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A Preliminary Study for Post-Kyoto Period for Turkey by MARKAL Model

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ABSTRACT – There are several mathematical models that have been developed for assessing specific energy systems and MARKAL, that has been developed by the Energy Technology Systems Analysis Program (ETSAP) of the International Energy Agency (IEA), is one of them. With several input parameters of technology related, economic and environmental coefficients MARKAL calculates the alternatives for minimum possible cost. This article reports the results of the Turkish energy model that has been developed by using MARKAL Model Generator.

***Keywords**: Energy Modeling, Emission Mitigation, Renewable Energy, Turkish MARKAL Model*

I. INTRODUCTION

Turkey is a developing country that has a pressing requirement for expanding its economy. Although Turkey is a member of the OECD, its development and welfare level is below the countries in the United Nations Framework Convention on Climate Change (UNFCCC) Annex-I all of which are highly developed. As a result, the special circumstance of the country was recognized and the country became a party to the UNFCCC in 2004. "The Endorsement of Turkey's Ratification of the Kyoto Protocol to the UNFCCC" was adopted in the Parliament on 5 February 2009. This decision took a long time because of the possible adverse effects of the protocol on the economy.

In the current post-Kyoto period it is envisaged that the modest first phase is to be succeeded by a series of new agreements that are to be negotiated in coming years. The negotiations will be mainly based on the stabilizing or perhaps reducing the fast-increasing greenhouse gas emissions (GGE) to designated levels.

Turkey is highly dependent on energy imports and the country continuously faces energy related problems. Some of these problems are security and cost concerns over growing oil and natural gas imports, limited domestic energy resources other than coal and renewable sources, and demand projections that is likely to exceed supply capabilities within a few years. An advanced decision support tool is required for analyzing complex and often conflicting energy issues such as demand, supply, cost, and the GGE.

This article attempts to quantify the sources of emissions from the country's energy system, provide a framework for exploring and evaluating energy alternatives, and quantify the system-wide effects of energy and environmental policies. To this end, a reference energy model (RES) has been developed in MARKAL which is a sophisticated modeling tool that mainly uses linear programming principles. The model is based on the Kyoto requirements for the country in the 2005-2025 timeframe.

This article is structured as follows: The next section will discuss a brief comparison of the GGE originating from Turkey and some other countries. It will be followed by some energy statistics of Turkey. This is followed by the section that discusses the MARKAL model along with its usage in some countries and regions. Turkey's Reference Energy System through MARKAL will be the topic of the next section and it will be followed by the section that discusses the two alternative GGE mitigating scenarios. The article is wrapped up by the conclusion section.

II. TURKEY'S STANCE ON ENERGY-RELATED ISSUES AND SOME INDICATORS

Turkey has the highest population growth in the OECD with 1.7 percent. The country ranks 79th in Human Development Index among 177 countries according to the Human Development Report 2009 of the United Nations Development Program (UNDP) (see http:// hdr.undp.org/en/media/HDR_2009_EN_Complete.pdf). The 2007-8 version of the UNDP Human Development Report had the theme of "Fighting Climate Change" and according to that report Turkey occupies the 23rd position in the highest polluting countries where the US is the in the first position followed by China. These two countries are responsible for the 38.2% of the global CO_2 emissions in 2004. The same figure is 0.8% for Turkey and this corresponds to 226 Mt CO_2. Turkey's share of global CO_2 emissions is lower than its share in global population which is 1.1%. Nevertheless, the CO_2 emission of the country has increased from 146 to 226 Mt in the 1990-2004 period and this figure is fairly high compared to several countries.

Turkish Ministry of Environment and Forestry issued the "National Climate Change Strategy" document in December 2009 (see http://www.undp.org.tr/energEnvirDocs/Ingilizce%20-%20Strateji%20Belgesi. pdf). The strategy envisages

"…to integrate the policies and measures on combat against and adaptation to climate change into the national development programs in line with the principle of 'common but differentiated responsibilities' established in UNFCCC and within the framework of its special circumstances."

and

"…to contribute to the global emission reduction policies and measures to the extend possible by limiting the growth rate of greenhouse gas emissions, without disrupting the development program."

