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AN ENERGY SYSTEM SIMULATION OF TURKEY WITH A 50% RENEWABLE ENERGY SCENARIO*

Emre LEBLEBİCİOĞLU[1]
Egemen SULUKAN[2]
Tanay Sıdkı UYAR[3]

[1]*Marmara University, Department of Mechanical Engineering, Istanbul, Turkey,*
leblebicioglu.emre@gmail.com; ORCID: 0000-0001-9974-3645

[2]*National Defence University, Turkish Naval Academy, Department of Mechanical Engineering, Istanbul, Turkey,*
esulukan@dho.edu.tr; ORCID: 0000-0003-1138-2465

[3]*Beykent University, Department of Mechanical Engineering, Istanbul, Turkey,*
tanayuyar@beykent.edu.tr; ORCID: 0000-0002-0960-1203

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ABSTRACT

Decreasing the usage of fossil fuels in the electricity production is a tough challenge for countries. The world is still depended on fossil fuels to generate electricity. Increasing the share of renewable energy systems in electricity production is significant in many aspects such as lower CO2 emissions, grid flexibility, decentralizing, etc. Nowadays, many countries shape their energy policies and strategies to use more renewable and indigenous resources. Turkey is one of these countries and has ambitions goals to use more domestic sources to produce electricity. Turkey generally aims to reduce the usage of imported energy sources in electricity generation. Thus this paper investigates the share of 50% renewable energy system (RES) simulation in the electricity production via the EnergyPLAN model. An energy system analysis was conducted in a 50% renewable scenario in 2023. The main target of this scenario is to perform a 50% renewable energy system in electricity production. A reference year is 2018 and the results of the 50% RES scenario were compared with a reference scenario. A main focus of this study is to investigate aspects of carbon emissions, RES share, and costs between the scenarios for the years 2018 and 2023.

Keywords: *Energy System Simulation, EnergyPLAN, Renewable Energy.*

An Energy System Simulation of Turkey with a 50% Renewable Energy Scenario

% 50 YENİLENEBİLİR ENERJİ SENARYOSU İLE TÜRKİYE'NİN ENERJİ SİSTEM SİMÜLASYONU

ÖZ

Elektrik üretiminde fosil yakıt kullanımının düşürülmesi zor bir süreçtir. Tüm dünya hala elektrik üretiminde fosil yakıtlara bağlı durumdadır. Güç üretiminde yenilenebilir enerji payının arttırılması, CO_2 emisyonunun düşürülmesi, şebeke esnekliğinin sağlanması ve merkezi olmayan elektrik üretimi gibi birçok yönden avantaj sağlamaktadır. Günümüzde birçok ülke enerji stratejilerini ve politikalarını daha fazla yerli ve yenilenebilir kaynakların kullanımı şekillendirmektedir. Türkiye de bu ülkelerden birisidir ve elektrik üretiminde daha fazla yerli kaynak kullanımı için etkili politikalara sahiptir. Türkiye genel olarak elektrik üretiminde ithal enerji kaynaklarının kullanımını düşürmeyi hedeflemektedir. Bu makalede EnergyPLAN modeli ile 2023 için %50 yenilenebilir enerji sistemi simülasyonu incelenmiştir. Enerji sistem analizi, 2023 için %50 yenilenebilir enerji sistem senaryosu üzerine kurulmuştur. Bu senaryodaki temel hedef, elektrik üretiminde %50 yenilenebilir enerji kullanımını gerçekleştirmektir. Bu çalışmada referans yıl ise 2018 olarak seçilmiştir ve 2023 senaryosunun sonuçları ile kıyaslanmıştır. Bu çalışmanın odağı 2018 ve 2023 senaryolarının yenilenebilir enerji payı, CO_2 emisyonu ve maliyetler yönünden incelenmesidir.

