Journal of Naval Science and Engineering
2010, Vol. 6 , No.1, pp. 27-38

DETERMINING OPTIMUM ENERGY STRATEGIES FOR TURKEY BY MARKAL MODEL

Egemen SULUKAN
Department of Professional Sciences,
Turkish Naval Academy, Tuzla, Istanbul, Turkey
esulukan@dho.edu.tr

Mustafa SAĞLAM
Institute of Pure and Applied Sciences, Department of Mechanical Engineering,
Marmara University, Göztepe, Istanbul, Turkey
fulbars@yahoo.com

Tanay Sıdkı UYAR
Institute of Pure and Applied Sciences, Department of Mechanical Engineering,
Marmara University, Göztepe, Istanbul, Turkey
tanayuyar@marmara.edu.tr

Melih KIRLIDOĞ
Institute of Pure and Applied Sciences, Department of Computer Engineering,
Marmara University, Göztepe, Istanbul, Turkey
melihk@marmara.edu.tr

Abstract

In the TURKISH MARKAL model studies; energy carriers and resource technologies in use and might be available in the future, process-conversion technologies and demands are determined, their interactions and positions in MARKAL hierarchy is identified, a general and simplified network of energy from source to end-use which means a "Reference Energy System" is constructed. This network is identified with numerical data; energy balance is named in general terms as a Base scenario. An indigenous Energy Model is developed for Turkey, which is available to analyze alternative scenarios in order to see their possible effects on our energy system.

MARKAL MODELİ İLE TÜRKİYE İÇİN OPTİMUM ENERJİ STRATEJİLERİNİN BELİRLENMESİ

Özetçe

Türkiye Markal modeli kurulumu çalışmalarında, enerji taşıyıcıları ile halihazırda kullanılan ve gelecekte kullanıma girecek olan kaynak teknolojileri, işlem-çevrim teknolojileri ve talepler belirlenmiş, aralarındaki etkileşim ve pozisyonları MARKAL hiyerarşisinde tanımlanarak "Referans Enerji Sistemi" olarak adlandırılan, kaynaktan son kullanıma kadar genel ve basitleştirilmiş bir enerji ağı kurulmuştur. Bu ağ sayısal verilerle tanımlanarak genel hatları ile enerji dengesi bir "Temel Senaryo" olarak adlandırılmıştır. Alternatif senaryoların muhtemel etkilerinin analiz edilebileceği yerli bir Enerji Modeli Türkiye için geliştirilmiştir.

Keywords: Energy Model; Markal; Reference Energy System.
Anahtar Sözcükler: Enerji Modeli; Markal, Referans Enerji Sistemi.

1. INTRODUCTION

Turkey continuously faces energy problems. Changing energy balances; security concerns over growing oil and especially natural gas imports; limited domestic energy resources other than coal and renewables; projected demands for energy that will exceed supply capabilities within a few years. A decision-making support tool should be used in solving such a complicated problem and the energy equilibrium should be modeled between the demand side and resources of the country.

Increasing greenhouse effect and global warming, has been attracting public attention in the last 20 years, has been informed and scrutinized about 100 years. "World Climate Conference" firstly held in 1979 emphasized the climate change caused by the fossil fuels and CO2 concentrations. The first serious conference was "Rio Conference" held on 5-12th of June 1992.

"Rio Declaration" has been published and "United Nations Framework Convention on Climate Change" (UNFCCC) came into force on 21st March 1994, ratified by 184 countries from United Nations and European Union. The main objective of UNFCCC was identified as "stabilizing greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". Another important convention ratified after Rio Declaration was 1997 Kyoto Protocol. The Protocol was drawn up in Kyoto, Japan in 1997 to implement the United Nations Framework Convention for Climate Change. The countries that sign up to the treaty are legally bound to reduce worldwide emissions of six greenhouse gases (collectively) by an average of 5 % below their 1990 levels by the period 2008-2012. The protocol came fully into force on February 2005, the pact needed to be ratified by 55 countries accounting for at least 55 % of 1990 carbon dioxide emissions to ratification came when Russia signed up to the agreement on 5th November 2004. The protocol is officially the first global legally binding contract to reduce greenhouse gases.

