Turkish Journal of Electrical Engineering & Computer Sciences

http://journals.tubitak.gov.tr/elektrik/

Research Article

Turk J Elec Eng & Comp Sci
(2018) 26: 2726 – 2736
© TÜBİTAK
doi:10.3906/elk-1802-185

An analysis of centennial wind power targets of Turkey

Egemen SULUKAN*
Department of Mechanical Engineering, National Defense University, Turkish Naval Academy, İstanbul, Turkey

Received: 04.03.2018 • **Accepted/Published Online:** 26.07.2018 • **Final Version:** 28.09.2018

Abstract: Wind power has become one of the cost-effective options for improving the energy mix, while the wind farm installations reach higher shares by new capacity additions in Turkey, similar to many other countries, in order to support the sustainable development targets. Various methodologies are implemented and applied for planning and optimizing energy systems of countries, taking into consideration the energy, economy, and ecology aspects as a whole. The objective of this paper is to demonstrate the implications of "2023 energy targets" policy in terms of wind power. A futuristic scenario was tailored and applied to a comprehensive energy model for the energy system of Turkey. The official wind energy vision and goal of Turkey were analyzed by applying a scenario based on 20,000 MW wind power capacity installation by the year 2023. The results indicated that, if applied, this action will increase the share of wind power utilization to the level of 16% in the total renewables while the installed wind capacity will reach 18%. Finally, the total cost of this strategic target which doubles the installed capacity and electricity generation by wind power, including the respective investment costs and subsidizations results, were calculated as $24.78 billion on the analysis horizon.

Key words: Wind power, renewable energy, energy modeling, MARKAL, Turkey

1. Introduction

Turkey has rising growth goals while the energy mix highly depends on hydropower, coal, oil, and natural gas for electricity generation. However, other renewables started to appear in the energy mix during the last decade after Turkey had already officially declared to evaluate the renewable potential for wind, geothermal, and solar power.

An emerging market and a country that has recently reached the developed country status, Turkey is still experiencing industrial progress while looking for options to meet the increasing energy demand with limited domestic resources and other alternatives. Different strategic planning approaches have been used in different countries to optimize the energy, economy, and ecology aspects simultaneously within the same framework. The respective efforts and perspectives were shaped and initially appeared in "Electricity, Energy Market and Supply Security Strategy Paper" published under the coordination of Undersecretariat of State Planning Organization of Turkey in 2009. It defines the necessary steps for ensuring supply security and announces the targets for resources plan for electricity supply in the long term. Meanwhile, it has officially been declared as a target to increase the share of renewables in electricity generation by the installed capacities of 600 MW in solar power plants, 600 MW in geothermal, 20,000 MW in wind, and 36,000 MW in hydroelectric-based power plants by the year 2023 in order to transform to a domestic resource-supplied country profile. This policy initiation is expressed in the strategy paper as follows: "Our primary target is to ensure that the share of renewable resources

*Correspondence: esulukan@dho.edu.tr

in electricity generation is increased up to at least 30% by 2023." In summary, 20 GW installed wind power capacity target has been designated in this strategy paper to maximize the renewable energy utilization by the year 2023, the centennial of the Republic [1].

With all these issues in mind, the main objective of this paper was to analyze the effects of 20 GW wind power integration in Turkey and to indicate the respective implications by applying an alternative energy scenario (WIND 2025) to Turkish energy-economy-ecology MARKAL (MARket ALlocation) model, based on the year 2005 and extended to 2025 [2].

MARKAL is an ongoing multinational cooperation project within the framework of Energy Technology System Analysis (ETSAP) Programme by the International Energy Agency (IEA) that operates under the Economic Development and Cooperation Organization (OECD). MARKAL model generator is currently used by 77 institutions in countries around the world in relevant analyses as a decision-making tool with comprehensive energy-economy-ecology-engineering (4E) capabilities [3].