Anahtar Kelimeler: *Enerji Sistem Simülasyonu, EnergyPLAN, Yenilenebilir Enerji.*

1. INTRODUCTION

Renewable energy sources are significant to reduce the usage of fossil fuels in the electricity production. Raising the share of renewables provides energy independence and lower CO_2 emissions. The world is still depended on fossil fuels in the electricity production. Even though Turkey has a huge renewable potential, it still has a high share of fossil fuels in the power generation. Using the high share of fossil fuels for the power generation also causes economic and environmental problems for Turkey. Turkey imports a significant amount of natural gas and coal to produce electricity. Importing energy sources increases an energy dependency and cause economic consequences. In 2018, the share of fossil fuels in the electricity production was more or less 70% (Republic of Turkey Ministry of Energy and Natural Resources, 2018). Even though increasing the share of renewables seems the best solution to decrease the usage of fossil fuels, it is not enough to supply all energy demand for the countries, which have high energy consumption, such as Turkey in the short term. That is why nuclear energy is another option to be considered.

In this article, the 50% renewable energy scenario for the year 2023 is the main target. The 50% RES scenario also contains nuclear and indigenous coal usage. The usage of natural gas was not ignored completely but was reduced. The year 2023 was chosen for this study since the Turkish government has ambitious goals for this year. The government aims to reduce the usage of non-domestic energy sources and to use more domestic and renewable sources. It is foreseen that Turkey will reach 38,8% RES share and decrease the natural gas share to 20,7% in the electricity production until 2023 (Presidency of the Republic of Turkey, 2019). This paper investigates the 2023 scenario by considering these goals. The year 2018 was also chosen as a reference year and a reference scenario was built for this year. This paper shows a pathway to increase the RES share from 2018 to 2023. Moreover installed capacity expansions, CO_2 emissions and economic analyses are fundamental topics of this paper.

Energy system simulations and analyses were performed by using EnergyPLAN, which is hourly energy system simulation software. A fundamental purpose of EnergyPLAN is to assist in designs of national or regional energy system planning and policy strategies. This software uses

hourly energy system simulations in a year and is based on technical and economic analyses. An energy system simulation of Turkey for 2018 and 2023 was implemented by using the EnergyPLAN model and results were discussed in this paper.

For Macedonia, Denmark, Ireland and Portuguese, country models were made by EnergyPLAN in the different studies.

The study titled "A 100% renewable energy system in the year 2050: The case of Macedonia" (2012) is a country model which was made by EnergyPLAN. This paper investigates the 100% renewable energy system implementation in Macedonia by using the EnergyPLAN model. The energy systems simulation and analyses were carried out for two renewable scenarios, designed for the years 2030 and 2050. The first scenario of this study is the 50% renewable energy system for the year 2030. The second scenario is the 100% renewable energy system for the year 2050 (Ćosić, Krajačić & Duić, 2012).

In the research of (2009) H. Lund and B. V. Mathiesen, an energy system analysis of 100% renewable energy systems for Denmark in the years 2030 and 2050 was implemented by EnergyPLAN. The method of energy systems analysis contains hour by hour computer simulations, leading to the design of flexible energy systems. The results were detailed energy system designs and balances for two target years: the year 2030 with 50% renewable energy and the year 2050 with 100% renewable energy from biomass and a combination of solar power, wind, and wave (Lund & Mathiesen, 2009).

The paper titled "The first step towards a 100% renewable energy system for Ireland" (2010) presents a 100% renewable energy system pathway for Ireland. EnergyPLAN was used as an energy system analysis tool in this study. First of all, a reference scenario of the existing Irish energy system was created, and three different 100% renewable energy systems were created with each focusing on various resources such as biomass, hydrogen, and electricity. Then the 100% renewable energy system model was established for Ireland (Connolly, Lund, Mathiesen & Leahy, 2011).

