A REVIEW ON THE STATE OF THE ENERGY SECTOR OF TURKEY FROM THE PERSPECTIVE OF OPERATIONAL RESEARCH
- AN INVITATION BY OR -

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Abstract

This paper surveys the the-of-the-art of the *energy sector* in Turkey. It explains the "portfolio" of energy sources and its consumptions. A special emphasis is paid to the present research challenges where *Operational Research* with it quantitative methods and its experience in interdisciplinary collaboration has the potential to become a *key technology*. The financial sector is one very important example in this context. This survey is written firstly about and for the nation of *Turkey* with its 70 million citizens – a nation between continents and cultures, between being developed and, regionally, still in the state a developing country. In this respect, our paper means an *invitation* to future research in Turkey and worldwide, for joint academical efforts and to foster development, both wealth of the people and a protection of the environment in the world. In this sense, our contribution and invitation mean a special address sent out by us at the days of the *Copenhagen Climate Summit 2009.*

Keywords: Energy, Electricity, Operational Research, Development, Environment, Financial Mathematics, Optimization, Societal Complexity.

1. Introduction

The models and methods offered by Operational Research, understood a multi-disciplinary scientific approach to support better decisions through the application of advanced analytical tools, have been broadly applied in the energy sector since the 1950s as it is well documented in the literature. Those models and methods have shown a very effective role to providing successful decision support in several problems arising in the energy sector. Decisions to be made range from long-term strategic planning, such as power generation capacity expansion planning, to short-term operational issues, such as optimizing unit commitment. Distinct players such as utilities, regulatory bodies and governments, marketers and end-users, consultants and researchers, are involved. Moreover, different perspectives to appraise the merit of distinct courses of action are generally at stake in the framework of global sustainability, such as technical issues, financial goals, socio-economic objectives, and environmental concerns [2]. Modeling and predicting electricity distribution play a vital role in developed and developing countries for policy makers and related organizations. Underestimation of the consumption would lead to potential outages that are devastating to life and economy, whereas overestimation would lead to unnecessary idle capacity that means wasted financial resources. Therefore, it would be better to model electricity energy consumption with good accuracy in order to avoid costly mistakes. Also, it is better to use models that can handle nonlinearities among variables as the expected nature of the energy consumption data is nonlinear [5].

Table 1. Primary energy consumption, GDP, population, electricity production and consumption in Turkey [5]

	Years							Average annual percent change (%) 1990-2002
	1990	1995	1998	1999	2000	2001	2002	
Population (millions)	56.20	61.55	64.79	65.82	67.46	68.61	69.20	1.92
GDP (1995 billion US$)	144.57	169.32	200.85	191.39	205.47	190.29	197.10	3.03
Total Primary Energy Consumption	53.00	61.86	72.23	70.98	77.49	72.46	74.55	3.58
Net Electricity Consumption (TWh)	46.82	67.39	87.70	91.20	98.30	97.07	103.30	10.05
Net Electricity Production (TWh)	54.23	81.86	105.50	110.70	118.70	116.25	122.11	10.43
Gross Electricity Production (TWh)	57.50	86.20	111.00	116.40	124.90	122.70	129.40	10.42
Total Primary Energy Consumption/GDP (ktoe/1995 thousand US$)	366.60	365.34	359.62	370.87	377.14	380.79	378.23	0.26
Total Primary Energy Consumption/Population (ktoe/per capita)	943.06	1005.04	1114.83	1078.40	1148.68	1056.11	1077.31	1.18
Net Electricity Consumption/GDP (kWh/1995 thousand US$)	323.86	398.00	436.64	476.51	478.42	510.12	524.10	5.21
Net Electricity Consumption/Population (kWh/per capita)	833.10	1094.88	1353.60	1385.60	1457.16	1414.81	1492.77	6.83
Gross Electricity Production of which: renewable (TWh)	23.23	35.85	42.57	34.93	31.15	24.30	33.97	3.85
Gross Electricity Production Renewable/Gross Electricity Production (%)	40.40	41.60	38.30	30.00	24.90	19.80	26.20	-2.93

Energy is essential for economic and social development and improved quality of life in Turkey, as in other countries. Much of the world's energy, however, is currently produced and consumed in ways that cannot be sustained if technology were to remain constant and if overall quantities were to increase substantially. The need to control atmospheric emissions of greenhouse and other gases and substances will increasingly need to be focused on efficiency in energy production, transmission, distribution and consumption in the country. On the other hand, electricity supply infrastructure in Turkey, as in many developing countries, is being rapidly expanded, as policymakers and investors around the world increasingly recognize electricity's pivotal role in improving living standards and sustaining economic growth. On the contrary, in the coming decades, global environmental issues could significantly affect patterns of energy use around the world, as in Turkey. Any future efforts to limit carbon emissions are likely to alter the composition of the total energy related carbon emissions by energy source in the country [3].