A number of energy modeling studies have been conducted in many countries and MARKAL-based energy models were developed at different levels focusing on different objectives. Salvia et al. used MARKAL model generator to form an energy model to analyze the activities of the waste management system in the Basilicata region of Italy [4]. Chen et al. developed an integrated MARKAL-MACRO model to foresee China's future energy development and carbon emission through the year 2050 and suggested that it would be more realistic for China to contribute to the international carbon mitigation mechanisms [5], then created three other MARKAL family models, i.e., MARKAL, MARKAL with elastic demand, and MARKAL-MACRO, to study the course of actions on mitigation strategies and relevant effects on the economy [6]. Ichinohe and Endo developed a MARKAL model representing the energy system of Japan from 1988 to 2032, suggesting a support mechanism based on carbon tax for the dissemination of hybrid vehicles [7], and then analyzed the energy system in Japan in order to achieve a clear determination about the subsidy levels for photovoltaic technologies supported by a carbon tax [8]. Rafaj et al. established a multiregional MARKAL-Model to address the impacts of internalization of external costs of power production, including the recent deployments of desulfurization, NOx removal, and CO2 scrubbers [9].

In another remarkably different study, Balash et al. examined some different scenarios involving MARKAL to explore their possible impacts and get insights on the future of US energy system using the Environmental Protection Agency's Nine Region MARKAL Database (EPAUS9r) [10]. Sarıca and Tyner modified the standard US MARKAL model including corn stover and miscanthus feedstocks and obtained new cost information for biochemical and thermochemical conversion technologies to estimate the impacts of different policy and technology choice scenarios [11]. Tsai et al. analyzed different technology-based scenarios to get an emission mitigation plan for the industrial sectors of Taiwan [12]. Dedinec et al. developed a MARKAL model for Macedonia as a basis for setting the national mitigation contributions and formulating the most appropriate national mitigation action plan [13].

In a recent study on renewable energy utilization and the 2023 targets of Turkey, Melikoğlu calculated the cost of renewable energy investments based on the Vision 2023 energy targets in detail and found that Turkey should spend 61.0 billion US$ on average on renewable energy sources and nearly 50.0 billion US$ on its two new nuclear power plants in the next decade to fulfill the Vision 2023 energy targets and concluded that a slight delay in the Vision 2023 energy targets can be expected if no urgent action is taken by the Turkish government [14].

The related literature denotes that MARKAL has been used worldwide for various objectives within socio-techno-economic and environmental aspects of energy systems on different scales. These studies are ever increasing with diversified objectives, both in developed and developing countries.

The remainder of this paper is divided into four sections. The next subsection presents a brief overview of the energy trends, primary energy reserves, and wind energy status in Turkey. Section 2 discusses the methodology of national energy system model developed for this study with a background about MARKAL family of energy models. Section 3 gives the analysis of the scenario results and Section 4 concludes with the key findings of the study.

1.1. Primary energy reserves and wind energy status in Turkey

The sixth largest electricity market in Europe and one of the fastest growing markets on a global scale, Turkey is an energy-importing country; more than half of its energy requirements are met by increasing imports. Table 1 shows the domestic potentials in Turkey.

Table 1. Primary energy reserves of Turkey [15].

Reserves	**Unit**	**Proven**	**Probable**	**Possible**	**Total**
Hard coal	(GWh)	4,477,550	3,459,925	2,995,888	10,933,363
Lignite (GWh)		22,137,600	1,888,287	1,236,737	25,262,624
Asphaltite (GWh)		206,794	139,465	33,664	379,923
Bituminous shale		599,786.48	1,173,636.25		1,773,422.73
Crude oil		479,049			479,049
Natural gas		83,736			83,736
Nuclear resources: uranium		3.70466E+11			3.70466E+11
Thorium		3.65712E+14			3.65712E+14
Hydro	(GWh/year)	127,381			127,381
Hydro (GW/year)		36.26			36.26
Geothermal electricity	(MW/year)	200		4300	4500
Geothermal heat		2250		28,850	31,100
Solar electricity					8.8
Solar heat					26.4

Turkey has a huge amount of lignite reserves as shown in Table 1. Hydro, geothermal heat, and electricity also attract attention among other reserves. These reserves should be taken into account and immediately evaluated in terms of utilizing domestic resources and increase the security level of supply.

Ministry of Energy and Natural Resources of Turkey announced that it is assumed that wind plants with a capacity of 5 MW can be established in Turkey in areas that are 50 meters above ground level and with wind speeds more than 7.5 m/s. In the light of this assumption, the Wind Energy Potential Atlas (REPA), in which the wind resource information is generated using the medium-scale digital weather forecast model and the microscale wind flow model, was prepared. Turkey was estimated to have 48,000 MW of wind energy potential. This sum corresponds to the potential area corresponding to 30.1% of Turkey's total surface area (http://www.enerji.gov.tr/tr-TR/Sayfalar/Ruzgar).