A study whose title is "Renewable energy scenarios in the Portuguese electricity system" addresses the topic of renewable energy scenarios for the

electricity sector, analysing different possible future strategies for the Portuguese system. Each one of these strategies was characterized according to the expected electricity consumption and renewable share, with the final aim of analysing a possible 100% RES scenario. EnergyPLAN was used to simulate each scenario for a year. The 100% RES scenario was found to be theoretically possible but a significant increase in the total capacity of the system would be necessary to ensure no shortfall during the summer season (Fernandes & Ferreira, 2014).

By considering the national studies which are emphasized above, this study was shaped for Turkey. The technical and economic results of this study may provide a different perspective to the decision-makers in Turkey.

2. BACKGROUND

2.1. Energy Overview of Turkey

Turkey supplies its energy demand by different sources such as lignite, hard coal, imported coal, natural gas, petroleum, and renewable resources. The energy production of Turkey is based on fossil fuels, mainly coal and natural gas. Moreover, Turkey's energy demand is growing day by day and this brings some concerns such as the rising fuel dependence. Thus, Turkey set ambitious energy policies, which will provide energy independence for the country.

2.1.1. Electricity Consumption of Turkey

Turkey is a growing country and its energy consumption rises every year due to the industrialization and the growth of population. The primary electricity consumption of Turkey increased by 2,2% to 304 TWh in 2018 and its electricity generation went up by 2,5% to 304.8 TWh (Republic of Turkey Ministry of Energy and Natural Resources, 2018). Furthermore, the electricity consumption is expected to increase by 4,3% annually and to reach 375,8 TWh in 2023 according to the base scenario (Presidency of the Republic of Turkey, 2019).

2.1.2. Electricity Production of Turkey

Turkey generates electricity by various energy sources such as fossil fuels and renewable sources to meet its total electricity consumption. At the end of 2018, Turkey supplied its energy demand by 37,8 % coal, 30,3% natural gas, 19,7% hydropower, 6,5% wind, 2,6% solar, 2,4% geothermal and 1,3% from other sources. The installed power capacity of Turkey reached 88.551 MW by the end of 2018. This capacity consisted of 31% hydropower, 29,5% natural gas, 22,2% coal, 7,9% wind, 1,4% geothermal, 5,7% solar and 1,4% other sources (Republic of Turkey Ministry of Energy and Natural Resources, 2018).

2.2. Estimated Energy Overview in 2023

The year 2023 is the 100th year of the Turkish Republic. Thus, Turkey has many goals to achieve until 2023. In this study, 2023 energy goals were taken as a reference to achieve the 50% RES scenario. Main energy goals for 2023 are shown in Table 1 below.

Table 1. 2023 Energy and mining goals of Turkey (Presidency of the Republic of Turkey, 2019).

2023 Energy and Mining Goals of Turkey	
Primary Energy Demand (BTEP)	174279
Electricity Demand (TWh)	375,8
Rate of Natural Gas in the Electricity Production (%)	20,7
RES Share of Electricity Production (%)	38,8
Power Production by Indigenous Sources (TWh)	219,5
Total Installed Power Capacity (MW)	109474

Turkey's energy goals and investments were analyzed to build the most realistic energy system scenario for the year 2023. The power capacity expansions were determined according to estimated energy capacities and the economic growth of Turkey. Furthermore, the year 2018 was chosen as a reference year. That is why scenarios should have been shaped in 5 years period. So time limitations were also considered to create scenarios.

3. METHODOLOGY

The EnergyPLAN model was used to analyze and simulate Turkey's energy systems in this study. EnergyPLAN is an input/output hourly simulation tool that is used for energy system analysis at the national or regional level. The EnergyPLAN computer model was developed by Aalborg University, Denmark. This model is based on hourly values during a year. It also carries out technical simulations and market-economic simulations. A fundamental purpose of this model is to assist the design of regional and national energy system strategies and policies (Lund & Thellufsen, 2019).

The model has inputs and outputs. Inputs are renewable energy sources, demands, costs, installed power plant capacities. Outputs are energy balances, fuel consumption, total costs, import/exports, and annual productions.