With a young and growing population, low per capita electricity consumption, rapid urbanization and—until recently—strong economic growth, Turkey for nearly two decades has been one of the fastest growing power markets in the world. Prior to Turkey's recent severe economic difficulties, Turkey's electricity consumption had been growing much faster than its production [5].

The relationship among the primary energy consumption, Gross Domestic Product (GDP), population, electricity production and consumption in Turkey has been given in Table 1. As shown in the Table, during the last 10 years, while population increased 1.92%, GDP and Total Primary Energy Consumption increased 3.03 and 3.38, respectively. Net Electricity Consumption, Net Electricity Production and Gross Electricity Production increased about 10% during the same period [5].

Table 2. Turkey's energy production values in the years 1990, 1995 and 2000 [3]

Energy carrier	toe [a]	1990		1995		2000	
		PJ	%	PJ	%	PJ	%
Hard coal	0.61	69.99	6.47	57.32	4.81	57.60	4.84
Lignite	0.21	389.80	36.03	463.11	38.89	534.18	44.89
Asphaltite	0.43	4.96	0.46	1.20	0.10	0.40	0.03
Petroleum	1.05	163.14	15.08	154.32	12.96	120.65	10.14
Natural gas	0.91	8.06	0.75	6.92	0.58	24.31	2.04
Wood	0.30	224.09	20.71	230.41	19.35	212.40	17.85
Biomass	0.23	77.20	7.13	65.04	5.46	57.50	4.83
Hydropower	0.086	104.16	9.63	159.88	13.43	138.76	9.33
Geothermal	0.86	39.29	3.63	47.09	3.95	64.81	5.22
Solar	0.86	1.01	0.09	5.14	0.43	9.42	0.79
Wind	0.086	0.29	0.03	0.31	0.03	0.39	0.03
Total		1082.00	100.00	1190.74	100.00	1220.42	100.00

[a] Tons of oil equivalent

Turkish energy consumption has risen dramatically over the past 20 years due to the combined demands of industrialization and urbanization. Table 2 shows the structure of total energy production in Turkey in the years of 1990, 1995 and 2000, while total energy (consumption) input during the same period is given in Table 3 [3].

Table 3. Turkey's total energy consumption in the years 1990, 1995 and 2000 [3]

Energy carrier	toe [a]	1990		1995		2000	
		PJ	%	PJ	%	PJ	%
Hard coal	0.61	208.85	9.34	217.96	8.05	388.82	11.02
Lignite	0.21	428.81	19.17	460.01	16.99	534.19	15.14
Asphaltite	0.43	2.50	0.11	1.19	0.04	0.40	0.01
Petroleum	1.05	996.30	44.55	1225.32	45.25	1477.60	41.89
Natural gas	0.91	130.01	5.81	263.87	9.74	571.30	16.20
Wood	0.30	224.09	10.02	229.13	8.46	212.40	6.02
Biomass	0.23	77.20	3.45	68.01	2.51	57.50	1.63
Hydropower	0.086	104.16	4.66	159.88	5.90	138.76	3.93
Geothermal	0.86	39.29	1.76	44.76	1.65	64.81	1.84
Solar	0.86	1.01	0.05	4.64	0.17	9.42	0.27
Wind	0.086	0.29	0.01	0.28	0.01	0.39	0.01
Coke	0.70	1.20	0.05	2.10	0.08	21.13	0.60
Petrocoke	0.77	22.60	1.01	30.80	1.14	50.85	1.44
Total		2236.32	100.00	2707.94	100.00	3527.33	100.00

[a] Tons of oil equivalent

The relationship between electricity consumption and Gross National Product (GNP) in Turkey has been erratic in the past, as Fig. 1 indicates. Net Electricity Consumption (NEC) increased steadily during the period of 1975–2000. There is a slight decrease between 2000 and 2001. On the other hand, GNP decreased three times (1979, 1993 and 2001) due to economic crisis. Most of the studies on the relationship between the energy consumption and economic indicators (such as GNP, import, export) were for the long time period. It could be argued that NEC of Turkey has not been sensitive to economic crisis since the effect of the economic crisis disappears in the period of one or two years [5].

