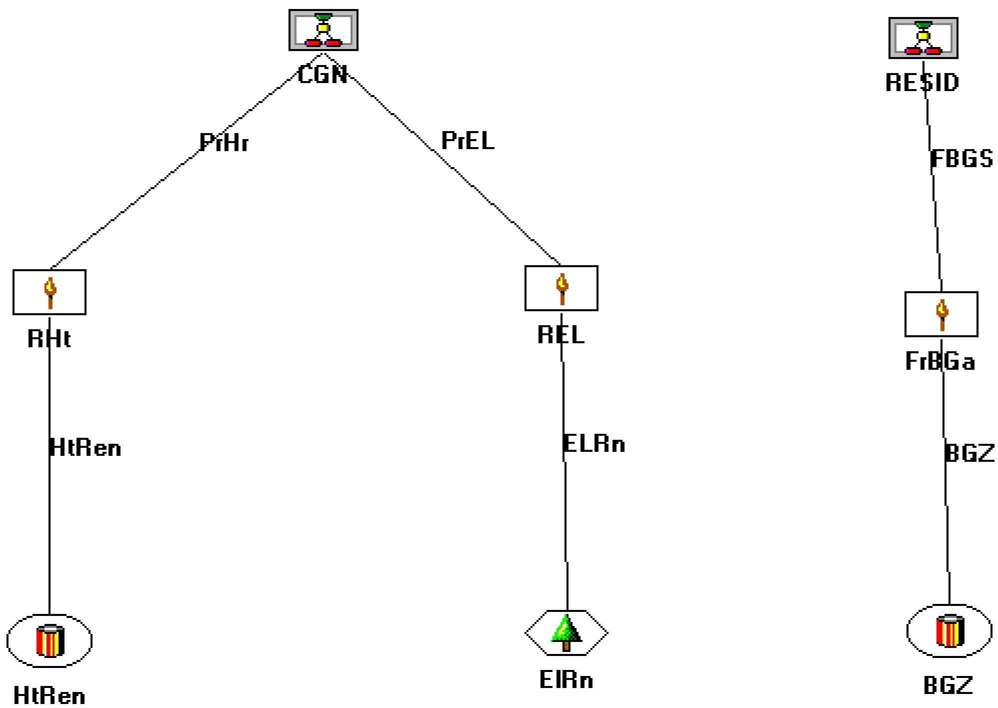


Fig. 5.2. Renewable sector elements

5.3 Electricity sector

Electricity generation is presented together with cogeneration in the “Cogeneration” case as presented in Fig. 5.3. It was developed with the electric dispatch node DsEL. The refinery node CgCog with the sizing link StGas are electricity and heat generation based on the natural and coke gas. The selection of the gas is performed in the node ChFue. And the refinery node CgMC with the sizing link StCl also represents cogeneration plants with the latter node using coal and fuel oil.

The ChFue allocation node chooses between natural and coke gas with a lag = 0.02 and price sensitivity = 0.09. Allocation nodes GS+DS chooses between gas- and oil-fired heat generation (lag = 0.01, price sensitivity = 0.02). The allocation node InDtr chooses between steam generated at boiler houses and cogeneration plants (lag = 0.01, price sensitivity = 0.02). Allocation node Cogen

chooses between electricity generated at the power plants (thermal, nuclear, hydrostations) and at the cogeneration plants. The TPP (thermal power plant), HPP (hydro power plant), and NPP, nodes were included as all existing power plants.
The process nodes gas, Kkgs, and MzBlr indicate gas from fuel oil fired boiler houses.

The links ElPr and HtPr do not show the supply of electricity and heat from renewable energy sources and the nodes PrHr and PELRn do not show regulation processes by the costs of heat and electricity.