The overall capacity of all wind turbines installed worldwide by the end of 2017 reached 539,291 MW, while 52,552 MW were added in the year 2017; more than in 2016 (51,402 MW). This is the third largest number ever installed within one year, after the record years 2015 and 2014, while the wind power has become a pillar in their strategies to phase out fossil and nuclear energy in many countries. In 2017, Denmark set a new world record with 43% of its energy generation coming from the wind.

The largest wind power market China installed an additional capacity of 19 GW, less than it did in 2016, and kept its position as the world's wind power leader with a cumulated wind capacity of 188 GW. Other than the leading markets, the US (6.8 GW new, overall 89 GW), Germany (6.1 GW new, overall 56 GW), India (4.6 GW new, 32.9 GW total capacity), and United Kingdom (3.3 GW new, 17.9 GW total) as stated by the World Wind Energy Association (http://www.wwindea.org/2017-statistics).

In Turkey, despite the domestic potential, the installed capacity in the wind was 18.9 MW in 2000, generating 33.4 GWh of electricity. These numbers recorded a big boom after the legislation passed in 2005 by the law number 5346 which regulated the issues on electricity generation by renewable energy sources [16]. This law was modified in 2010, and then came into force by the law number 6094, determining the prices of electricity generated per kWh of 7.3 USA cents for hydropower and wind power, 10.5 USA cents for geothermal, and 13.3 USA cents for biomass and solar-based electricity generation. As another important support for renewables, domestic contribution of renewable technologies was also regulated and respective prices on related technologies were determined by this law [17].

After this official support on renewables in Turkey, electricity generation by solar power appeared in energy balance statistics for the first time, investments in wind power slightly increased, installed wind power capacity and the wind-based electricity generation reached 5.75 GW and 15,517 GWh, respectively by the end of 2016.

2. Materials and methods

2.1. MARKAL model and objective function

MARKAL model generator was used in this study. MARKAL is an energy-economic-environmental optimization model. The energy system is simulated with numerical parameters including all phases of the energy production, supply, consumption, and demands with all environmental emission and economic coefficients over a multiperiod horizon at national or international level. The model chooses the most cost-effective combination of technologies and energy carriers that meet the demands for energy services specified while taking the user-defined constraints into account.

The objective function of MARKAL is the sum of the present value of the stream of annual costs incurred in each year of the horizon. Therefore:

$$NPV = \sum_{r=1}^{R} \sum_{t=1}^{t=NPER} (1+d)^{NYRS \times (1-t)} \times ANNCOST(r,t) \times (1 + (1+d)^{-1} + (1+d)^{-2} + \cdots + (1+d)^{1-NYRS}). \tag{1}$$

As given in Eq. (1) above, net present value (NPV) of the energy system stands for the total cost for all, while *ANNCOST(r,t)* is the annual cost in region r for period **t**, **d** is the general discount rate, *NPER* is the number of periods in the planning horizon, *NYRS* is the number of years in each period t, and R is the number of regions.

The total annual cost ANNCOST(r, t) is the sum of various costs such as all technologies k, all demand segments d, all pollutants p, and all input fuels f. These costs are annualized investments, annual operating costs including fixed and variable technology costs, fuel delivery costs, costs of extracting and importing energy carriers, minus revenue from exported energy carriers, plus taxes on emissions, plus cost of demand losses [2].