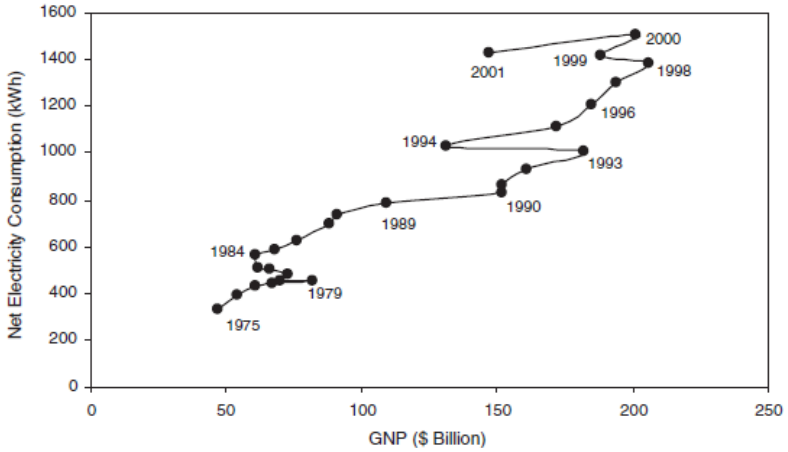

Figure 1. The relationship between electricity consumption and GNP in Turkey [5]

2. A Brief Overview of Turkey's Energy Sources Used for Generating Electric Power

In Turkey, electricity is produced by thermal power plants (TPPs), geothermal energy, wind energy, and hydropower plants. Thermal resources meet approximately 60% of Turkey's total installed capacity for electric power generation, while 75% of total electricity is generated from TPPs. Of the total thermal generation, natural gas accounts for 49.2%, followed by coal for 40.65, and 9.9% for liquid fuel. When the fuels used in cogeneration plants are examined, it is seen that natural gas, liquefied petroleum gas (LPG), naphtha, diesel, coal and fuel oil are present. Among fuel types used by auto-producers as of March 2000, natural gas accounted for about 64%, followed by fuel oil with 22% and the remainder with 14%. Natural gas is preferred as a fuel in regions where it is available because it is efficient, cheap, and clean. In this regard, the following subsection will briefly review some of the above mentioned energy sources in terms of their potential and utilization [5].

Coal

Turkey accounts for almost 90% of the coal consumed in the Middle East. In 1999, Turkish coal consumption reached 84 Mt, most of it low calorific value, locally produced lignite. As a result of the planning studies of the MENR, production and consumption of coal (both HC and LG) is expected to increase after 2002, primarily to fuel additional coal-fired generating capacity. Hard coal and lignite consumption is projected to increase by 139 Mt, from 8 and 46 Mt in 1990 to 147 and 185 Mt in 2020, respectively. Two projects currently in the construction phase include a 1210 MW hard coal-fired plant being built on the southern coast of Turkey near Iskenderun, to be fueled by imported coal, and a 1440 MW lignite-fired plant (Afsin-Elbistan B plant) being built in the Afsin-Elbistan region in southern Turkey. When completed between 2003 and 2005, the two plants could add more than 10 Mt to Turkey's annual coal consumption. In 1999, Turkey's installed electricity capacity reached 26, 117 MW. Sixty percent of the total installed capacity was obtained from thermal resources, while the remainder came from hydro and geothermal resources. Until 1985, lignite-fired power plants were used, and had the largest share in the total thermal capacity. Since then, the share of lignite plants has gradually decreased. Recently, natural gas-fired generation has been gaining great importance. In 1999, the share of coal-fired plants in the total installed capacity was 26%, followed by natural gas at 24%, and oil at 6%. The coal share of energy consumed in Turkey for electricity generation is projected to be 30 and 27% in 2010 and 2020, respectively, with imported coal shares of 6 and 10% over the period, respectively.