According to the strategy document Turkey's primary energy consumption per capita was equivalent to 1.29 tons of oil in 2008. This figure for the world average was 1.80 tons and OECD average was 4.70 tons. The document also reports that Turkey has the lowest figure for GGE among all OECD countries with 5.3 tons of CO_2 emissions per capita compared with OECD average of 15.0 tons.

III. ENERGY PRODUCTION AND CONSUMPTION IN TURKEY

Excluding the hydro, the geography occupied by Turkey is not very rich in natural energy resources and as a result, Turkey can domestically produce only some part of its energy needs. The country is mainly dependent on external resources for energy. Lignite and hydro are the most important domestic primary energy resources. The energy production and consumption figures in Turkey in 2005 are shown in Table 1 [1].

Table 1 - Primary Energy Production and Supply in Turkey in 2005 (in PJ).

	Domestic Production		Primary Energy Supply		
	PJ	Percent	PJ	Percent	Imp. Share
Hard Coal	49.6	5.0%	528.2	13.2%	90.6%
Lignite	373.5	37.4%	373.5	9.3%	
Asphaltite	16.0	1.6%	16.0	0.4%	
Petroleum	100.3	10.1%	1544.2	38.4%	93.5%
Natural Gas	34.2	3.4%	1060.9	26.4%	96.8%
Hydro	142.4	14.3%	142.4	3.5%	
Geothermal Electricity	3.4	0.3%	3.4	0.1%	
Geothermal Heat	38.8	3.9%	38.8	1.0%	
Wind	0.2	0.0%	0.2	0.0%	
Solar	16.1	1.6%	16.1	0.4%	
Biomass	173.6	17.4%	173.6	4.3%	
Animal-Biomass Waste	49.4	5.0%	49.4	1.2%	
Petro Coke	0	0.0%	69.6	1.7%	100.0%
Total	997.5	100%	4000.7	100%	

Table 1 shows that Turkey produces only about a quarter of its energy needs and close to the half of the domestic primary energy production is coal-based, i.e. hard coal and lignite. Most of the lignite produced in Turkey is of low quality and this has adverse effects on greenhouse gas emissions. Turkey's topography is usually mountainous and this results in high potential for hydro energy production. This makes hydro-electricity an important source for domestic primary energy production. After using a substantial part of this potential in large rivers, smaller hydro plants are being constructed all over the country to the dismay of environmentalists. Hydro-electricity production is sensitive to climate and Turkey suffers from irregularities of this kind of production resulting from occasional droughts.

Production of biomass, which used to be an important energy resource in rural areas, gradually declined in the last few decades. It can be expected that this trend will continue in coming years. The last decades also witnessed the increasing production of wind and solar energy resources, albeit from quite a low level. The legislation for "The Usage of Renewable Sources for Electricity Production" has been passed from the Parliament in 2005. The legislation brings purchase guarantee, price support mechanism, and tax abatement for renewable energy production. Encouraged by these supports, there have been 78 GW of license applications for wind farms as of 2007. Although it is unlikely that all of those applications will result in actual energy production, materialization of even only a small part of them will positively affect the greenhouse gas emissions mitigation efforts.

The Ministry of Energy and Natural Resources has an official set of targets for increasing the share of renewable sources for energy production. According to the targets, which are for the year 2023, wind power utilization should be 20 GW and all of the hydro and geothermal potential of the country should be utilized for energy production. As a result, the share of renewable sources in electricity production should be at least 30% by the target year [2].

Although there is some petroleum production in Turkey only seven percent of the demand was satisfied by domestic production in 2005. This is also true for domestic natural gas production where only about three percent of the consumption is produced domestically. Thus, Turkey is critically dependent on the import of these two items which constitute an important part of the huge account deficit of the country.