ANNCOST(r,t) is expressed as given below in Eq. (2) [2]:

$$\begin{aligned} ANNCOST(r,t) = \sum_{k} \{ & Annualized\_Inv\,cost(r,t,k) \times INV(r,t,k) + Fixom(r,t,k) \times Cap(r,t,k) \\ & + Varom(r,t,k) \times \sum_{s,s} ACT(r,t,k,s) + \sum_{c} [Delivcost(r,t,k,c) \times Input(r,t,k,c) \\ & \times \sum_{s} ACT(r,t,k,s)]\} + \sum_{c,s} \{Miningcost(r,t,l,c) \times Mining(r,t,l,c) \\ & + Tradecost(r,t,l,c) \times TRADE(r,t,c,s,i/e) + importprice(r,t,l,c) \\ & \times import(r,t,l,c) - Exportprice(r,t,l,c) \times Export(r,t,l,c)\} \\ & + \sum_{c} \{Tax(r,t,p) \times ENV(r,t,p)\} + \sum_{d} \{DemandLoss(r,t,d)\} \end{aligned} \tag{2}$$

The first period specified in the model is a past period and the quantities are all fixed by the user at their historical values. The capacities and operating levels of all technologies, the extracted, exported, and imported quantities for all energy carriers are the main variables to be identified and then calibrated. The calibration of the first period affects the respective calculations over the future periods with existing capacities of related energy technologies. The model does not require making any additional investments for the existing capacities but the operating and maintenance costs are involved in the total cost of the system. Mainly, any energy technology will be decommissioned at the end of its specified lifetime and the new capacity may appear in the next time period when defined by the modeler. The emissions caused by the energy flows are calculated according to the IPCC methodology. The respective emission factors are specified by the modeler for any associated energy activity.

MARKAL is based on reference energy system (RES) concept consisting of demands representing all the energy end uses, energy sources, exports, including the process, conversion, end-use demand technologies, and commodities of energy carriers as illustrated in Figure 1.

The Turkey-MARKAL Model is structured in six columns which shape the main body of the system. Further identifications designate the interaction and hierarchy in the energy system. The energy resources and resource technologies to have primary forms of energy carriers with conversion and process technologies to obtain secondary or final energy carriers constitute the supply side of the system. The ideal RES concept is applied to the energy system and this structure has been developed specifically for Turkey. In-depth knowledge of the Turkey-MARKAL model is given in [18].

2.2. Development of energy database for Turkey

The energy balances of the year 2005 given by the Ministry of Energy and Natural Resources of Turkey (MENR) is specified to MARKAL Model generator using ANSWER user interface. This database, namely reference energy system (RES), represents the status of the Turkish energy system. After compiling the data in MARKAL hierarchy, under an appropriate conventional naming of system variables; “optimal solution” is obtained by a system run for the base case.

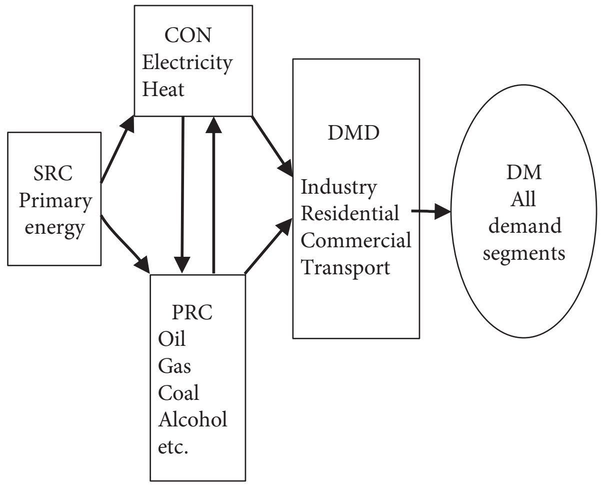

Figure 1. A simplified representation of a typical MARKAL RES [18].

The World Bank's forecasting has been the foundation for the demand projections and the growth of Turkish economy. Gross domestic product (GDP) is taken as 481.5 billion US dollars in the base year, 2005 [19].

All GHG emission factors for the sectors and technologies are typically obtained from Intergovernmental Panel on Climate Change (IPCC) methodology and then calibrated to the official values in National Emissions Inventory reported to United Nations Framework Convention on Climate Change (UNFCCC), based on the energy consumption statistics retrieved from the energy balance tables published by MENR (http://www.eigm.gov.tr/tr-TR/Denge-Tablolari/Denge-Tablolari).

Energy demands are structured in six clusters, i.e., agriculture, commercial, industrial, non-energy, residential, and transportation sectors. Total demands are given in Table 2, as projected along the modeled time horizon. The abbreviations for the specified parameters are determined according to the naming convention of MARKAL. Demand shares in the year 2023 are listed for industry, residential, and transportation sectors respectively. Naturally, these sectors should be considered as potential candidates for energy saving applications.