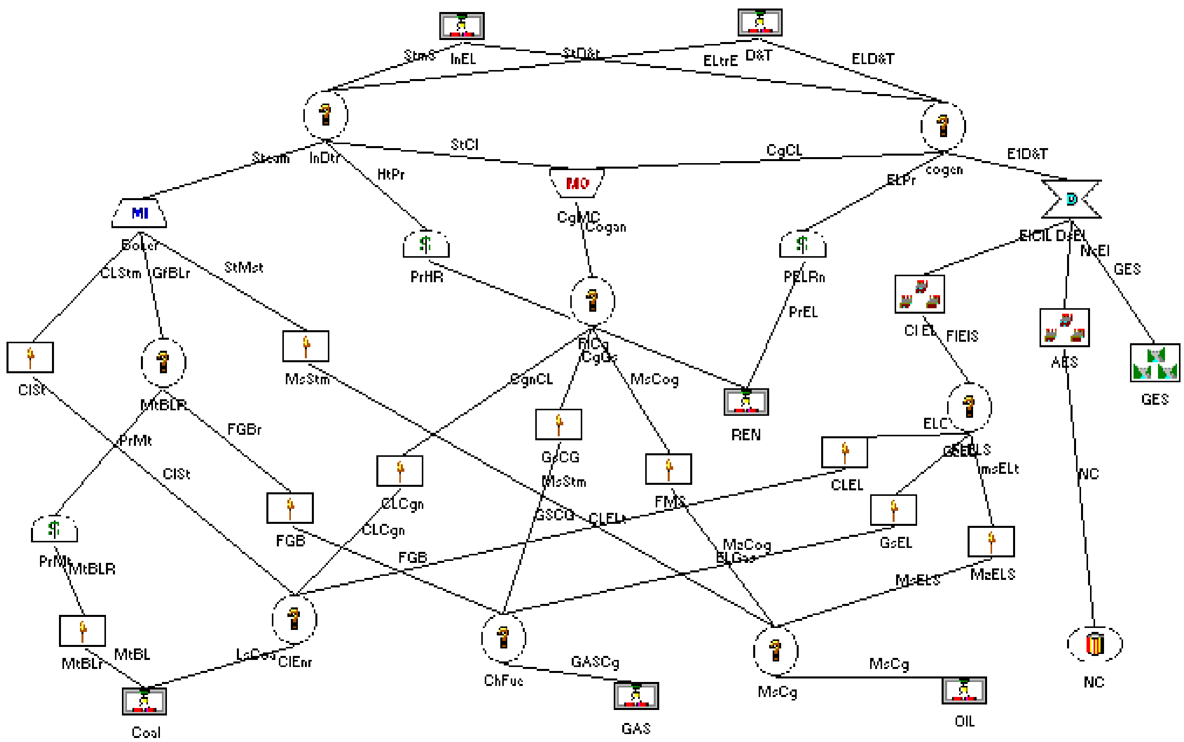


Fig 5.3. Energy Sector Elements

6. MODELING CONDITIONS AND ASSUMPTIONS

6.1. Factors influencing GHG emissions

The main factors influencing GHG emissions are economic development (characterized by GDP), energy efficiency, and fuel and energy prices. We used these factors for developing a model and analysis of energy efficiency measures aimed at reducing GHG emissions.

Construction of base energy consumption and GHG levels by considering economic development without energy efficiency is necessary for measuring the impacts of the main factors mentioned above. Other factors to consider in the model as limits include:

- The priorities for development of the fuel and energy complex, which are determined by the countries energy security.
- The capacity of the fuel mining and processing sectors of the economy.

- The thru-put of oil and gas pipelines as well as social and environmental factors, and other aspects of economic policy.

6.2. Base year for modeling

When selecting a base year for modeling it was necessary to consider the following:

- Reliable input data for energy consumption.
- Proximity to the current period.
- The same base year for initiating the model and GHG inventories (1990)
- The same base year for initiating the model and estimation of the energy efficiency level (1990).

It was not possible to comply with all conditions, so 1997 was chosen as the base year for modeling. In addition, 1997 is the last year for which official statistical information can be found and the first year, when energy efficiency programs began to be implemented.

6.3. Input data for modeling

Tables 6.3.1-6.3.3 contain information on GDP, energy consumption and direct GHG emissions in the sub-sectors of the energy sector of Ukraine in the base 1997 year; based on the available data from 'Additional Measures and Amended Results of Executing the State Comprehensive Program for Energy Conservation of Ukraine,' 'Fuel and Energy Sector of Ukraine: Numbers and Facts,' and 'Final Report. The Second National Report on Climate Change'.

Table 6.3.1. – GDP and Energy Consumption in Sub-sectors of the Energy Sector of Ukraine in 1997.

Sub-sector	GDP, billion Hr	Energy Consumption		
		Electricity, million kWh	Heat, million Gcal	Fuel, thousand t.c.e.
Heat and electricity generation	36,36	90112	97,707	140,4
Industry		24926	93,000	9,1
Communal sector	15,33	9545	4,829	7,7
Transport	14,69	17455	3,392	7,1
Agriculture	39,32	7403	25,154	33,5
Other sectors	105,7	178002	228,482	197,8
Total	211,4	327443	195793,028	395,6

Table 6.3.2. – Production and Import of Fuel and Energy in the Economy of Ukraine in 1997.

Fuel and Energy	Production	Import
Coal, thousand tons	65714.29	12577.92
Coal, thousand t.c.e.	50600	9685
Oil, thousand tons	4125.87	9505.59
Oil, thousand t.c.e.	5900	13593
Natural gas, million m^3	18173.91	57588,67
Natural gas, thousand t.c.e.	20900	66227
Methane, million m^3	905,91	
Methane, thousand t.c.e.	1041,8	
Wood, thousand m^3	1134	1304
Wood, thousand t.c.e.	300	345

Table 6.3.3. - Direct GHG Emissions in the Economic Sectors of Ukraine During 1997 in CO_2 Equivalent

Sub-sector	CO_2, thousand tons	CH_4, thousand tons	N_2O, thousand tons	Total thousand tons in CO_2 equivalent
Heat and electricity generation	114462,7	38,2	270,1	114771
Industry	81634	28526,2	253,6	110413,8
Communal sector	48698,9	461,3	59,9	49220,1
Transport	12882	41,0	33,5	12956,5
Agriculture	2266,5	11	5,4	2282,9
Other sectors	4096,3	47,5	165,8	4309,6
Total	264040,5	29125,3	788,4	293954

Table 6.3.4. contains information on generation of electricity and heat at electric stations and boiler plants of Ukraine in 1997.

Table 6.3.4. – Generation of heat and electricity in Ukraine in 1997

Energy source	Electricity generation		Heat generation	
	million kWh	t.c.e.	thousand Gcal	t.c.e.
Nuclear station	79,433	9,722,521		
Hydro-power station	10,000	1,223.99		
THPS	76,979.3	942,219		
CHP	11,589.7	1,418,568	27,070.174	3,853,656
Boiler plants			148,822	21,186,002

6.4. Scenarios of Economic Development

The model presents three levels of GDP related to three scenarios of economic development consistent with 'Concept of the State Energy Policy of Ukraine for the period till 2020'.

Scenario 1 – unfavorable (low) envisages slow structural reforms, a slow pace for elimination of the shadow economy, promoting engineering innovations, unfavorable conditions on the international energy market, and a lack of the visible changes for diversification of external energy sources. Under these conditions, annual average GDP grows slowly – 2-3% in 2001-2010, and up to 4-5% in 2011-2020. Under this scenario Ukraine's GDP will grow to nearly twice it's current level (1.99 times) over 20 years, however, this is short of the level reached in 1990.