Turkey's energy consumption is mainly fossil-based. Table 1 shows the consumption of primary energy resources in the country in 2005. There have been important changes in consumption in the last few decades. Primary Energy Supply has increased by 73% from 2306.6 PJ to 4000.7 PJ from 1990 to 2005 excluding 216.5 PJ of energy exported. Petroleum maintained its dominant share in total consumption, albeit dropping from 45% in 1990 to 33% in 2005. The gap was filled by natural gas which has increased its share from 6% to 27% in the same period. During that time biomass consumption was reduced from 25900 kton to 18946 kton. Reduction in its share of total usage was more dramatic due to the significant increase in total energy consumption, from 14% to 7%. Usage of hydro increased by about 70% and this figure is approximately equal to the increase in total energy consumption thereby maintaining its share of 4% in the total consumption in 2005.

As of 2005 the industry consumed the highest share of the total energy by 40%. It was followed by residences and service sector by 33%. Transportation's and agriculture's shares were 19% and 5% respectively, and 3% went to non-energy sector.

IV. THE MARKAL MODEL AND THE LITERATURE ABOUT ITS USAGE

MARKAL is a family of models that have been used in large-scale energy systems since the 1980s. The system is used by over 80 institutions in 40 countries [3]. Although the model was only a linear programming (LP) application in the beginning, it later acquired non-linear programming (NLP) formulation which combines the "bottom-up" technology model with a "top-down" simplified macro-economic model. In recent years, stochastic programming (SP) and mixed integer programming (MIP) principles were also used in MARKAL, the former for future uncertainties and the latter for modeling endogenous technology learning. Currently, by employing LP and NLP the model also allows the values of more than one region to be entered into the system. Thus, either a country can be processed in its entirety by the model or its regions can be processed simultaneously, perhaps yielding a more accurate result in the latter case [4].

MARKAL's building blocks, which are energy resources, processes, generation, and services are defined by the user and introduced to the system. Also given to the system are energy carriers among the building blocks. The energy network in the model contains primary supplies such as petroleum extraction, conversion such as refineries, and end-use demand such as cars and residential space conditioning. This network is referred as the Reference Energy System (RES).

Once the RES is developed and all the required relevant parameters are set up in their fields, the model can be run for optimization. For this end, energy sources, carriers, and conversion technologies are taken into account along with the constraints on them. The model aims to produce the least-cost solution for an input set. The input set for technology costs, technical characteristics such as conversion efficiencies, and energy service demands may easily be changed for various alternatives and the model can be run with each result set to examine the results. Each run of the model matches supply-side technologies to energy demands and least cost is sought by those matches (ibid.).

The model can incorporate several constraints such as balancing energy inputs to outputs and capacity constraints. Constraint about emission of greenhouse gases can also be given as a constraint to the system which makes MARKAL a useful tool for complying with the current and future international agreements like Kyoto protocol.

For optimization purposes MARKAL uses CPLEX and GAMS (General Algebraic Modeling System). The users do not have to be knowledgeable about the specific computational methods or underlying theory of GAMS, because MARKAL uses a shell (ANSWER) that works as an interface between the user and GAMS. Thanks to the ANSWER interface, the complexities of GAMS are transparent to the user. Input and output values of MARKAL are stored in a MS Access database which optionally uses MS Excel files for importing and exporting data.