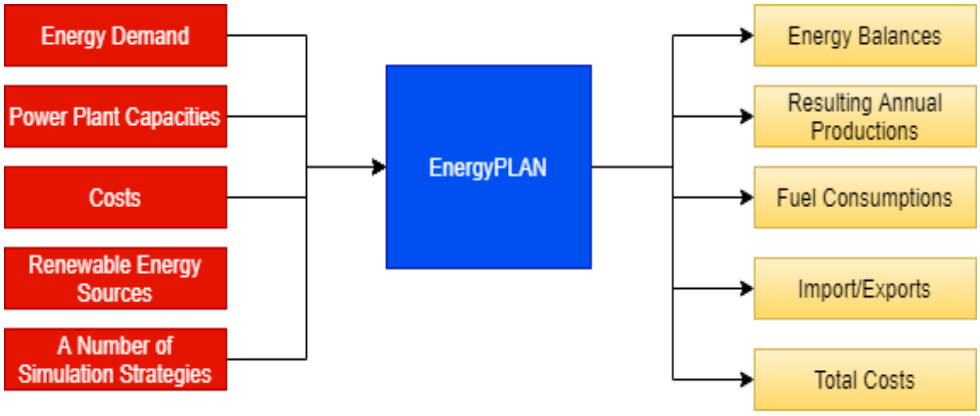

Figure 1. EnergyPLAN model input/output parameters.

Figure 1 shows those fundamental input/output parameters of the EnergyPLAN model. In this study, data of energy demand, power plant capacities, costs, and renewable energy sources were entered in the software for the reference and 50% RES scenarios. Moreover, output parameters such as total costs, annual productions were analyzed and compared.

4. ENERGY SCENARIOS OF TURKEY FOR 2018 AND 2023

A long term energy strategy of Turkey is to reach its energy independence. Turkey also wants to decrease its carbon emissions by shifting electricity production from fossil fuels to clean energy sources. Yet, Turkey cannot give up the coal in the short term because of the large amount of coal reserves which are existed in the Turkish territory. Turkey is going to decrease coal and natural gas imports for electricity production by using more domestic coal and renewable.

Nuclear energy is a part of Turkey's energy strategy for 2023. Akkuyu Nuclear Power Plant in Mersin is being commissioned nowadays and it is going to be operational with full capacity of 4800 MW until the end of 2023. Akkuyu nuclear power plant is going to produce annually 35 TWh electricity, which is almost 9% of total electricity demand in 2023 (Republic of Turkey Ministry of Energy and Natural Resources, 2020). Akkuyu nuclear power plant is also a vital part of this study. The fundamental aim of the energy scenario for 2023 is to model the country's energy system with lower carbon emissions, using more indigenous and renewable resources.

4.1. A Reference Energy Scenario and Model Validation

First of all, a reference energy scenario for a specific year was implemented to analyze and to compare energy scenarios. In this study, the year 2018 was chosen as a reference year due to the availability of real proven data. Moreover, the reference scenario was built for this year.

4.1.1. 2018 Reference Energy Model

The reference energy model is an existing energy system in 2018. The main purpose of this model is to compare results with the 50% renewable scenario for 2023. All approved energy system data in 2018 were obtained and inserted into EnergyPLAN software. Furthermore, the total electricity demand in 2018 is 304,2 TWh/year. The installed power capacity of Turkey by sources is shown below.

Table 2. Installed electricity capacity by sources in 2018 (EPIAS, 2018).

Resources	**2018 (MW)**
Hard Coal + Lignite	10213
Imported Coal	8939
Asphaltite	405
Fuel Oil	739
Natural Gas	25647
River Hydro	7749
Hydropower	20505
Geothermal	1260
Biomass + Waste	946
Wind Energy	6950

Along with the installed power capacities that are shown in Table 2, hourly electricity production data by sources in 2018 were taken from the EPIAS Transparency Platform. Hourly power generation data was loaded into EnergyPLAN software as text files for each source separately. The text files were created with vertically 8784 rows and this number represents the number of hours in a year.