Scenario 2 – favorable (mid) envisages aggressive structural reforms, accelerated elimination of the shadow economy, rapid growth of engineering innovations, and diversification of external energy sources. The accelerated reforms and elimination of the shadow economy provides that GDP will achieve a high (up to 7%) rate of growth and decrease in energy intensity during the 2006-2010 period. After the complete elimination of the shadow economy, the rapid growth of GDP slows to 5-6%. In this scenario Ukraine's GDP grows 2.78 times over 20 years and achieves the 1990 level in 17 years.

Scenario 3 – most favorable (high), in addition to the assumptions in Scenario 2, envisages favorable conditions in the international energy market. This provides for GDP growth rate to increase by an additional 1% to 6-7% with a high of 8%. In this case Ukraine's GDP grows 3.36 times over 20 years and achieves the 1990 level of 1990 in 14 years.

Tables 6.4.1 presents the GDP dynamics /Concept of the State Energy Policy of Ukraine for the period till 2020/ for three scenarios of Ukraine's economic development.

Table 6.4.1. – Average GDP growth, %

Scenario of the economic development	2001-2005	2006-2010	2011-2015	2016-2020
Low	2	3	4	5
Mid	3	7	6	5
High	4	8	7	6

Figure 6.1 provides the historical levels of GDP (in billion Hryvna) for the period 1990-2000 and the predicted levels of GDP for the three growth scenarios for the period 2001-2020.

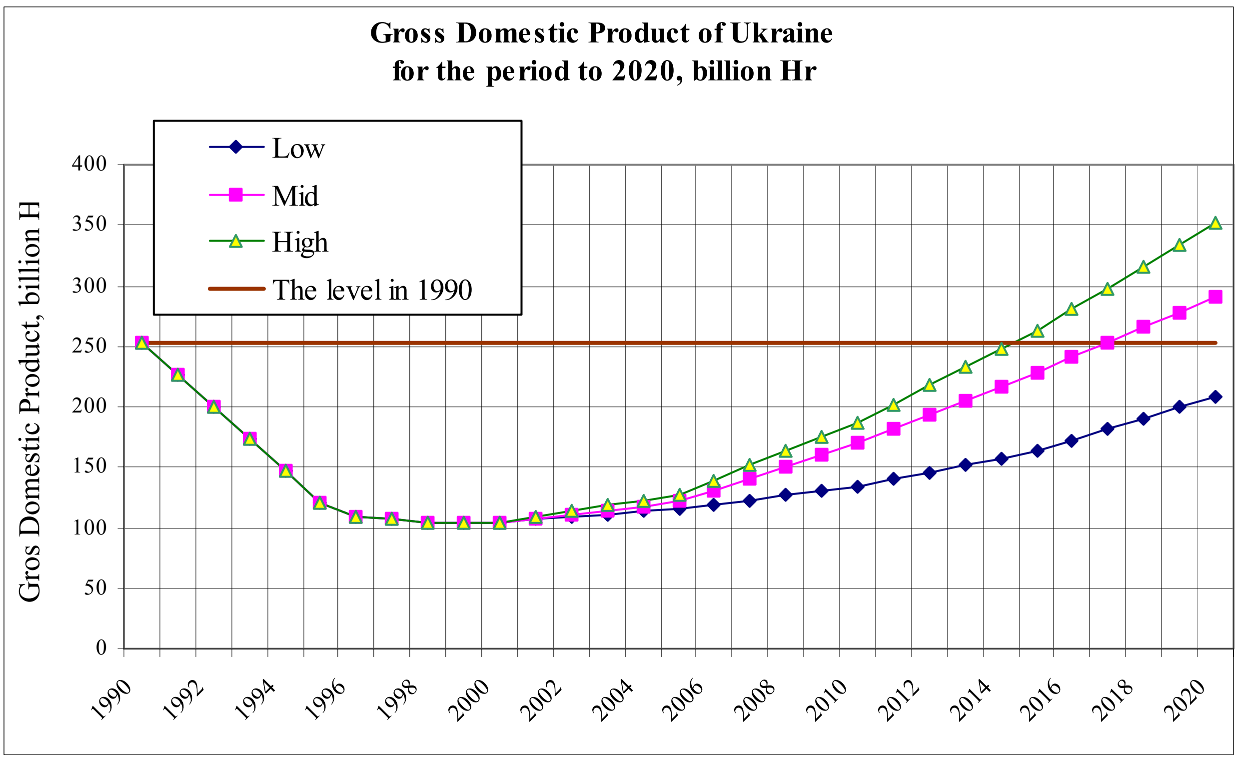


Figure 6.1. Historical and Predicted Gross Domestic Product of Ukraine for the Low, Mid, and High Growth Scenarios (1990-2020)

6.5. Energy Consumption Baseline

The objective of the development of the model is to determine energy consumption, including energy efficiency potential and GHG emission reduction by implementing energy efficiency measures. Thereby, energy consumption specified by GDP dynamics for all three scenarios of economic development was taken as a baseline.

The energy consumption baseline was identified assuming that the structure of the Ukraine's economic sectors is permanent beginning from modeling base year (1997). Energy consumption of the Ukraine's economy in the forecast year is determined by the base year energy consumption, escalated by GDP growth.

Each scenario of economic development and the associated levels of energy consumption and GHG emissions provide baselines for subsequently measuring the implementation of energy efficiency. That is, there are three baseline scenarios of energy consumption and GHG emissions – low, mid, and high.

6.6. Scenario of Energy Efficiency Development

Energy efficiency programs and activities are developed under the State Comprehensive Energy Consumption Program of Ukraine as stated in 'State Comprehensive Energy Conservation Program of Ukraine' at the sector, regional and oblast levels. These programs and activities are integrated with state policy through improvement of energy management, development and implementation of regulatory and methodical frameworks that facilitate energy efficiency, as well as developing and promoting technologies and equipment, improving control and consumption of fuel and energy consumption, cooperating with and participating in international scientific activities, and raising awareness of the importance of energy efficiency issues.