Natural gas

Turkey is located at the strategic crossroad between the abundant oil and natural gas reserves of the Middle and Near East and primary consumers in Europe and America. Turkey consumes 30 Mt of crude annually, of which 24.6 Mt is imported. It is estimated that Turkey's total oil imports will reach approximately 42,000 ktoe by 2010. It was reported that natural gas import of Turkey reached 14,344 million cubic meters (Mcm) in 2000. Turkey's natural gas demand and supplies may be summarized as follows:

(a) In Turkey, the first auto-producer natural gas-fired plant was installed in 1992. Following this application, many other cogeneration facilities using natural gas were established in the country. The use of natural gas in cogeneration plants has risen dramatically.

(b) Turkey continues to expand the use of natural gas. Currently, five municipalities, six industrial zones, 200 industrial plants, two fertilizer production facilities, and seven power plants utilize natural gas as an energy source.

(c) Current Turkish gas production of 0.85 billion cubic meters (Bcm) at 14 fields meets around 7% of domestic gas consumption requirements.

(d) In 2001, power generation had the biggest portion with 68.6%, followed by residential with 20.85%, industry with 9.80%, and fertilizer sectors with 0.75%.

(e) In Turkey, as in Europe and the United States, energy policies have had an important effect on the availability of natural gas and its development as a fuel for electricity generation. In other words, the driving force behind the growth in Turkey is the increased consumption of natural gas for electric power generation.

(f) Turkish natural gas demand is projected to increase extremely rapidly in the coming years, with the prime consumers expected to be natural gas-fired electric power plants and industrial users.

LPG

LPG (or LP gas) stands for liquefied petroleum gas. Since the beginning of the 1960s, LPG has been used as an alternative to city gas and kerosene in Turkey, while the first LPG use in cogeneration plants was in 1996 in Denizli, Turkey. The consumption of petroleum products in 2000 was 34 Mt, of which about 13.2% was accounted for by LPG [4]. The share of oil in energy demand will drop from 52% in 1995 to about 36% in 2020, but it will remain the main energy source, while that of natural gas will jump from 11.3% in 1995 to 37% in 2010.

Utilization of LPG as an energy sources in Turkey may be summarized below [1].

(a) Since the beginning of the 1960s, LPG has been used as an alternative to city gas and kerosene in Turkey. The recent expansion of the LPG industry in Turkey has demonstrated the long-term potential for the regional LPG markets.

(b) In 2000, the share of LPG and natural gas in the gas fuel market was 30 and 70%, respectively. It is also estimated that this ratio will change in favor of natural gas with the handling of new natural gas projects.

(c) In Turkey, the first LPG use in cogeneration took place in 1996 in the city of Denizli. Following this application, many other cogeneration facilities using LPG were established in the country. The use of LPG in cogeneration plants is, however, under 1% today.

(d) In Turkey, LPG is marketed in three different segments, namely LPG cylinder, bulk storage (storage container), and auto-gas. Among these, auto-gas (or automotive LPG) is the branch that has grown the most of the three segments in recent years.

(e) In 2000, the consumption of petroleum products was 30 Mt, of which nearly 87% was accounted for by liquid fuel, while LPG constituted the rest.

Oil

The Turkish historian Evliya Celebi first mentioned the existence of oil in Turkey in the 18th century. Exploration began in the second half of the 19th century, when both domestic and foreign companies carried out exploration in Thrace. The first productive well, operated by the European Petroleum Company, was located in the Hora Deresi region (Thrace). According to the theoretical calculations, 954 Mt of oil reserves exist in Turkey's already known areas. Of this, 156 Mt is extractable oil. At the end of 2002, 117 Mt of oil was extracted and the remaining recoverable reserve amounts to 39 Mt. With the current production level and no additional reserve discovery, the production capacity will still be available for some 16 years. In 2002, Turkey's crude oil production was 2.4 Mt, which corresponds to 8% of the total oil demand. Besides this, production has declined since the early 1990s. Oil is mainly produced in the southeast, with a small amount from the northwest of the country. In the coming years, oil production is also expected to decrease due to the natural depletion of the fields. During 2002, a total of nine companies, of which two and seven are domestic and foreign, have been in production activities as a single company or joint producing companies. Between 1990 and 2002, oil supply increased at an average growth rate of 2.2% annually. Oil consumption reached from 22.7 Mt in 1990 to 29.6 Mt in 2002. Final oil consumption of 24.2 Mt in 2002 corresponds to 42.7% of Turkey's total final energy consumption. In 2002, 8.3% of the total electrical energy generation came from oil fired plants.

