Progress in Nuclear Energy 61 (2012) 17–25

Contents lists available at SciVerse ScienceDirect

Progress in Nuclear Energy

journal homepage: www.elsevier.com/locate/pnucene

Uncertainty and sensitivity analysis for economic optimisation of new energy source in Lithuania

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ARTICLE INFO

Article history:
Received 30 November 2011
Received in revised form
17 June 2012
Accepted 28 June 2012

Keywords:
New energy source
Uncertain data
Cogeneration
Energy system
Economic optimisation
Uncertainty and sensitivity analysis

ABSTRACT

Study presented in this paper consists of two main parts: the modelling of future energy system development scenarios and the analysis of the influence of main initial model parameters to the calculation results (sensitivity and uncertainty analysis). Economic modelling and optimisation was concentrating on evaluation of possibilities to construct a new energy source. The MESSAGE modelling tool was used for modelling and optimisation of the future energy system development. In this study, the introduced approach was applied focussing on small and medium nuclear reactor (SMR), which could be one of the future energy source options in Lithuania. As an example of SMR, the IRIS (International Reactor Innovative and Secure) nuclear reactor was chosen in this study. Finally, the analysis of uncertainty and sensitivity enabled to investigate how uncertain are results of modelling and how this uncertainty is sensitive to the uncertainty of model parameters. In the particular case we have analysed how Lithuanian energy system development scenarios could change, when changing the initial model parameters describing IRIS technology. If IRIS could be built near the cities without Emergency Planning Zone (EPZ) where a big heat demand is, it could be safely used not only for electricity generation, but also for heat supply for residential and industrial consumers. This will allow not only to reduce energy prices but also to decrease fossil fuel consumption and greenhouse gas emissions.

1. Introduction

The biggest electricity generator in Lithuania – Ignalina Nuclear Power Plant (NPP) was closed at the end of 2009. Before closure of the Ignalina NPP the electricity production from nuclear fuel was dominant in Lithuania. Share of electricity produced at Ignalina NPP in 2005–2009 made 60–70% of total generated electricity while before 2005 its production was even higher. The nuclear power was replaced by the electricity generated using natural gas and electricity import from neighbouring countries. Starting from 2010 the variety of primary energy used for electricity generation decreased and the energy sector dependence on natural gas from Russia has increased even more. In addition, still there are no electricity grid connections with Sweden and Poland electricity systems. Such situation in Lithuanian electricity sector is causing a complex of serious economic, ecological, and social problems.

The series of various studies were carried out in order to answer the question what energy sources should replace the lost nuclear electricity capacities (International Atomic Energy Agency, 2007; International Atomic Energy Agency, 2004). The results of various studies concerning the future structure of power plants in Lithuanian energy system have shown that looking from the economical point of view the best option to replace Ignalina NPP are new nuclear unit, new combined cycle condensing units together with the existing and new units of Combined Heat and Power plants (CHP) (International Atomic Energy Agency, 2004; Norvaisa, 2005). Due to climate conditions in Lithuania, district heating presents a notable fraction of energy consumption in winter months, and infrastructure is available in most population centres in Lithuania. So, in the future new cogeneration units are likely to be the best alternative for electricity and heat generation in Lithuania. Currently all Baltic region countries cooperating and seeking to solve energy supply and energy security problems and planning to construct new nuclear reactors in Lithuania at the existing NPP site. In order to expand the research of the Lithuanian energy future we have added another option to the analysis: Small and Medium type nuclear Reactor (SMR) in the new site close to the cities with large heat demand. In general it could be considered for small countries like Lithuania, as alternative for the big nuclear units due to limitation imposed by the grid size and available financial resources.

The IRIS (International Reactor Innovative and Secure) nuclear reactor as an example of SMR was chosen for this analysis. This is

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0149-1970/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.pnucene.2012.06.006

a pressurised light water cooled, medium-power (335 MWe) reactor (Carelli, 2003; Carelli et al., 2004, 2005). The IRIS designing supports idea of licensing the power plant with reduced or even without the need for off-site emergency response planning (Alzbutas and Maioli, 2008). This would allow IRIS to be treated as any other industrial facility, located closer to population centres. This allows better implementation of cogeneration option and reduction of transmission costs. If IRIS could be built near the cities without Emergency Planning Zone (EPZ) where a big heat demand is, it could be safely used not only for electricity generation, but also for heat supply for residential and industrial consumers (Alzbutas and Maioli, 2008; Kling et al., 2005). This will allow not only to reduce energy prices but also to decrease fossil fuel consumption for heating and emissions into atmosphere (Miller, 2005).