In addition, energy efficiency developments are also controlled by the Presidential Decree of Ukraine 10.03.2000 №457 "On the decision of the Council of National Security of Ukraine as of February 14, 2000", "On the urgent measures to overcome crises in the fuel and energy sector of Ukraine" and the related resolution of the Cabinet of Ministries of Ukraine, 27.06.2000 №1040 "On the urgent measures to execute the State Comprehensive Energy Conservation Program of Ukraine". These documents provide for additional review and development of the Comprehensive Program to amend and supplement the sector, regional and oblast energy efficiency programs, and to identify priority investments for energy efficiency projects.

While fulfilling the tasks set by the Activity Program of the Cabinet of Ministries of Ukraine "Reforms for Welfare", special attention was given to executing the Presidential Decree "On measures to reduce energy consumption by budgetary institutions, organizations, and state enterprises" for two tasks of the Comprehensive Program (Program of measures on reducing natural gas consumption and Program of state support in developing alternative and renewable energy and small hydro and thermal energy sectors) to provide economic incentives to producers to increase the energy efficiency of energy consumption.

In reality, the state energy efficiency programs don't receive appropriate financial support due to the difficult economic situation, which results in the delayed and partial implementation of these programs. Despite the lack of targeted financing, actual fuel and energy savings, according to preliminary data, were 21.5 million ton of coal equivalent in 1996-2000, and estimated savings were 82.7 million ton of coal equivalent (with the total investments of 6.94 billion Hr.).

Table 3.3 presents the dynamics of the overall energy saving in Ukraine for 1997-2000 as compared to 1990 (see data /Additional Measures and Amended Results of Executing the State Comprehensive Program for Energy Conservation of Ukraine/).

Table 6.6.1. - Energy Savings in Ukraine in comparison with 1990

Units	1997	1998	1999	2000	Total
Level of Energy Consumption, mil. Ton c.e.	209.6	203.3	200.1	200.7	813.7

Reduced Energy Consumption million ton of coal equivalent	3.7	4.2	6.5	7.1	21.5
Energy Efficiency, %	1.8	2.1	3.2	3.6	2.6

The development of energy efficiency during the forecast period will, to a considerable degree, depend on overall economic development and the dynamics of energy efficiency dynamics, but the motivation to facilitate the implementation of energy efficiency is based upon non-economic factors as well. The scenarios are based on the assumption that the Comprehensive Program will be executed, but with a 5 year lag. Thus, beginning in 2005 reductions in energy consumption will equal the data presented in 'Additional Measures and Amended Results of Executing the State Comprehensive Program for Energy Conservation of Ukraine'.

6.7. Energy Efficiency Measures

Energy efficiency improvement is the main tool for GHG emission reduction. The well-known classification of energy efficiency measures comprises three basic energy efficiency directions: structural changes, inter-sectoral improvements, and technological measures. For economic and energy modeling, and analyzing GHG emission reductions resulting from energy efficiency improvements, two factors are noted for estimating the three energy consumption baselines and the associated levels of energy efficiency.

The first peculiarity concerns the energy consumption baselines. The energy consumption baselines are estimated for the three economic scenarios presented in section 6.4 reflect Ukraine's' economic and development policies and thereby excludes the implementation of any energy efficiency measures. The reduced energy consumption that results from the implementation of energy efficiency programs and activities for each of the three baseline scenarios is taken as the measure of the improvement resulting from energy efficiency. It is recognized that a third case between the two should account for naturally occurring energy efficiency and, in part, this is accounted for in the baselines, and, in part, it is felt that the amount of change resulting from naturally occurring energy efficiency is small.

The second peculiarity is based on interactions among the energy efficiency measures, as well as special ENPEP characteristics used for modeling. To avoid inaccuracy due to neglected interconnections of the energy efficiency measures, which are implemented at the same site, each individual measure should be analyzed, see Panchenko G., Surnin S.

To estimate reduction of energy consumption and GHG emissions due to implementation of energy efficiency measures it is necessary to identify modeling consistency for specific measures (or a range of measures). With this, baseline estimate for influence of the measures from the second group is based on the results of energy consumption assessment for modeling measures from the first group. Thereby, baseline estimate for the each next group of measures is based on estimate of energy consumption after implementing the previous group of measures. Correctly determined consistency of measures implementation and analysis is important.

- The measures were considered in the following order:
- Coal-bed methane utilization.

- Implementing non-traditional and renewable energy.
- Applying modern equipment for metering, control and optimization of energy supply and consumption systems.
- Applying energy efficiency electric lighting systems and devices.
- Implementing power electronic devices.
- Applying advance technologies for burning low-quality coal.
- Recovery of waste energy.
- Technological measures

Table 6.7.1 presents information concerning the efficiency of the energy saving measures (listed according to the sequence of the analysis) used in the model. Information is based on the data contained in 'Additional Measures and Amended Results of Executing the State Comprehensive Program for Energy Conservation of Ukraine; Inventory of Methane Emissions from Coal Mining Enterprises in Ukraine: 1990-1999' on the cost-effective levels of energy efficiency potential in the Ukraine's economy. Cost efficient level of energy efficiency is determined by self-sufficient energy saving measures.

Expedient economic potential for energy efficiency is determined as total energy savings from implementing measures with less payback period then their life cycle.

Table 6.7.1. – Cost-effective level of energy efficiency potential in Ukraine's economy in 2010

Sub-sector	Energy savings		
	electricity, million kWh	heat, million Gcal	fuel, 1000 ton of coal equivalent
Extraction and generation of energy resources	3900	2.45	3782.5
Industry	15090	34.25	16719.9
Utilities	11000	35	5779.3
Transport	1500	0.42	44447
Agriculture	480	-	4336.7
Inter-sectoral measures	51000	42.2	8000
Total	82970	114.32	83065.4

6.8. Energy Market

Energy prices are major determinants for energy balance. Factors reflected in energy prices are energy safety and security, which require establishing priority use of domestic rather then imported energy, and continued subsidies for energy producers and consumers.