The EU has already promised to reduce to pollution by 8 % from their 1990 levels. Lately, UNFCCC was held in Bali on 3-14 December 2007; which is evaluated as an important political breakthrough. Turkey, as a developing country, has to be aware of her responsibilities and establish convenient energy options for preparation and adaptation for this process.

2. AIM AND SIGNIFICANCE

Establishing a MARKAL energy-system model for Turkey and use it for an analysis of alternative technological options might pursue over the period 2005-2020 to address these options. The technology scenarios in this study developed for the evolution of Turkey' s energy system will aim not to predict the future, but just like done in the sample MARKAL models generated for other countries, to provide insights into the implications of energy options that could be preferred. [1-8]

Aiming to support the decision-making processes technically and to participate in energy resource management, the national reference energy system for year 2005 and decision support model of Turkey is set as the first step.

Based on our modeling results, we are able to draw several conclusions regarding energy-resource and technology choices that would enable Turkey to meet future demands for energy services while limiting energy import dependence and environmental impacts.

3. MATERIALS AND METHODOLOGY

MARKAL and its user interface ANSWER is used for this study. MARKAL is Energy Systems Optimization Program developed by an international programme Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA). [9-13]

MARKAL is a linear programming model. There are supply data of an energy system at one side and the demand at the other side. It categorizes the technological pattern for the energy system and optimize it minimizing the total discounted energy-system cost, satisfying the constraints that user specified. Turkish MARKAL model is established, primarily by expanding the technology options in the model to include an extensive variety of energy technologies.

For setting a MARKAL model, the user has to determine the costs and maximum available potential of primary energy resources as the supply, the cost and species of conversion technologies for which the primary energy sources can be changed into final energy alternatives and similar data belonging to end-use technologies that convert final energy carriers for satisfying the demands. The general structure and the components of an energy system are given in Figure 1. Values for all of these user-specified data should be composed at each 5-year time step during the analysis time horizon, which is planned as 2005-2025 in this work. Obtaining, developing and to input the parameter values from various official or non-governmental organizations' publications or statistics to the model has been the major part of the work [14-27].