2.3. Description of the BAU and WIND2025 scenarios

Two scenarios were hypothesized in the scope of this study: business as usual (BAU) and wind power plant installation by the year 2025 (WIND2025). That is, analysts project the impacts on the supply and demand side, the economic costs, as well as the emissions under a different alternative case and compare the results under a reference case. This allows determining the incremental cost, as well as the changes in emissions of each alternative policy or measure.

The reference case is typically thought as a BAU scenario, essentially representing a continuation of current policies and technology trends. The reference case is designed to serve as a reference point relative to which alternative scenarios and energy strategies can be compared. From this perspective, the base scenario is determined to represent the status of the country's calibration year and is required to be identified with the best possible level of data.

Strategic wind power utilization target of installing 20 GW by 2023 is identified to model as a scenario named "WIND2025", which involves the installed capacity bounds of each year in the model's time horizon.

Table 2. End-user energy service demands (PJ).

Sector	Demand	Parameter	2005	2010	2015	2020	2023	2025	Sectoral demand	Share in total (2023)
Agriculture	Electricity	AELC	13.73	16.14	18.99	22.34	24.698	26.27	148.91	3.90%
	Oil products	AOIL	69.02	81.19	95.5	112.33	124.21	132.13		
Commercial	Electricity	CELC	12.75	15	17.64	20.75	22.946	24.41	22.95	0.60%
	Cement	ICEM	159.72	187.87	220.98	259.93	287.422	305.75		
	Chemical-petrochemical	ICPCM	78.16	96.78	113.84	133.9	148.06	157.5		
	Hydrocarbons for non-energy use	IH	92.67	109	128.21	150.81	166.758	177.39		
Industrial	Iron and steel	IISM	109.93	129.31	152.1	178.91	197.828	210.44	1821.07	47.66%
	Miscellaneous	IMSC	497.82	601.42	707.43	832.12	920.116	978.78		
	Nonferrous metals	INFM	34.35	40.4	47.52	55.9	61.81	65.75		
	Sugar	ISGR	21.7	25.54	30.04	35.34	39.078	41.57		
Non-energy	Non-energy sector	NESC	93.7	110.21	129.64	152.49	168.618	179.37	168.62	4.41%
	Cloth drying	RCD	4.76	5.6	6.58	7.74	8.562	9.11		
	Cooking	RCO	73.97	87.01	102.34	120.38	133.112	141.6		
	Cloth washing	RCW	8.84	10.4	12.23	14.38	15.904	16.92		
	Dish washing	RDW	4.31	5.07	5.96	7.02	7.758	8.25		
	Lighting	RLI	5.42	6.37	7.49	8.81	9.746	10.37		
Residential	Miscellaneous electric	RME	15.78	18.57	21.84	25.69	28.408	30.22	1245.25	32.59%
	Other energy using	ROE	170.08	200.06	235.33	276.8	306.074	325.59		
	Refrigerating and freezing	RRF	30.23	35.56	41.82	49.19	54.392	57.86		
	Space cooling	RSC	20.25	23.82	28.02	32.96	36.446	38.77		
	Space heating	RSH	233.35	274.48	322.86	379.77	419.934	446.71		
	Water heating	RWH	124.98	147.01	172.92	203.4	224.91	239.25		
	Elc. railways	TRERAI	2.55	3	3.52	4.15	4.588	4.88		
	Cng land transport	TRNLAN	0.06	0.07	0.08	0.1	0.106	0.11		
	Aviation	TRPAVI	20.04	23.58	27.73	32.62	36.07	38.37		
Transportation	Maritime	TRPMAR	13.76	16.19	19.04	22.4	24.77	26.35	414.36	10.84%
	Oil railway	TRPRAI	3.68	4.33	5.1	6	6.63	7.05		
	Street illumination	TRSIL	2.01	2.37	2.79	3.28	3.622	3.85		
	Oil firing land vehicles	TRTOTD	188.14	221.3	260.31	306.19	338.572	360.16		

This capacity reaches 29.87 GW in the year 2025, the end of analysis horizon. The WIND2025 scenario only focuses on the wind power target, growth of the other renewables have the same patterns as in the base scenario.