The following assumptions were made in consideration of these factors:

- Priority use of domestic fuels and energy supplies.
- As domestic fuels and energy supplies are exhausted, energy will be purchased in accordance with the price mechanism set in the ENPEP program.
- Gas price will be constant over the forecast period (this assumption is felt to be reasonable given the agreement on a long-term gas supply between Ukraine and Russia (concluded in 2001) through 2010.
- Oil prices will grow according to the scenario in the 1998 World Energy Outlook 'World Energy Outlook'.
- Coal prices will grow at a rate lower than oil prices.

Table 6.8.1 provides the fuel and energy prices used (1997 and 2000) and forecasted prices by 5-year increment from 2005 to 2020.

Table 6.8.1. – Energy Prices, 1997 - 2020

Energy Form	Source	Units	Year					
			Actual		Forecast			
			1997	2000	2005	2010	2015	2020
Natural gas	Ukraine	\$/1000 м^{3}	83	83	83	83	83	83
	Imported	\$/1000 м^{3}	80	80	80	80	80	80
Coal	Ukraine	$/т	85	85	90	95	100	110
	Imported	$/т	40	40	43	46	48	50
Oil	Ukraine	$/т	85	85	90	95	130	130
	Imported	$/т	108	108	110	125	165	165
	Business as Usually[1]	$/т	120,1	122	125	130	186	186

7. MODELING RESULTS

Table 7.1 presents modeling results for energy consumption, energy efficiency improvement, and GHG emission reductions. Note that the GHG emissions reductions include the economic conditions discussion in section 6.6 in addition to the energy efficiency improvement by sub-sectors from 2000 to 2020.

[1] See Source: World Energy Outlook. – International Energy Agency. – 1998.

Table 7.1. -Forecast of Energy Consumption, Energy Efficiency, and GHG Emissions by Sub-sectors in Ukraine's Energy Sector

Scenario of economic development	2000	2005	2010	2015	2020
Baseline Forecast Values					
Gross Domestic Product, million Hr					
Low	104.6	115.7	134.1	163.2	208.2
Mid	104.6	121.5	170.4	228.0	291.0
High	104.6	127.5	187.4	262.7	351.6
Fuel Consumption, 1,000,000 ton of coal equivalent					
Low	193.34	164.6	144.46	147.3	161.9
Mid	193.34	149.7	158.4	177.2	208.9
High	193.34	159.2	174.8	211.2	258.8
Fuel and Energy Reductions Resulting from Energy Efficiency (compared to 1990 levels), %					
Low	3.55	19.9	35.3	41.55	45.3
Mid	3.55	28.9	38.63	44.8	46.3
High	3.55	26.4	36.76	41.82	43.9
Baseline Emissions					
Baseline CO2 Emissions, 1,000 ton					
Low	262,690.1	282,665.3	311,077.3	359,797.3	433,148.3
Mid	262,690.1	270,242.6	338,057.7	428,973.7	527,809.8
High	262,690.1	299,997.8	393,321.0	529,573.1	685,268.7
Baseline Methane Emissions, 1000 ton					
Low	1,413.8	852.9	456.5	673.5	994.3
Mid	1,413.8	1,565.6	2,143.9	2,889.2	3,715.6
High	1,413.8	108.5	152.9	216.7	291.7
Baseline NOX Emissions*, 1,000 ton					

Low	2.2	2.4	2.6	2.9	3.5
Mid	2.2	2.2	2.6	3.3	3.9
High	2.2	2.5	3.2	4.2	5.4
Total Baseline GHG emissions, 1000 ton CO2 equivalent					
Low	262,828.6	282,900.7	311,312.0	359,992.2	433,244.5
Mid	262,828.6	30,4487.8	384,747.0	491,722.2	608,351.5
High	262,828.6	30,3898.4	388,617.2	536,931.8	694,995.9
Emissions Reflecting Energy Efficiency					
Carbon-dioxide Emissions Reflecting Energy Efficiency, 1000 ton					
Low	262,690.1	198,782.7	156,456.3	163,529.4	186,975.1
Mid	262,690.1	174,685.7	171,071,6	198,944.9	244,142.0
High	262,690.1	192,534.1	199,945.8	253,889.6	320,495.4
Methane Emissions Reflecting Energy Efficiency, 1000 ton					
Low	1,413.8	1,7911.0	9,586.9	14,180.4	20,882.2
Mid	1,413.8	889.2	669.3	1,055.8	1,636.5
High	1,413.8	772.7	607.9	1,064.1	1,672.5
NOX Emissions Reflecting Energy Efficiency, 1000 ton					
Low	2.2	1.7	1.3	1.3	1.4
Mid	2.2	1.6	1.6	1.7	2.0
High	2.2	1.9	2.1	2.6	3.2
Total GHG Emissions Reflecting Energy Efficiency, 1000 ton CO2 equivalent					
Low	262,828.6	215,770.6	164,673.6	175,911.0	205,442.1
Mid	262,828.6	194,416.3	186,200.3	222,349.5	279,993.3
High	262,828.6	209,883.2	213,891.9	277,702.7	357,448.9

Figures 7.1-7.3 present the forecasted energy consumption and GHG emission rates in the energy sector of Ukraine from 1997 to 2020.