EnergyPLAN analyses the installed power capacities and the hourly electricity generation and gives the most realistic output. The result of the reference model was compared with the real data and validated.

4.1.2. Model Validation

This scenario was created by real energy demand and supply data. All data were taken from energy balance tables (Republic of Turkey Ministry of Energy and Natural Resources, 2018) and EPIAS-Transparency Platform. After establishing the reference EnergyPLAN model, the output of this model was compared with EPIAS electricity generation and production data as shown in Table 3 below.

Table 3. Model validation between EPIAS data and EnergyPLAN model output.

Demand and Supply	**EPIAS Data (TWh/year)**	**EnergyPLAN Model Output (TWh/year)**	**Difference (%)**
Demand	304,2	304,2	0,01
Wind	19,85	19,9	0,25
Solar	5,76	5,84	1,37
Hydro-Dams	41,01	41,06	0,12
Geothermal	6,92	6,92	0,02
Hydro-Rivers	18,88	19,86	0,1
Thermal Power	203,7	205,53	0,89

As can be seen in the Table 3, differences between EnergyPLAN output and EPIAS data are in the acceptable range, which means all technical data such as the annual hourly supply and the demand data, were identified to the software correctly. Then, renewable energy and indigenous scenarios can be built on this reference scenario.

The result of the reference energy scenario shows that the RES share is 31,6% and the amount of yearly electricity production by renewables is 96,20 TWh/year.

4.1.3. Cost of Reference Energy Model

Costs of energy systems are another important parameter that needs to be analyzed. The estimated costs of the existing energy system capacity in Turkey were calculated and identified in the software. The annual fixed operation-maintenance and installed costs of power plants in 2018 were calculated, using the average of costs between 2010 and 2018. (IRENA, 2020)

Table 4. Costs of power plants (IRENA, 2020).

Type	Installed Cost (USD/kW)	Fixed O&M Cost (USD/kW)	Fixed O&M Cost (%)
Onshore Wind	1740	26,22	2
Solar	2366	15,19	1,15
Hydropower	3045	41,63	1,5
Geothermal	5268	113,29	4,22
Biomass	5800	125,19	3
Coal	3661	40,41	1,1
Natural Gas	954	12,15	1,27

The unit costs of power plants are shown in Table 4. These values were entered in EnergyPLAN software and calculated the total cost of all power plants in 2018, as 221770 MUSD.

Table 5. Costs of the reference energy scenario.

Costs	Amount (MUSD)
Variable Cost	997
Fixed Operation Cost	4059
Investment Cost	216713
Total Cost	221770

The given costs in Table 5 were calculated using the unit costs and installed power plants by sources. Total cost represents the cost of the existing Turkish energy system in 2018. By 2023, power capacity expansion will be carried out in 5 years period since 2018. Using the estimated capacity expansions from 2018 to 2023, the total installation cost to perform the 50% RES scenario is calculated.

4.2. The 50% Renewable Energy Scenario

After validating the reference energy scenario for the year 2018, the 50% renewable energy scenario for 2023, can be implemented by expanding the 2018 scenario.

The scenario is based on the high share of renewable in electricity production. As it is mentioned before, energy independence and high renewable energy penetration shape Turkey's energy strategy and policies. This scenario is a re-arranged version of Turkey's 2023 Energy Plan. The renewable energy capacity was expanded and energy dependency was reduced by ignoring petrol and imported coal and reducing the usage of natural gas in electricity production.

4.2.1 Power Capacity for the 50% RES Scenario

The installed capacity of the renewable energy system was increased by considering the renewable energy potentials of Turkey, time and policy limitations. 2019-2023 National Energy Strategic Plan of Turkey is also considered as a reference for determining installed power capacity by sources in 2023. According to this plan, estimated installed renewable and indigenous power capacities in 2023 are in Table 6 below.