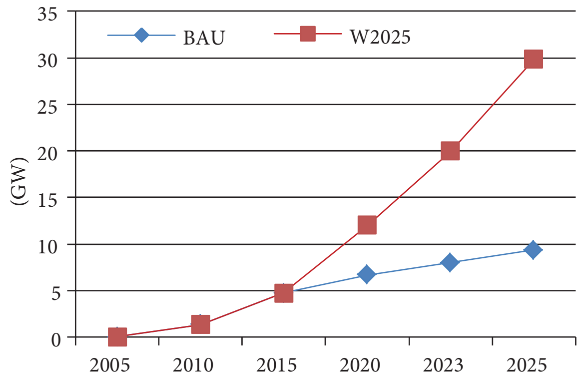

Figure 2. Installed capacities in wind power (GW)

Once the RES development is finished, the energy model runs properly and gives optimal solution under the specified conditions, i.e., the applied lower, upper, and fixed bounds on activity or capacity of technologies for the reference case. Under the current policies and technology trends, total installed wind power capacity in 2005 is 0.22 GW and 1.32 GW in 2010 and 4.718 GW as of the end of 2014. According to electricity balance statistics published by MENR, wind power installed capacity is 1.32 GW with a respective wind-based electricity production of 2916 GWh (10.5 PJ). As projected to promote the installed wind power capacity up to 20 GW level in 2025 as specified in the BAU scenario, this capacity is shifted to 20 GW in the year 2023 and 29.87 GW in 2025 in the WIND2025 scenario as shown in Figure 2. Imports and exports of all types of energy carriers and the technological selections for the future are all set free for this scenario in order to indicate the economic and technological selection responses of the model.

3. Analysis of the scenario results

The selected results are collected among the output parameters and represented in Table 3. This table gives the numbers about the general situation of the electricity network of Turkey, including the changes in the analyzed wind power related issues. The WIND2025 scenario proposes the installed wind power capacity of 20 GW in 2023 and 29.87 GW in the year 2025, as the BAU scenario results at 9.36 GW in 2025. This means an additional wind power capacity of 12.01 GW would be installed just between the years 2020 and 2023.

Firstly, as a general look at the energy system including all the supply items, the total primary energy supply of the country is 3861.4 PJ in 2005 and then gears up to 7593.58 PJ in 2023 and 7930.63 PJ in 2025; by 105% increase in a period of twenty years under the main economic assumptions, including the required investments to improve the existing electricity network infrastructure. The capacity increases according to the trends in the BAU scenario by the additional wind power capacity affect total primary energy supply (TPES) by climbing to 7593.58 PJ and 7930.63 PJ, while the wind power utilization increases the total renewable energy utilization to 1677.70 PJ and 1942 PJ in 2023 and 2025, respectively.

Secondly, the share of wind capacity reaches 6.13% in BAU, but the WIND2025 scenario pushes this ratio to 18% depending on wind power's share in the total installed capacity of the country. Normally, the doubled wind power capacity also doubles the wind-based electricity generation from the projected value of 78.52 PJ

Table 3. General results (BAU vs WIND25).

Parameter	Scenario	Unit	2005	2010	2015	2020	2023	2025
Total primary energy supply	BAU	PJ	3861.64	4645.97	5526.39	6960.31	7837.86	8422.90
	WIND2025	PJ	3861.64	4645.97	5526.39	7088.00	7593.58	7930.63
Total renewable energy utilization	BAU	PJ	639.08	777.35	963.01	1153.57	1331.35	1449.87
	WIND2025	PJ	639.08	777.35	963.01	1281.25	1677.70	1942.00
Total installed capacity (all energy technologies)	BAU	GW	40.56	52.91	73.15	91.94	109.10	127.11
Installed capacity in wind	BAU	GW	0.02	1.32	4.72	6.68	7.99	9.36
	WIND2025	GW	0.02	1.32	4.72	12.00	20.00	29.87
Share of installed wind capacity	BAU	%	0.05%	2.49%	6.45%	7.27%	7.32%	7.36%
	WIND2025	%	0.05%	2.49%	6.45%	13.05%	18.33%	23.50%
Wind-based electricity generation	BAU	PJ	0.21	10.50	31.81	64.13	78.52	89.86
	WIND2025	PJ	0.21	10.50	31.81	115.20	218.13	286.75
Increase in wind-based elc. generation		PJ				51.07	51.07	139.61
Total electricity generation	BAU	PJ	583.03	754.96	911.39	1142.02	1268.70	1353.16
	WIND2025	PJ	583.03	754.96	911.39	1193.09	1350.42	1455.31
Total CO2 emission (& projection)	BAU	kT	236,841.69	293,979.36	346,746.85	411,642.87	452,629.57	479,954.04
CO2 reduction		kT				12,767.50	34,640.50	49,222.50
CO2 reduction		%				3.10%	7.65%	10.26%
Investment costs	BAU	M USD	33.76	2090.11	5302.58	3061.7	3733.964	4182.14
	WIND2025	M USD	33.76	2090.11	5302.58	11,363.56	12,035.82	12484
Subsidies on wind-based electricity	BAU	M USD	0	-532.17	-1612.59	-3250.84	-4033.46	-4555.2
	WIND2025	M USD	0	-532.17	-1612.59	-5840.01	-8176.01	-9733.34