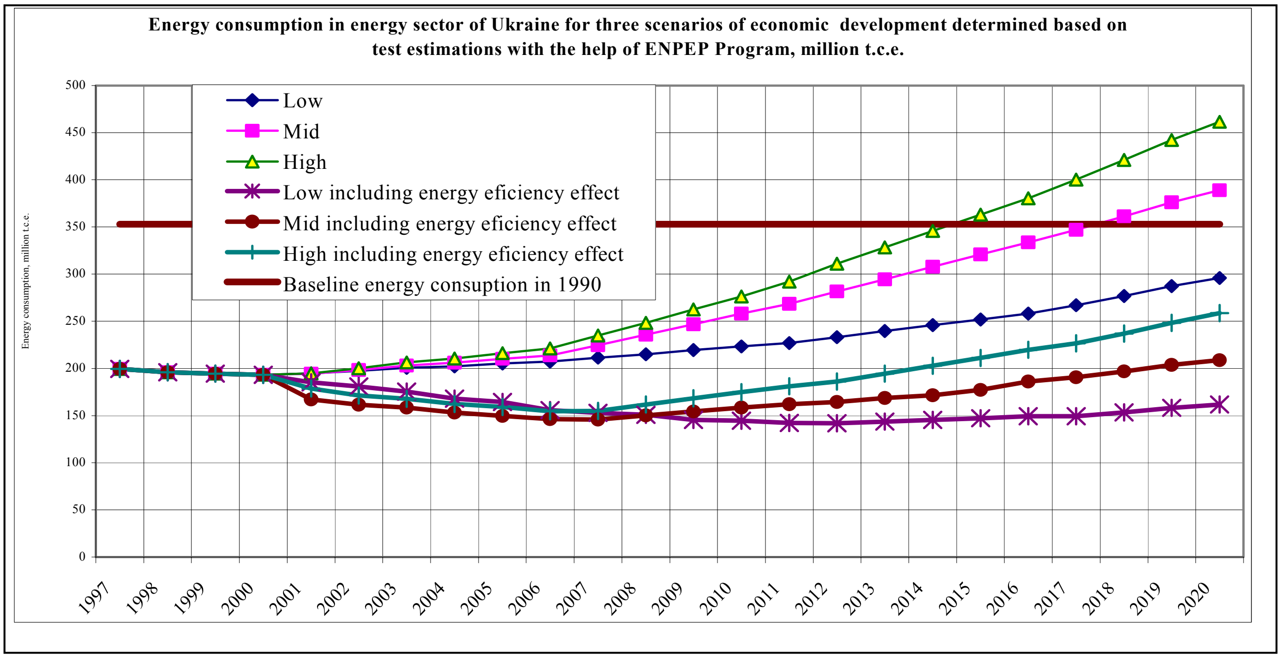


Fig. 7.1. Forecasted Energy Consumption by Economic Growth Scenario Without and With Energy Efficiency, 1990-2020

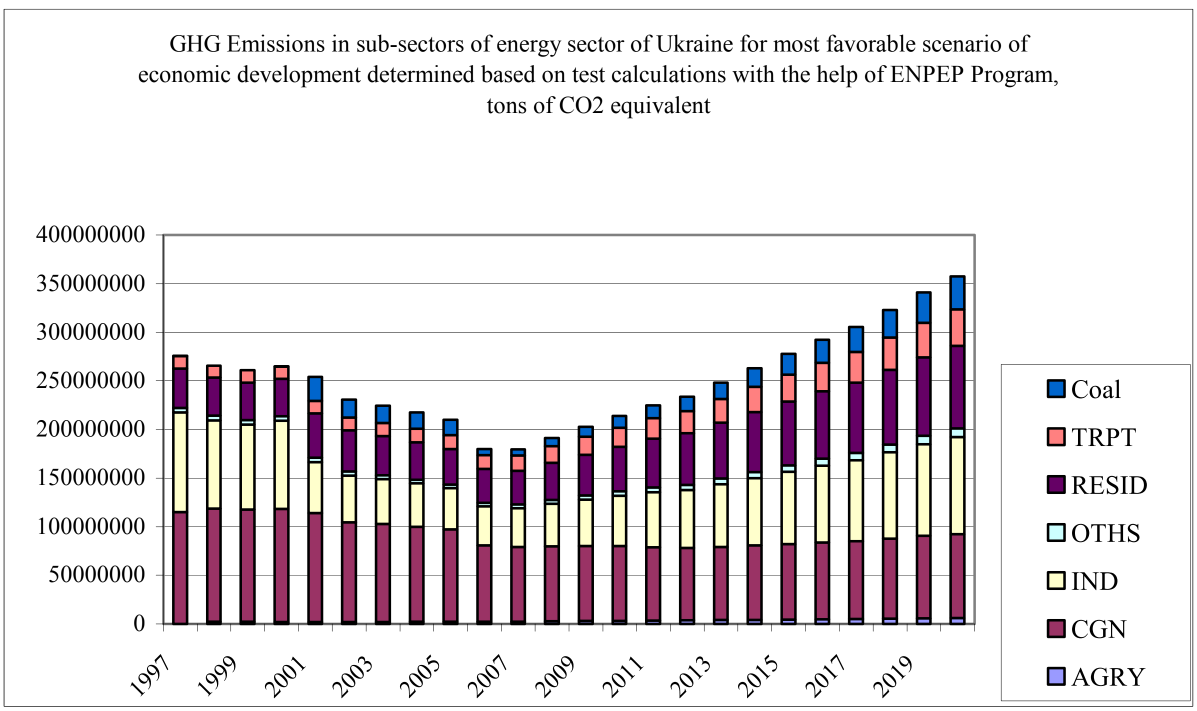


Fig. 7.2. GHG Emissions in Tons of CO2 Equivalent by Subsector for the High Growth Scenario, 1997-2020 Schedules of GHG emission rates at the sub-sectors of the energy sector of Ukraine till 2020.