Table 6. Installed power capacity goals for 2023 (Republic of Turkey Ministry of Energy and Natural Resources, 2020).

Sources	**Estimated Installed Power Capacities in 2023 (MWe)**
Solar PV	10000
Wind	11883
Geothermal	2884
Hydropower	32037
Indigenous Coal	14664

For the 50% renewable scenario in 2023, installed power capacities were expanded as shown below:

- **Coal:** 14664 MW
- **Natural Gas:** 19736 MW
- **Biomass:** 3400 MW
- **Nuclear:** 4800 MW
- **Solar:** 13950 MW
- **On-Shore Wind:** 15350 MW
- **Dammed-Hydro:** 24737 MW
- **River-Hydro:** 9650 MW
- **Geothermal:** 2450 MW

The electricity demand of Turkey is estimated to reach 375,8 TWh/year, according to the 2023 Energy and Mining Goals of Turkey which are shown in Table 6.

For expanding power capacity, the feasible energy potential of Turkey was used by taking Melikoglu's study (Melikoglu, 2016) as a reference. This study mainly discusses the role of renewable and nuclear energy for Turkey's 2023 vision by emphasizing theoretical and economical energy potentials by sources.

Table 7. Difference between installed power capacity goals for 2023 and the 50% renewable energy scenario.

Sources	Installed Capacity Goals in 2023 (MWe)	The 50% Renewable Energy Scenario for 2023 (MWe)	Difference (%)
Solar PV	10000	13950	39,5
Wind	11883	15350	29,18
Geothermal	1550	2450	58,06
Hydropower	32037	34387	7,33
Indigenous Coal	14664	14664	0
Natural Gas	19736	19736	0
Biomass	1334	3400	154,87
Nuclear	4800	4800	0

Table 7 shows the power capacity changes by sources between the installed capacity goals in 2023 and the %50 renewable scenarios for 2023. As can be seen in Table 7, there is a significant amount of power capacity growth in biomass, geothermal, solar PV and wind. On the other hand, the power capacity of natural gas and indigenous coal power plants remained stable. Since there is just one nuclear power plant, under construction in Turkey nowadays, the nuclear capacity was remained the same to provide a more realistic scenario. Power capacity growths were calculated carefully to obtain the most realistic scenario and results. Time, economic and political limitations were combined with the capacity potentials by sources in Turkey and the best and most realistic scenario was created.

EnergyPLAN is based on hourly simulation. That is why hourly electricity production files were also created for 2023 by the increasing hourly electricity production in 2018. According to installed power capacities, the

annual estimated electricity generation by sources is shown in Table 8 below.

Table 8. Annual electricity production and consumption for the 50% RES scenario.

Sources and Demand	Electricity Demand and Supply (TWh/year)
Electricity Demand	375,8
Wind	51,86
Solar PV	23,06
River Hydro	35,8
Dammed Hydro	53,37
Biomass	16
Natural Gas	77,8
Indigenous Coal	74,27
Nuclear	35
Geothermal	14,63
Import Electricity	0

Table 8 shows the annual estimated electricity production by sources and consumption for the 50% RES scenario. All power plants supply electricity demand since there is no import electricity.

Figure 4 shows the shares in electricity production by sources. As it can be seen in the figure that RES share makes up 50% of the total electricity generation as it is aimed. On the other hand, the share of natural gas is 20% as the energy goals of Turkey for 2023. Furthermore, the rate of indigenous and renewable is 70%. This rate is also significant to decrease the country's energy dependence.

4.2.2 Cost Analysis of the 50% RES Scenario

Increasing the installed power capacity causes investment costs. Along with investment costs variable and operational costs also grow. EnergyPLAN also calculates costs, when unit costs by sources are entered into the

software. The growth of power capacity was multiplied by the unit installed costs which are shown in Table 9. Then the total investment cost for 50% was obtained.