MARKAL has been used extensively for analyzing the energy systems for countries or regions. Chen used MARKAL for analyzing the costs associated with mitigating carbon emissions in China in the period of 2000-2050 [5]. Changhong et al. used the model for a region of China, namely Shanghai, for forecasting energy consumption and emissions of air pollutants [6]. The authors also analyzed the effects of possible reductions in CO_2 emissions in the timeframe of 2000-2020. Agoris et al. analyzed the Greek energy system and its alternatives with MARKAL and WASP IV models [7]. The authors developed three scenarios reflecting different alternative policies and calculated the costs of Kyoto and non-Kyoto targets. Making use of MARKAL, the situation in Italy was analyzed by Salvia et al. [8] and Contaldi et al. [9]. In the former article the authors investigated the anthropogenic energy system of Basilicata region by developing scenarios for determining behavior of the optimal mix of fuels and technologies in the presence of carbon dioxide emissions constraints imposed by the Kyoto protocol which involves re-definition of the regional energy systems. The latter article evaluates the effects of the Italian Renewable Energy Supply of Electricity (RES-E) obligation and compares those effects to the economic outcomes of the scenarios. Mathur et al. [10] used MARKAL for examining the possible effects of carbon tax in India for the period of 2000-2020.

V. THE TURKISH REFERENCE ENERGY SYSTEM

Figure 1 shows the summary of Turkish RES which contains primary energy supply, energy carriers, demand technologies, and end-use demands. The RES contains the business-as-usual (BAU) values. In other words, past values of energy production, consumption, and emission are simply projected into the future with no attempts for optimization such as GGE mitigation or cost improvement. The RES mainly serves as a comparison tool with possible alternative scenarios for future that have been developed for emission or cost optimization. Hence, the RES should contain relevant data for the time period for which the analysis is performed.

The details of these values are given in Table 2.

The RES has been developed for the time period of 2005-2025 and values for this article were mainly taken from the Ministry of Energy and Natural Resources and World Energy Council Turkish National Committee [11]. The values for five main sectors, namely residential, industry, commercial, transportation, and non-energy have been the basis for the RES. The values for primary energy carriers in these sectors have been transformed into secondary energy carriers for consumer use. The secondary carriers are organized in such a way that all end-use demands would be satisfied by implementing the final usage technologies. To this end, demand items are classified according to sectors mentioned above. Conversion and process technologies are also investigated and classified according to the demands they satisfy and their energy sources. As a result, 27 energy carriers, 21 source technologies that have been used in conversions, 9 process technologies, 18 conversion technologies, 137 end-use technologies, and 31 demand types have been identified and entered into the system. Additionally, transmission efficiency for each energy carrier, fraction of energy carrier input and end-use demand output for each conversion and process technologies, and fraction of capacity entering peak equations have been entered.