to 218.13 PJ, with 139.62 PJ incremental electricity generation. This amount of electricity from 20 GW wind power utilization constitutes 16% of the total electricity of the country, supplying more than half of the officially designated future target of 30% of electricity from renewables in the year 2023.

From the environmental point of view, assuming the above-mentioned electricity generation from wind sources by decommissioning the equivalent coal-based power plants or other measures, this action would result in a reduction of 12,767.5 and 34,640.50 kT in CO2 emissions, which means 3.1% and 7.65% mitigation in 2020 and 2023, respectively. This amount of reduction in emissions caused by power generation will create a significant contribution to the battle against climate change.

Thirdly and possibly the most challenging side is that the financial consequences of this official target sum up to $6.79 billion for the new wind installations between 2020 and 2023 for the projected total wind investments (6.68 GW in 2020 and 7.99 GW in 2023) according to the BAU scenario, while these numbers change to $24.78 billion for additional total 11.71 GW installation in 2020 and 20 GW in 2023. The incremental cost between the BAU and WIND2025 scenarios to realize the capacity expansion addresses an additional investment of $16.60 billion through 2020–2023.

Finally, the positive effect of the current legislative regulations on the subsidization of wind-based electricity generation by the law (no: 6094) should also be considered while looking at the financial dimension of this issue. The purchase guarantee of 7.3 USA cent/kWh for the electricity generated by wind results in a total amount of subsidization approximately $7.28 billion in BAU, but this amount increases to $14.02 billion for the 2020–2023 period, depending on the 139.61 PJ increased additional electricity generated by the wind. Therefore, the total cost of this strategic target, which doubles the installed capacity and electricity generation by wind power, including the respective investment costs and subsidizations results in nearly $24.78 billion on the analysis horizon.

4. Conclusion

The official wind power vision of Turkey was analyzed in this paper as an alternative scenario to foresee the environmental and economic aspects of 20 GW wind power installation by the year 2023. The total cost of this strategic target which doubles the installed capacity and electricity generation by wind power, including the respective investment costs and subsidizations, results nearly in $24.78 billion on the analysis horizon.

Turkey's energy policy objectives have officially been declared as to ensure sufficient, reliable, and economic energy supplies in order to support economic and social development, to maintain the security of energy supply, and to encourage sufficient investments to meet the growing energy demand while taking environmental protection into consideration. In this respect, it is obvious that all these issues can be covered by utilizing higher renewable potentials, especially the wind option may have a great contribution to the energy economy of the country if the required financial sources can be transferred to reach the designated target.

Acknowledgments

The author would like to thank the Scientific Research Commission of Marmara University for funding the research project "Determining Optimum Energy Strategies for Turkey by MARKAL Model" (FEN-KPS-080805-0177) and operating agents of the Energy Technology System Analysis Programme of the International Energy Agency for their collaboration and close support.

References

[1] Electricity Energy Market and Supply Security Strategy Paper. Republic of Turkey State Planning Organization, 2009.

[2] Sulukan E, Saglam M, Uyar TS, Kırlıdoğ M. Determining optimum energy strategies for Turkey by MARKAL model. J Nav Sci Eng 2010; 6: 27-38.