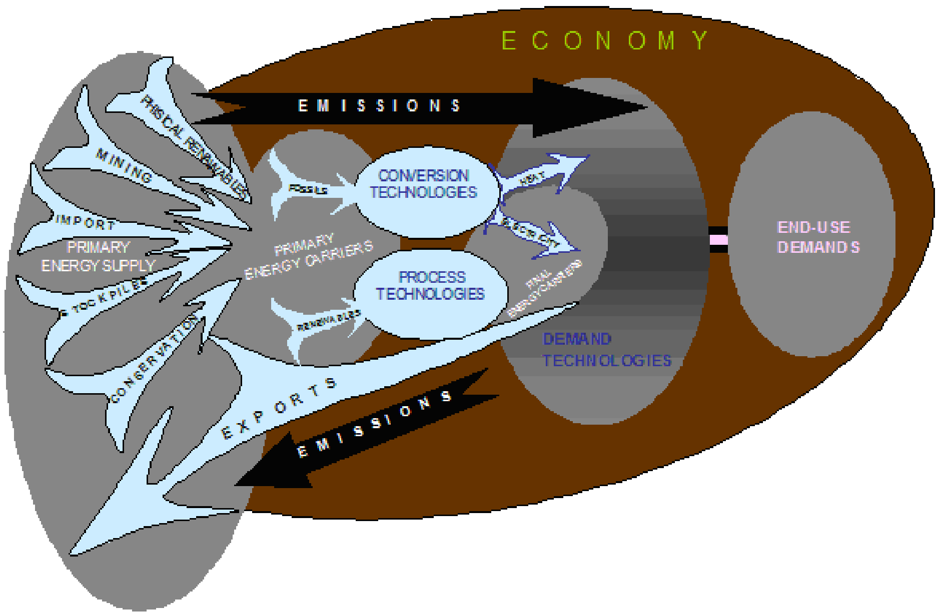

Fig.1. General Structure of an Energy System

Turkey is modeled as a single region. More detailed modeling will provide us more sensitive analyzing options; but geographic largeness would significantly increase the complexity of the model. Estimates of commercially mature performance and cost (investment and O&M) may be used for all technologies in the model, including for technologies that are not yet penetrated into today's energy markets. Some of various types of technologies will be involved in this category in model analysis period. Turkish MARKAL model is established flexible so as to add new source, process, conversion and demand technologies later.

Two main bodies are required to be determined by the user in the model; including the first one as conversion side of the primary energy alternatives into final energy carriers, the second one as demand segments satisfied by these final energy carriers. The profiles describe capital costs, operating costs, energy efficiencies, pollutant emissions, availability factors, constraints on market penetration rates, and other characteristics. Using these profiles and the user-specified primary energy costs and availabilities, MARKAL finds the combination of energy resources and conversion technologies that meet the specified energy service demands while minimizing the energy system cost for the full period of the analysis. These user-defined bodies identify all costs, emission factors and constraints in general terms. MARKAL optimizes the cost-effective option of energy supply and alternative technologies by minimizing the total energy system cost, as the main objective of the model structure.

End-use technologies for converting final energy into energy services in each of five main demand sectors are defined as **industrial, commercial, residential, agricultural** and **transport**. In each of these sectors, technology options include the current ones and the candidates during the analysis period of the study.

4. Objective Function of MARKAL

The objective function energy model MARKAL, formed as the sum of actual costs depending on time as given below, in equation (1):

$$NPV = \sum_{r=1}^{R} \sum_{t=1}^{t=NPER} (1+d)^{NYRS \bullet (1-t)} \bullet ANNCOST(r,t) \bullet \left(1+(1+d)^{-1}+(1+d)^{-2}+\cdots+(1+d)^{1-NYRS}\right) \quad (1)$$

- NPV: Net present cost of the system as defined in the region (MARKAL objective function),
- ANNCOST (r, t): r region, the annual cost for period t,
- NPER: Number of periods in the planning process, (determined as 4)

- NYRS: Number of years in each period t, r is the number of regions. T value at each period of 5 years, r-value determined to be 1, Turkey defined as one region.
-

ANNCOST (r, t), as expressed in the total annual cost of all the **k** technologies, all **d** demand in the identified region, all **p** pollutants, all imported fuel **f** and annual investment of fixed and variable costs of technologies, fuel delivery costs, extracting the energy carriers including import costs, annual operating costs with the emission taxes applied. The cost of exported energy carriers is subtracted from this value.

Mathematically, ANNCOST (r, t) can be expressed as follows in equation (2);

$$\begin{aligned} ANNCOST(r,t) = \Sigma_k \{ & Annualized\_Invcost(r,t,k) * INV(r,t,k) \\ & + Fixom(r,t,k) * CAP(r,t,k) \\ & + Varom(r,t,k) * \Sigma_{s,s} ACT(r,t,k,s) \\ & + \Sigma_c [Delivcost(r,t,k,c) * Input(r,t,k,c) * \Sigma_s ACT(r,t,k,s)] \} \\ + \Sigma_{c,s} \{ & Miningcost(r,t,c,l) * Mining(r,t,c,t) \\ & + Tradecost(r,t,c) * TRADE(r,t,c,s,i/e) \\ & + Importprice(r,t,c,l) * Import(r,t,c,l) \\ & - Exportprice(r,t,c,l) * Export(r,t,c,l) \} \\ + \Sigma_c & \{Tax(r,t,p) * ENV(r,t,p)\} \\ + \Sigma_d & \{DemandLoss(r,t,d)\} \end{aligned} \quad (2)$$

Meaning of the variables in the equation is given briefly below:

· Annualized_Invcost : Annual investments for technologies,
· Fixom : Fixed operation and maintenance costs,
· Varom : Variable operation and maintenance costs,
· Delivcost : Distribution costs,
· Miningcost : Mining extraction costs,
· Tradecost : Interregional trade costs,
· Importprice : Import costs,
· Exportprice : Export costs,

· Tax : Taxes,
· DemandLoss : Reduction in demand.