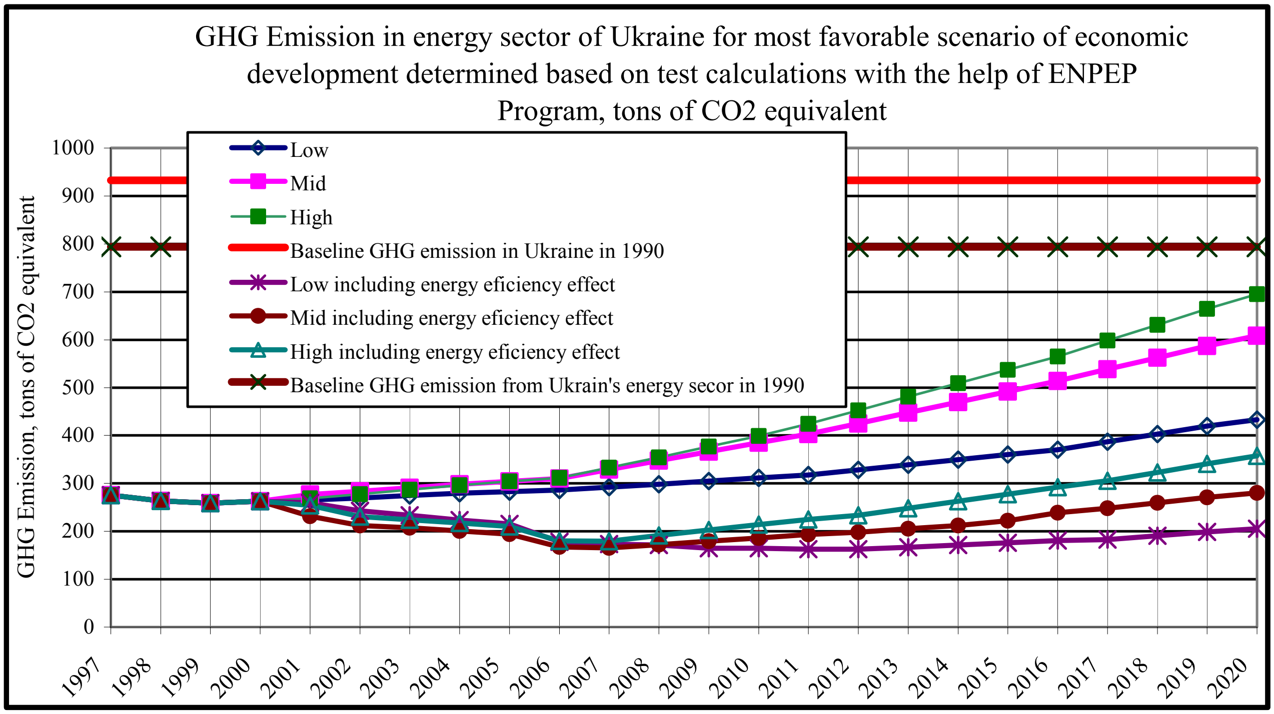


Fig. 7.3. GHG emission rates (regardless of and including energy efficiency measures) at the energy sector of Ukraine till 2020.

Analysis of Figure 7.3 allows the conclusion that the amount of GHG emissions in the energy sector of Ukraine in 2020 will not reach the 1990 level even under the most favorable scenario of economic development and without considering energy saving measures implementation. Implementing energy saving measures will provide for reductions in Ukraine's energy sector energy consumption of approximately 36% in 2010 and 45% in 2020 and reductions in energy sector GHG emissions of approximately 46% of emissions level without considering energy saving measures (165 to 213 million tons of CO_2 equivalent depending on the scenario of economic development) in 2010 and by 51% (205 to 357 million tons of CO_2 equivalent) in 2020. The baseline for energy consumption is determined by the level of energy consumption (or GDP energy intensity) in 1997, GDP scenarios (unfavorable, favorable and maximum favorable) as well as the GDP forecast in the sub-sectors of the energy sector. The latter means that in base energy consumption, structural changes in the economy have been considered. The following assumption has been made -- structural changes in the economy are invariant in relation to GDP scenarios and implementing measures for reducing GHG emissions.

CONCLUSIONS

1. For achieving the goal of the project to help Ukrainian policy makers better understand emission scenarios and elaborate effective mitigation strategies the following criteria for the selection of the most appropriate model were defined:

   - Compliance with the project objectives.
   - Software availability.
   - International access.
   - Consultant guidance.
   - Availability of experienced domestic model-builder.
   - Opportunity to be applied in other transition countries.
   - Opportunity to provide personnel with the relevant training.
   - Degree of the model's dissemination and development in Ukraine.
   - Support and improvement of the model by the developers.

2. As a result of the assessment of five models, only the ENPEP program was used fully or partially in Ukraine. ENPEP is partially used for power industry development modeling. In Ukraine there are several specialists (including those working in ARENA-ECO) who received training at Argon National Laboratory to use ENPEP model. The ENPEP program is supported by the developers, and also provided at no charge by the IAEA to organizations for conducting research. Following our request, IAEA has officially provided the Agency of Rational Energy Use and Ecology (Ukraine)

3. As far as the structure of the statistical information is concerned, the energy sector of Ukraine is presented in the model by the following sub-sectors:

   - Heat and electricity generation.
   - Fuel combustion in industry
   - Fuel combustion in communal sector.
   - Fuel combustion in transportation.
   - Fuel combustion in agriculture.
   - Fuel combustion in other sectors of the economy.

4. Three GDP forecast options correspond to three scenarios of economic development in 'Proposals to a Concept of the Ukrainian National GHG Inventory System' and were designated as:

   - Scenario 1 (Low) envisages slow structural reforms, eliminating the shadow economy, promoting engineering innovations, maintaining the unfavorable structure of the international energy market, and a lack of visible changes related to diversification of external energy sources. Under these conditions, annual average GDP will grow slowly from 2-3% in 2001-2010 to 4-5% in 2011-2020. Under this scenario Ukraine's GDP will grow to nearly twice it's current level (1.99 times) over 20 years, however, this is short of the level reached in 1990.