[3] Sulukan E, Sağlam M, Uyar TS. Energy–economy–ecology–engineering (4E) integrated approach for GHG inventories. In: Erşahin S, Kapur S, Akça E, Namlı A, Erdoğan H, editors. Carbon Management, Technologies, and Trends in Mediterranean Ecosystems. The Anthropocene: Politik—Economics—Society—Science, vol 15. Springer, Cham, 2017. pp. 79-88.

[4] Salvia M, Cosmi C, Macchiato M, Mangiamele L. Waste management system optimisation for Southern Italy with MARKAL model. Resour Conserv Recy 2002; 34: 91-106. http://dx.doi.org/10.1016/S0921-3449(01)00095-7.

[5] Chen W. The costs of mitigating carbon emissions in China: findings from China MARKAL-MACRO modeling. Energ Policy 2005; 33: 885-896. http://dx.doi.org/10.1016/j.enpol.2003.10.012.

[6] Chen W, Wu Z, He J, Gao P, Xu S. Carbon emission control strategies for China: a comparative study with partial and general equilibrium versions of the China MARKAL model. Energy 2007; 32: 59-72. http://dx.doi.org/10.1016/j.energy.2006.01.018.

[7] Ichinohe M, Endo E. Analysis of the vehicle mix in the passenger-car sector in Japan for CO2 emissions reduction by a MARKAL. Appl Energ 2006; 83: 1047-1061. http://dx.doi.org/10.1016/j.apenergy.2005.08.002.

[8] Endo E, Ichinohe M. Analysis on market deployment of photovoltaics in Japan by using energy system model MARKAL. Sol Energ Mat Sol C 2006; 90: 3061-3067. http://dx.doi.org/10.1016/j.solmat.2006.06.049.

[9] Rafaj P, Kypreos S. Internalisation of external cost in the power generation sector: analysis with Global Multi-regional MARKAL model. Energ Policy 2007; 35: 828-843. http://dx.doi.org/10.1016/j.enpol.2006.03.003.

[10] Balash P, Nichols C, Victor N. Multi-regional evaluation of the U.S. electricity sector under technology and policy uncertainties: findings from MARKAL EPA9rUS modeling. Socio-Econ Plan Sci 2013; 47: 89-119. http://dx.doi.org/10.1016/j.seps.2012.08.002.

[11] Sarica K, Tyner WE. Analysis of US renewable fuels policies using a modified MARKAL model. Renew Energ 2013; 50: 701-709. http://dx.doi.org/10.1016/j.renene.2012.08.034.

[12] Tsai MS, Chang SL. Taiwan's GHG mitigation potentials and costs: an evaluation with the MARKAL model. Renew Sust Energ Rev 2013; 20: 294-305. http://dx.doi.org/10.1016/j.rser.2012.12.007.

[13] Dedinec A, Taseska-Gjorgievska V, Markovska N, Grncarovska TO, Duic N, Pop-Jordanov J, Taleski R. Towards post-2020 climate change regime: analyses of various mitigation scenarios and contributions for Macedonia. Energy 2016; 94: 124-137. http://dx.doi.org/10.1016/j.energy.2015.10.085.

[14] Melikoglu M. The role of renewables and nuclear energy in Turkey s Vision 2023 energy targets: economic and technical scrutiny. Renew Sust Energ Rev 2016; 62: 1-12. http://dx.doi.org/10.1016/j.rser.2016.04.029.

[15] Hamdan MO, Hejase HAN, Noura HM, Fardoun AA. Renewable Energy: Generation and Applications (ICREGA 14). Cham, Switzerland: Springer, 2014.

[16] Law on utilization of renewable energy sources for the purpose of generating electrical energy, Official Journal of the Republic of Turkey, Law No: 5346; 2005.

[17] Law on utilization of renewable energy sources for the purpose of generating electrical energy, Official Journal of the Republic of Turkey, Law No: 6094; 2010.

[18] Sulukan E, Sağlam M, Uyar TS. A native energy decision model for Turkey. In: Uyar TS, editor. Towards 100% Renewable Energy. Springer Proceedings in Energy. Cham, Switzerland: Springer, 2017. pp. 167-177.

[19] Global Economic Prospects: Crisis, Finance, and Growth. Washington DC: The World Bank, 2010.