5. BASE SCENARIO RESULTS

Reference Energy System, which can also be named as Baseline Scenario or Reference Case, has been run and **optimal solution** is obtained. Analysis of the changes in supply and demand side, economic values, and the amount of greenhouse gas emissions related to the results produced on this basis.

Base Scenario serves as a reference which other scenarios would be analyzed and compared with. In this respect, determination of the country' s Base Scenario depends on the status of the calibration year, which is required to be equipped with optimal level of data. In analysis period, between the years 2005-2025, 3% of overall consumption and demand assumed an increase at a rate of 3.3%. Gross Domestic National Product (Gross Domestic Product-GDP) was taken as 481.5 billion dollars for the year 2005.

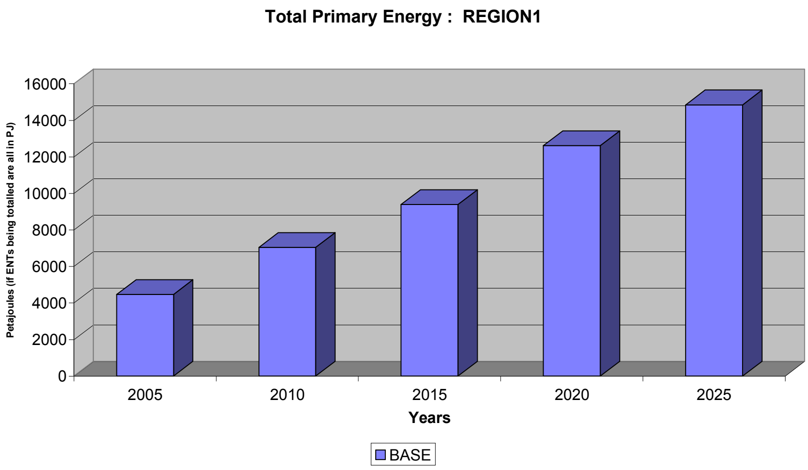

Fig.2. Total Primary Energy

Total primary energy resources going up from 4472 PJ to the level of 14849 PJ in Turkish Energy System, so the total energy supply would increase at a rate of 232% in period of 2005-2025 as illustrated in Figure 2 above.