Applying mathematical models for the analysis of energy system development scenarios the results significantly depend on the quality of the initial data. Usually it is difficult to define precise values of initial parameters such like Gross Domestic Product (GDP) forecast, future energy demand and fuel prices, investments and operation costs, etc. The recent economic recession has showed that these data and forecasts used in mathematical models can be highly uncertain and change in a very broad range. So, in this work we have taken into account this important aspect of complete analysis and investigated sensitivity of model results to the primary data. The model sensitivity indexes can show how particular parameter is important to the model results and where the accuracy of primary data could be increased (in order to decrease the uncertainty of the results). The aim of sensitivity analysis is to identify the main contributors to the possible variations of results. Sensitivity analysis could be performed in connection with uncertainty analysis in order to see the combined influence of all the potentially important uncertain parameters on the results.

2. Modelling of Lithuanian energy system

In order to reach one of the objectives of this paper the MESSAGE modelling tool was used for modelling and optimisation of the future energy system development scenarios for Lithuania. MESSAGE is designed to formulate and evaluate the alternative energy supply strategies consonant with user-defined constraints on new investment limits, market penetration rates for new technologies, fuel availability and trade, environmental emissions, etc. The underlying principle of the tool is the optimisation of an objective function under a set of constrains (International Atomic Energy Agency, 2003). This modelling tool is extremely flexible and can also be used to analyse various energy system modelling tasks. It was originally developed at the International Institute for Applied Systems Analysis. The International Atomic Energy Agency acquired the latest version of the MESSAGE and added a user-interface to facilitate its applications.

The objective of model application is determination of an optimal allocation of technologies in whole energy chain and the associated energy resources to satisfy the projected final energy demand. The Model for Analysis of Energy Demand (MAED) widely applied for forecasting of energy demand was used for energy demand projections in Lithuania. In drawing up the energy demand forecast, detailed information on the GDP growth, its structural changes, development of social indicators, technological indicators of energy consumption by economic sectors (industry, construction, agriculture, transport, households, trade, and service sector), changes in energy consumption and other indicators were used. The mathematical method used in the MESSAGE model is linear programming, which means that all technical and economic relations describing the energy system are expressed in terms of linear functions. The optimisation criterion or objective function of the software is the minimisation of the present value of the cumulated energy system costs in the analysing period.

The technologies are represented and aggregated in the model in such a way that the real technological energy supply structure of a country or region is represented in a reasonable way. The technologies are represented by a set of parameters in the model database, which is transformed into the model's system of equations. Such parameters are e.g. prices of primary energy curriers, investment, fixed and variable costs, of various technologies, energy conversion efficiencies, existing capacities, availability factors, emission factors and others. The application of the model based on MESSAGE tool results in a least-cost inter-temporal mix of primary energy, energy conversion and emission control technologies for each scenario. Scenarios may represent different hypotheses on important parameters, like the future fuel price, the market penetration of new technologies, political decision on development of one or another type of technology, etc., in order to take into account uncertainties in the future. By analysing the results, "what if?" statements on the future energy supply structure can be made, and different strategies of utilisation of various primary energy sources can be compared with respect to their emission reduction efficiencies and their impact on structure and economy of the energy system. The model was used for the development of medium-term strategies (until year 2025). It takes into account demand variations of various final energy forms during day, week and seasons, as well as different technological and political constrains of energy supply.

The mathematical model for the analysis of development of the Lithuanian energy system was created on the basis of the above-described MESSAGE modelling tool. The prepared model represents the whole energy system of the country, including all processes from the primary energy extraction or import to the supply of final energy. However, the main attention was paid to heat and electricity supply sectors, while other sectors were represented in a simplified way. Power and heat supply systems are very interdependent. Both systems are being connected by CHP plants. Therefore, the future development of these sectors cannot be analysed separately. The model represents specific conditions and peculiarities of Lithuanian energy system. Seeking to have consistent modelling of the energy sector development in this work, final electricity and heat demand were used as input information for the model.

The created model consists of 12 different modules, which are connected by technologies representing energy transmission or distribution (Fig. 1). The 10 modules represent heat supply systems in 10 counties of Lithuania together with modules "Electricity" and "Fuel". Module "Fuel" describes import, preparation, transportation and distribution of gas, oil, nuclear and other fuels. Variable cost of technologies representing the import of various fuels includes fuel prices in the world market and transportation cost till Lithuanian border.

Total installed capacity of the Lithuanian power plants is about 3700 MW. The installed capacity of the Lithuanian Thermal Power Plant (Lithuanian TPP) is 1800 MW. The new Combined Cycle Gas Turbine (CCGT) unit with installed capacity of 455 MW is under construction at this power plant site and should start operation in 2012. The installed capacity in existing CHP accounts for about 800 MW, Kruonis Hydro Pumped Storage Power Plant for 800 MW, hydro power plants for 120 MW, etc. Maximal domestic electricity demand in 2010 was about 2000 MW. Lithuania has a well-developed electricity network and strong connections with Latvia and Belarus. However, it has no direct connection with Poland or Sweden.

Lithuania also has a large heat supply sector (consisting of many district-heating systems) which is represented in the model. The