Hydro

The gross hydro potential, which is a function of topography and hydrogeology, is estimated to be 432,986 GW h annually for Turkey. The hydroelectric energy production of 23,148 GW h in 1990 reached 33,684 GW h in 2002 with an annual average growth rate of 3.2%. As of the end of 2002, Turkey's economically feasible hydropower potential amounts to about 126 billion kW h, of which 34% has been exploited. It is projected that the increase in the hydro production will continue in the coming years.

Geothermal

The estimated geothermal electrical power and direct use (heat) potentials are reported to be 4000–4500 MWc and 31,500 MWt, respectively. In addition, visible potential for electricity generation is 764.81 MWc, while that for heat is 3173 MWt according to the data given by the MTA. The potential of geothermal development in Turkey is generally considered large in terms of moderate and low temperature resources. Therefore, the resources are mostly suitable for direct use applications. The Denizli Kizildere geothermal power plant, which is at present the only operating geothermal power plant in Turkey, produced an electrical energy of 105 GW h in 2002.

Wind

Progress in wind energy technology in recent years has drawn private-sector attention to this energy resource. As a consequence, numerous companies have submitted their applications to the MENR for the construction of new wind power plants. Turkey's wind energy market may be summarized as follows:

(a) Aegean, Marmara, and East-Mediterranean regions of Turkey are generally seen as promising higher wind power potential compared to other parts of Turkey.

(b) Turkey's total theoretically available potential for wind power is estimated to be around 88,000 MW.

(c) Turkey's total economically feasible potential for wind power is estimated at some 10,000 MW.

3. Conclusion

The electricity consumption rate in the past was showed that it will continue to increase in the future due to the increase of the population, the change of social and economic development and urbanization. Therefore, the installation of the electricity power plant will be very important for the near future [5].

This paper is a sort of a survey that is opening the possibilities for applications of OR in the energy sector for Turkey. It would help if there are more examples of possibilities for OR studies. This could be gleaned from the latest business news in Turkey, e.g., expected exponential growth of demand which exceeds current plans; huge capital outlays for power generating and transmission facilities; problems with maintenance costs of old plants; decision to mothball certain facilities; a privatization program going on, etc. In each of these cases, the OR tool that could possibly help could be suggested.

Concerning the offers which modern Operations Research makes to the energy and electricity sectors, there are

- *mathematical programming,*
- *stochastic programming,*
- *multi-criteria decision making,*
- *control and system theory,*
- *stochastic optimal control,*
- *martingale method,*
- *applied probability,* by the use of
- *stochastic calculus* and
- *financial mathematics,* especially,
- *portfolio optimization,*
- *graphs and networks,*
- *combinatorial optimization,*
- *OR in environmental protection,* etc..

The diversity of problems, scopes of analysis, actors and objectives has risen with the trends for deregulation and the end of the vertical integration in several industries in the energy sector, namely as far as electricity is concerned. Therefore, a broad set of questions emerges underlying important decision-making issues. Among the challenging questions there are:

- *How to guarantee secure supplies?*
- *How to promote energy efficiency in industry, services and households?*
- *How to deal with market power?*
- *What are the links between energy use and industrial production patterns?*
- *How to value the benefits of renewable?*
- *How to integrate optimally dispersed production into the grid?*
- *What are the best options for greenhouse gas mitigation?*
- *How could the regionalization (or* decomposition [6]*) of the energy markets be refined for an improved analysis, decision making and development?*

In sum, *how to deal with the political, economic, planning, environmental and social aspects of energy production and consumption?*

These questions open new and challenging domains for the application of Operational Research models and methods, which can provide quantitative insights into complex problems and uncover the best courses of action. Also, new and multifaceted problems arising in the energy sector require novel approaches and methodological developments, which are incorporated into the Operational Research toolbox and can be creatively applied in other fields [2].

Integer linear programming models can be used to determine which combination of the existing power plants must be operated to yield the lowest costs. The model constraints could consider forecasted demand, plant capacities, spinning reserves, transmission requirements, fuel

consumption for each plant, payment scheme, set up time per plant and preventive maintenance.

We regard our paper as an invitation to the international community of researchers and practitioners to make use of the rich methodologies and toolboxes of modern OR. Let us mention the examples of the sectors of *development and developing countries* (cf. [7, 8]), of *optimization* and *financial mathematics* (see [9]) to offer a further flavour of some of OR's societal concerns, its methods and the wealth of its experience, sense of responsibity and academical excellence to serve mankind in years of great challenges, but also of great chances.

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