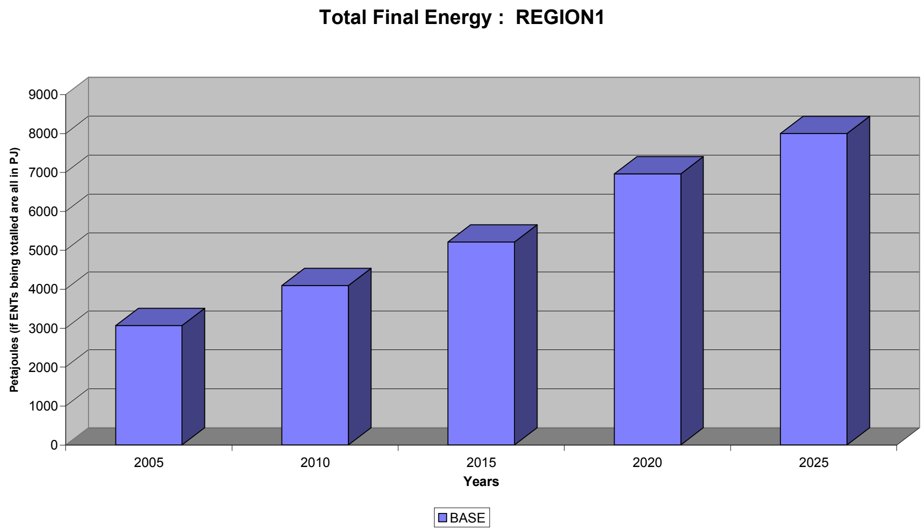

Fig.3. Total Final Energy

Similarly, looking at the consumption level results of all sectors in Figure 3, 3067 PJ of final energy in 2005 goes up to 8000 PJ by the year 2025 and analysis period consumption increases at a rate of 160%. However, due to various losses in 2005, 2026 PJ of useful energy consumed, while 5141 PJ in 2025. The fact that serious differences observed between the amount of energy supply to meet demand because of both transmission and distribution losses occurred and present technical efficiencies of technologies used by the system. Energy savings can be achieved by new investments in the electricity transmission system with energy efficiency measurements in the current technologies in each sector which a number of power plants to generate the equivalent amount.

6. WAY AHEAD

For further and more detailed Turkish MARKAL studies, additional alternative scenarios may be applied and run on this Base Scenario in order to analyze the possible effects on the energy system as follows:

- Options for efficiency improvement of thermal power plant expansion plans or technologies used in end use sectors, which effects the energy generation, consumption and also greenhouse gases emission levels,
- Options of candidate power plant analyses to obtain the annual investment levels and electricity load percentages,
- Analyzing the possible effects of increasing the alternative potentials of hydraulic, wind, solar and wave energy resources to national energy system,
- Utilizing the cogeneration in all sectors, especially power generation and industrial sub-sectors,
- Analyzing the candidate nuclear power plants' effects in the energy system,
- Analyzing the domestic renewable energy resources' utilization on possible higher levels,
- Analyzing the carbon dioxide mitigation scenarios to estimate a road map of environmental aspects,
- Analyzing the effects of possible changes in natural gas import prices.

7. CONCLUSION

Energy carriers and resource technologies in use and assumed to be available in the future, process-conversion technologies and demands are determined, their interactions and positions in MARKAL hierarchy are identified, a general network of energy from source to end-use which means a "Reference Energy System" is constructed in Turkish MARKAL model. This network is identified with numerical data; energy balance is constructed and by running this scenario, "optimal solution" is obtained.

In the long-term, in acquiring our economy and giving the priority to national interests with the target of reducing dependence on imported fossil energy carriers from foreign countries. Firstly, domestic renewable sources should be promoted besides the each issue given above as alternative scenarios, which the important areas for improving the whole system parallel to the country' s national energy strategies. Energy efficiency measurements should be applied in all energy technologies for all main sectors identified in the system, rehabilitation of energy transmission lines and distribution equipment and increasing cogeneration applications in terms of minimizing both demands and system cost.

REFERENCES

[1] Schulz, T.; Barreto, L.; S.Kypreos; Stucki, S.; "Assessing wood-based synthetic natural gas technologies using the SWISS-MARKAL model", Energy Volume 32, Issue 10, (October 2007), 1948-1959.

[2] Endo, E.; "Market penetration analysis of fuel cell vehicles in Japan by using the energy system model MARKAL", International Journal of Hydrogen Energy Volume 32, Issues 10-11, , EHEC2005, (July-August 2007) 1347-1354.

[3] Nguyen, Q.; "Impacts of wind power generation and CO2 emission constraints on the future choice of fuels and technologies in the power sector of Vietnam", Energy Policy Volume 35, Issue 4, (April 2007) 2305-2312.

[4] Changhong, C.; Bingyan, W.; Qingyan, F.; Green, C. ; Streets, D.G.: "Reductions in emissions of local air pollutants and co-benefits of Chinese energy policy: a Shanghai case study", Energy Policy 34, (2006) 754–762.