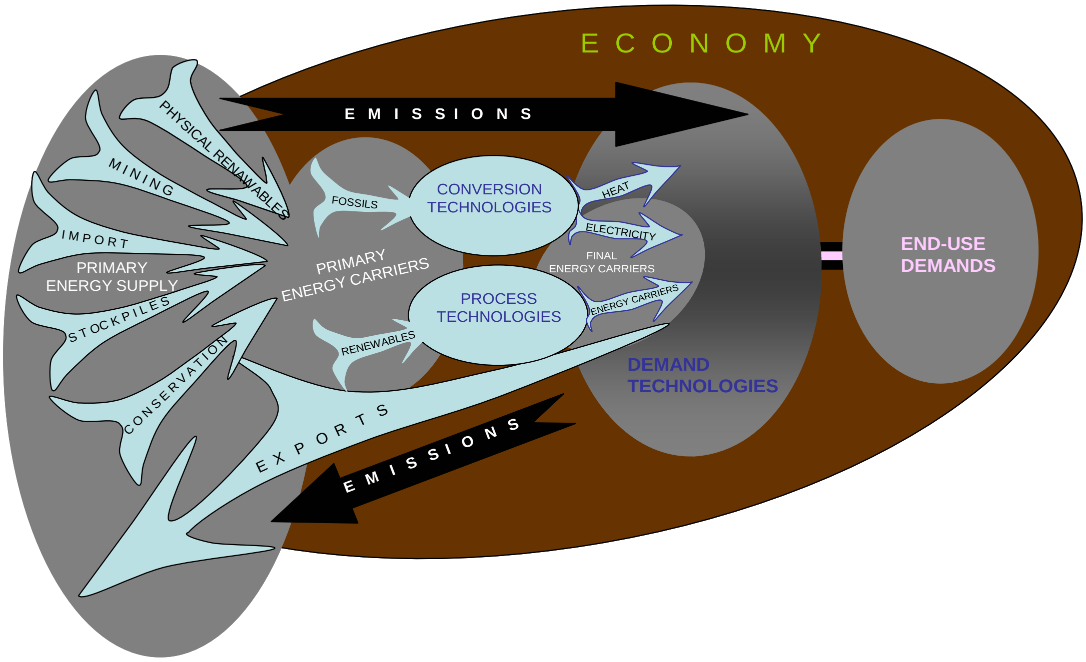

Figure 1 - The Turkish Reference Energy System

Table 2 - Total Final Energy by Sectors according to the RES (in PJ)

	2005	2010	2015	2020	2025
Agriculture	140.6	165.4	194.6	236.9	277.2
Commercial	13.4	15.7	18.6	21.9	25.7
Industry	1232.1	1527.9	1797.2	2114.0	2486.6
Non-energy	93.7	88.1	103.7	122.0	143.5
Residential	962.8	1132.5	1332.1	1566.9	1843.1
Transportation	579.7	681.9	802.1	943.5	1109.8
Total	3022.4	3611.7	4248.3	5005.1	5885.9

In order to identify the emissions greenhouse gases have been linked to energy carriers and limitations have been introduced for emissions in some cases. Emission coefficients that have been defined by IPCC (Intergovernmental Panel on Climate Change) for each technology have been introduced into the system so that emissions for each technology are calculated

The model contains several values for the technologies used. They are annual utilization, technical efficiencies, installed capacities, possible economic lifetimes, and service start dates.

Altogether 2443 items in 11 item groups have been entered into the system. These items were processed by 1868 equations in the 60 blocks of equations of the GAMS that produced 18145 non-zero items. The limit for iterations for solving the model has been set to 200,000. In the optimization phase CPLEX has been run with the limit of 400,000 iterations. CPLEX calculated optimal values for yearly system costs within the given boundaries for several values such as capacities, night and day differences, and emission limits.

In the process of developing the RES the model has been run several times until it gets free of errors and optimal solution is achieved. Since the problem is wide and complicated logical and other errors have been eliminated in different phases in this process. It was observed that an important part of the errors stemmed from discrepancies in the available energy statistics.

VI. THE SCENARIOS

Once the RES is introduced into MARKAL it is easy to develop scenarios for studying various possible alternatives to the BAU such as the cost implications for mitigations of the GGE. For this article two scenarios sustaining the economic growth have been developed:

Table 3 - Comparison of the BAU and the CO_2 STA Scenarios

Scenario	Units	2005	2010	2015	2020	2025
BAU	CO_2 Emission (Mton)	236.8	294.0	346.6	411.6	479.9
CO_2STA		236.8	236.8	236.8	236.8	236.8
Diff. BAU- CO_2STA		0.0 %	-19.4%	-31.7%	-42.5%	-50.6%
BAU	Total Primary Energy (PJ)	3859.70	4703.70	5542.70	6848.30	7841.40
CO2STA		3859.70	4734.20	5654.50	6561.10	7192.90
Diff. BAU- CO_2STA		0%	1%	2%	-4%	-8%
BAU	Total Imports of Fossil Energy Carriers (PJ)	3031.00	3594.60	4232.60	5058.00	5864.70
CO_2STA		3031.00	2922.90	3196.70	3251.30	3022.60
Diff. BAU- CO_2STA		0%	-19%	-24%	-36%	-48%
BAU	Total Domestic Supply of Fossil Energy Carriers (PJ)	3394.40	4188.60	4930.80	6087.60	6931.90
CO_2STA		3394.40	3907.80	4361.90	4746.10	4690.90
Diff. BAU- CO_2STA		0%	-7%	-12%	-22%	-32%
BAU	Total Usage of Renewable Energy Carriers (PJ)	637.20	750.60	882.70	992.40	1223.60
CO_2STA		637.20	2207.90	2925.80	3548.20	4249.00
Diff. BAU- CO_2STA		0%	194%	231%	258%	247%
BAU	Total System Cost (Million USD)	79096.40	95499.20	112422.90	128075.00	161386.60
CO_2STA		79096.40	120454.40	144742.20	169182.90	185429.60
Diff. BAU- CO_2STA		0%	26%	29%	32%	15%
BAU	New Investment Cost (Million USD)	58279.20	69273.70	81538.20	86822.70	114148.20
CO_2STA		58276.50	96243.30	118054.90	140135.60	155758.50
Diff. BAU- CO_2STA		0%	39%	45%	61%	36%
BAU	Total System Cost, Net of Taxes/Subsidies (Million USD)	1019028.00				
CO_2STA		1180348.00				
Diff. BAU-CO2STA		16%				