- Scenario 2 (Mid) envisages aggressive structural reforms, accelerated elimination of the shadow economy, rapid growth of engineering innovations, and diversification of external energy sources. The accelerated reforms and elimination of the shadow economy provides that GDP will achieve a high (up to 7%) rate of growth and decrease in energy intensity during the 2006-2010 period. After the complete elimination of the shadow economy, the rapid growth of GDP slows to 5-6%. In this scenario Ukraine's GDP grows 2.78 times over 20 years and achieves the 1990 level in 17 years.
- Scenario 3 (High), in addition to the assumptions in Scenario 2, envisages favorable conditions in the international energy market. This provides for GDP growth rate to increase by an additional 1% to 6-7% with a high of 8%. In this case Ukraine's GDP grows 3.36 times over 20 years and achieves the 1990 level of 1990 in 14 years.

5. The GHG emissions associated with the energy sector of Ukraine were developed to correspond to the three GDP forecast options in both the baseline (without efficiency) and with efficiency cases.
6. The energy efficiency scenarios were developed with the assumption that the Comprehensive State Program of Energy Conservation (CSPEC) will be fulfilled, but with a 5 year delay in its fulfillment, i.e. since 2005 energy saving levels, which will be reached in accordance with this scenario, will correspond to the appropriate data in 'Additional Measures and Amended Results of Executing the State Comprehensive Program for Energy Conservation of Ukraine', and in 2011 – 2020 the energy saving growth will depend on GDP growth.
7. The analysis of efficiency of energy saving measures leading to reductions in GHG emissions was based on the Comprehensive State Program of Energy Conservation. The model views influence of three main groups of energy saving measures:
   - Non-traditional and renewable energy;
   - Inter-sectoral measures;
   - Technological measures.
8. The following assumptions were made for considering price factor influence in the model:
   - Priority use of local fuels and energy supplies.
   - As local fuels and energy supplies are exhausted, energy will be purchased in accordance with the price mechanism set in the ENPEP program.
   - Gas price will be constant over the forecast period (this assumption is felt to be reasonable given the agreement concluded in 2001 on a long-term gas supply between Ukraine and Russia through 2010).
   - Oil prices will grow according to the scenario in the 1998 World Energy Outlook 'World Energy Outlook'.
   - Coal prices will grow at a rate lower than oil prices.
9. Results of estimations show that:

- The model reflects the level of the existing energy consumption and GHG emissions in the enegy sector of Ukraine to provide forecasts of energy consumption and GHG emissions with three corresponding to scenarios of economic development through 2020.
- Energy Sector GHG emissions do not reach the 1990 level even under the most favorable scenario of economic development and without factoring in energy efficiency improvements.
- Implementation of energy efficiency measures will provide for reduced energy consumption of Ukraine approximately by 36% in 2010 and by 45% in 2020;
- GHG emissions in the energy sector of Ukraine are approximately 46% of emissions level without considering energy saving measures (165 to 213 million tons of CO_2 equivalent depending on the scenario of economic development) in 2010 and by 51%n (205 to 357 million tons of CO_2 equivalent) in 2020.

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ANNEX

Node abbreviations meaning indicated on the schemes

Fig. 5.1. Balance Study Sectors Network:

Item value	Meaning of abbreviations, nodes indicated on the schemes
Coal	Coal sector
OIL	Oil sector
GAS	Gas sector
LGAS	Liquid gas sector
WOOD	Forestry sector
REN	Renewable energy sector
TURF	Turf sector
CGN	Cogeneration sector
D&T	Energy transportation and distribution sector
Ind	Industry
InEL	Heat and electricity consumption by power plants for their own purposes
RESID	House holding services and utilities
AGRY	Agricultural sector
TRP	Transportation
OTH	Other economic sectors

Fig. 5.2. Renewable sector elements

Item value	Meaning of abbreviations, nodes indicated on the schemes
HtRern	Generation of heat from renewable resources
EIREN	Generation of electricity from renewable resources
BGS	Biogas

RHt	Heat losses of renewable resources
REL	Electricity losses of renewable resources
FrBGa	Heat generation from biogas

Fig 5.3. Energy sectors elements

Item value	Meaning of abbreviations, nodes indicated on the schemes
AES	Nuclear power stations
ClEL	Thermal power stations
GES	Hydro power stations
CgMC	Cogeneration systems, which produce both electricity and steam
BoLer	Boiler plants
NC	Imported nuclear fuel
FICg	Fuel selection for thermal power plants
GsCG	GHG emissions from gas combustion at cogeneration plants
FMS	GHG emissions from fuel oil combustion at cogeneration plants
CLCgn	GHG emissions from coal combustion at cogeneration plants
FLELS	Selection of fuel for power plants
GsEL	GHG emissions from gas combustion at thermal power plants
CLEL	GHG emissions from coal combustion at thermal power plants
MsELS	GHG emissions from fuel oil combustion at thermal power plants
MtBLr	GHG emissions from coal methane combustion at boiler plants
FGB	GHG emissions from gas combustion at boiler plants
MtBLR	Simulation of choice between gas and coal methane for boiler plants
MsStm	GHG emissions from fuel oil combustion at boiler plants
CISt	GHG emissions from coal combustion at boiler plants

MsCg	Fuel oil distribution for generation of heat and electricity
CIEnr	Coal distribution for generation of heat and electricity
ChFue	Gas distribution for generation of heat and electricity
Cogen	Selection of electricity supply sources
E1D&T	Electricity dispatching from different type of power plants
PrMt	Price correction for coal methane
PrHR	Price correction for heat from renewable sources
PELRn	Price correction for electricity from renewable sources