[5] Agorisa, D.; Tigasa, K. ; Giannakidisa, G.; Siakkisa, S.; Vassosb, N.; Vassilakosc,V.; Kiliasa, M.; Damassiotisa, V.: "An analysis of the Greek energy system in view of the Kyoto commitments", Energy Policy 32, (2004) 2019–2033.

[6] Salvia, M.; Pietrapertosa , F.; Cosmi, C. ; Cuomo, V. ; Macchiato, M.: "Approaching the Kyoto targets: a case study for Basilicata region (Italy)", Renewable and Sustainable Energy Reviews 8, (2004) 73–90.

[7] Barreto, L. ; Kypreos, S.: "Emissions trading and technology deployment in an energy-systems ''bottom-up'' model with technology learning", European Journal of Operational Research 158, (2004) 243–261.

[8] Mathura, J.; Bansalb,N.K.; Wagner ,H.J.: "Investigation of greenhouse gas reduction potential and change in technological selection in Indian power sector", Energy Policy 31, (2003) 1235–1244.

[9] Noble-Soft Systems Pty. Ltd.: "AnswerV5 User Manual", http://www.etsap.org/Tools/ANSWER.htm (2009).

[10] Brooke, A.; Kendrick, D.; Meeraus, A.; Raman, R.; "The General Algebraic Modeling System (GAMS) Use' sr Guide", http://www.gams.com/docs/document.htm (1998).
[11] Loulou, R.; Goldstein, G.; Noble, K.; "Standart MARKAL User Manual", Volume-I, http://www.etsap.org/documentation.asp (2009).
[12] Loulou, R.; Goldstein, G.; Noble, K.; "MARKAL MACRO User Manual", Volume-II, http://www.etsap.org/documentation.asp (2009).
[13] Loulou, R.; Goldstein, G.; Noble, K.; "MARKAL (SAGE) User Manual", Volume-III, http://www.etsap.org/documentation.asp (2009).
[14] World Energy Council (WEC) Statistics, http://www.worldenergy.org/publications/115.asp (2007).
[15] The Chamber of Electrical Engineers (EMO) Statistics, http://www.emo.org.tr/genel/bizden_listele.php?bizden_kod=41&sube=0 (2007).
[16] Turkish Statistical Institute (TURKSTAT) Statistics, http://www.tuik.gov.tr/Start.do;jsessionid=yBQCHKKFjLVRqCzmTcMgKrdphFCvgR1jJJpVvrLFVsyxs2t6R81v!-761374785 (2007).
[17] The Presidency of the Republic of Turkey, The State Supervisory Council (DDK) Statistics, http://www.cankaya.gov.tr/tr_html/DDK/DDK1.HTML (2007).
[18] State Planning Organization (SPO) Statistics, http://www.cankaya.gov.tr/tr_html/DDK/DDK1.HTML (2007).
[19] Ministry of Energy and Natural Resources Statistics, http://www.enerji.gov.tr/istatistik.asp (2007).
[20] Electric Survey Administration (EİEİ) Statistics, http://www.eie.gov.tr/ (2007).
[21] International Energy Agency (IEA) Statistics, http://www.iea.org/Textbase/stats/index.asp (2007).
[22] Electricity Generation Incorporated Company (EÜAŞ) Statistics, http://www.euas.gov.tr/ (2007).
[23] Turkish Electricity Transmission Co. (TEİAŞ) Statistics, http://www.teias.gov.tr/ (2007).
[24] Turkish Petroleum Corporation (TPAO) Statistics, http://www.tpao.gov.tr/v1.4/ (2007).
[25] Turkish Industrialists' and Businessmen's Association (TÜSİAD) Reports, http://www.tusiad.org/tusiad_cms.nsf/mainpage?OpenForm (2007).
[26] Union of Chambers of Turkish Engineers and Architects (UCTEA) Energy Report, http://www.tmmob.org.tr/modules.php?op=modload&name=News&file=article&sid=1639 (2006).
[27] International Energy Agency; "World Energy Outlook 2005", http://www.worldenergyoutlook.org/2005.asp (2005).