The first scenario is about keeping the emission level of CO_2 constant, i.e. 2005 value of 236.8 Mton, during the 2005-2025 period (CO_2STA).

The second scenario is about mitigating the CO_2 emission by 11% during the period of the study, i.e. reducing the CO_2 emissions to 210.8 Mton by 2025 (CO_2MITG).

The scenarios have been developed according to the requirements of international agreements such as Kyoto protocol. Several countries have officially determined mitigated emission targets and are in the process of taking measures to conform those targets so that in order to protect the atmosphere against the devastating effects of the GGE. Although Turkey has not officially determined such a target, it might have to do it in future with increasing pressure against the countries that have no such targets.

The comparison of values of the BAU and CO_2STA scenarios are presented in Table 3.

The aim of the CO_2STA scenario is to keep the CO_2 emissions constant in the 2005-2025 timeframe and this means that the CO_2 emission in 2025 is about the half of the BAU scenario in that year. This is quite a demanding scenario and radical measures are required to realize it. The most important of them is to increase the use of renewable energy quite substantially. Renewable sources replaced the fossil fuels depending on the availability and possibility. Additionally, the use of fossil fuels was reduced in some sectors and was totally abandoned in some others. This is reflected in the substantial reduction in the “Total Imports of Fossil Energy Carriers” compared to the BAU scenario. The amount for this item, which is about 3000 PJ, does not change much during the course of the scenario although the “Total Primary Energy” becomes close to twofold in 2025 compared to 2005. This trend is also reflected in the “Total Domestic Supply of Fossil Energy Carriers”, albeit the reduction in this item compared to BAU is less dramatic. This implies that the domestic supply of fossil fuels will be emphasized for providing cost efficiency. The current effort for petroleum search in Black Sea encourages this trend. Lignite, which has a large share of energy supply in Turkey, has been replaced by coke which has higher energy content and is less pollutant. According to the scenario the usage of animal and plant waste was gradually reduced.

Keeping the CO_2 emissions constant has naturally comes with a cost in an environment where energy use constantly increases. “Total System Cost” and “New Investment Cost” items compare the costs of the two scenarios. The CO_2STA scenario is about a quarter more costly than the BAU in the former. The differences are 26%, 29%, 32%, and 15% for the

Table 4 - Comparison of the BAU and the CO_2MITG Scenarios

Scenario	Units	2005	2010	2015	2020	2025
BAU	Emission (Mton CO2)	236.8	294.0	346.6	411.6	479.9
CO_2MITG		236.8	230.3	223.8	217.3	210.8
Diff. BAU- CO_2MITG		0.0 %	-22.0%	-35.0%	-47.0%	-56.0%
BAU	Total Primary Energy (PJ)	3859.7	4703.7	5542.7	6848.3	7841.4
CO_2MITG		3859.7	4793.6	5776.0	6742.8	7407.7
Diff. BAU- CO_2MITG		0%	2%	4%	-2%	-6%
BAU	Total Imports of Fossil Energy Carriers (PJ)	3031.0	3594.6	4232.6	5058.0	5864.7
CO_2MITG		3031.0	2922.9	3196.7	3251.3	3022.6
Diff. BAU- CO_2MITG		0%	-19%	-24%	-36%	-48%
BAU	Total Domestic Supply of Fossil Energy Carriers (PJ)	3394.4	4188.6	4930.8	6087.6	6931.9
CO_2MITG		3394.4	3907.8	4361.9	4746.1	4526.1
Diff. BAU- CO_2MITG		0%	-7%	-12%	-22%	-35%
BAU	Total Usage of Renewable Energy Carriers (PJ)	637.2	750.6	882.7	992.4	1223.6
CO_2MITG		637.2	2294.6	3102.2	3798.0	4682.9
Diff. BAU- CO_2MITG		0.0%	205.7%	251.4%	282.7%	282.7%
BAU	Total System Cost (Million USD)	79096.4	95499.2	112422.9	128075	161386.6
CO_2MITG		78694.7	125846.3	154670.4	183805.6	198871.5
Diff. BAU- CO_2MITG		-1%	32%	38%	44%	23%
BAU	New Investment Cost (Million USD)	58279.2	69273.7	81538.2	86822.7	114148.2
CO_2MITG		58276.5	101633.3	127985.0	154742.6	169817.3
Diff. BAU- CO_2MITG		0%	47%	57%	78%	49%
BAU	Total System Cost, Net of Taxes/Subsidies (Million USD)	1019028.0				
CO_2MITG		1233161.0				
Diff. BAU- CO_2MITG		21%				

years 2010, 2015, 2020, and 2025, respectively. Differences in the latter are more dramatic by 39%, 45%, 61%, and 36%. This can be expected, because the scenario oversees extensive use of renewable sources which require substantial new investments.

The CO_2MITG scenario is even more demanding than the CO_2STA scenario for the reason that it foresees to mitigate the CO_2 emissions rather than keeping them constant. This is indeed a difficult task for a country in the course of economic and social development. Table 4 compares the BAU and the CO_2MITG scenarios.

The CO_2MITG scenario has similarities with the CO_2STA scenario. The target of emission mitigation is 56.0% in the former and it is 50.6% in the latter. “Total Imports of Fossil Energy Carriers” and “Total Domestic Supply of Fossil Energy Carriers” values are identical in both scenarios; there is only a slight difference in year 2025. The CO_2MITG scenario foresees slightly more use of “Total Primary Energy” than the CO_2STA scenario and this is mainly realized by the even wider usage of renewables. This results in the increased “Total System Cost.” It is also worth noting that the increase in “New Investment Cost” compared to “Total System Cost” in the CO_2MITG scenario is higher than the corresponding values in the CO_2STA scenario. This is plausible, because the former foresees comparably wider use of renewables which require immense new investments.

VII. CONCLUSION

MARKAL offers a flexible modeling and optimization environment where BAU scenarios are created by projecting the current values into future. As a next step, several what-if scenarios can be developed for Turkish Energy System by imposing constraints in some energy components and scrutinizing the changes in some others. Today’s ordinary personal computers are so powerful that running the energy model of a country can be completed within minutes. Such a speed allows running a series of models, thereby facilitating a sensitivity analysis.

In this article the RES of Turkey that has been developed by MARKAL is discussed along with the two alternative models for mitigating the GGEs. The models are demanding in the sense that they foresee very substantial reductions in GGE. This has, of course, serious implications not only for hindering economic development, but also for the requirements for vast investments for renewable energy sources. It is not very likely that the policy makers for whom the economic development is regarded to be of utmost importance will realize such scenarios. Nevertheless, the scenarios explained in this article show the flexibility and suitability of MARKAL for developing energy analyses for the decision makers.

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BIOGRAPHIES

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He previously studied on wind turbine technology and manufacturing options and currently studying on his PhD thesis titled “Establishing Energy Efficient Utilization and Cost-Effective Energy Technologies Selection Strategies for Turkey Using MARKAL Family of Models.”

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