Table 9. Unit costs of power plants.

Type	Installed Cost (USD/kW)	Fixed O&M Cost (USD/kW)	Fixed O&M Cost (%)
On Shore Wind	1319	26,22	2
Solar	1331	15,19	1,15
Offshore Wind	4356	109,59	2,5
Hydropower	2752	41,63	1,5
Geothermal	2680	113,29	4,22
Biomass	4080	125,19	3
Coal	3661	40,41	1,1
Nuclear	6016	121	2
Natural Gas	954	12,15	1,27

In Table 9, unit costs of each power plant are shown by using data from U.S. Energy Information Administration, 2020. The cost analysis of this scenario was implemented using 2020 data.

Calculated total costs in 2018 and 2023 are the costs of the installed power capacity. Hence, the total costs for the 2023 50% RES scenario can be calculated by installed capacity expansions from 2018 to 2023. The amount of power plants' expansions is multiplied by the unit installed costs which are shown in Table 9. Then the total investment cost for 50% is obtained.

5. RESULTS AND DISCUSSION

Analyses in the EnergyPLAN software were implemented only for the electricity. Heating, cooling and transportation were not considered in this study. The reference energy scenario and the 50% renewable energy scenario were carried out in the software. Moreover, results were compared with each other. The main comparison parameters are RES electricity

production and annual CO_2 emission. These parameters show the benefits of renewable energy penetration in electricity production.

Table 10 describes the differences between the reference scenario and the 50% renewable scenario. The reference energy scenario represents the existing energy system of Turkey in 2018. On the other hand, the 50% renewable energy scenario is a target for this study. The main difference between these two scenarios is the renewable energy penetration in electricity production.

Table 10. Comparison between the reference energy scenario and the 50% renewable energy scenario.

Sources	**Reference Year 2018**	**The 50% Renewable Energy Scenario for 2023**	**Difference (%)**
Solar PV	5064	13950	175,47
Wind	6950	15350	120,86
Geothermal	1260	2450	94,44
Hydropower	27455	34387	25,25
Biomass	946	3400	259,41
Indigenous Coal	10213	14664	43,58
Natural Gas	25647	19736	-23,04
Nuclear	0	4800	

In Table 10, there is a significant growth in biomass, geothermal, wind, solar PV and indigenous coal power plants. Due to the government's energy policy, indigenous coal power plants have a high share of the installed power capacity. The target is based on the usage of indigenous and renewable sources. The annual renewable electricity production was estimated as 188,72 TWh/year for the 50% renewable scenario for 2023, while it is 96,2 TWh/year in the reference scenario for 2018.

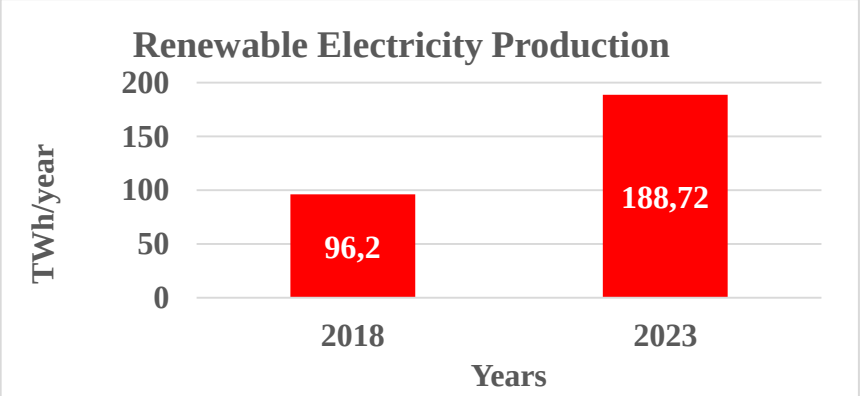

Figure 2. Renewable electricity production.

RES share in the power generation is the main target of this scenario, as can be seen in Figure 3 below. 188,72 TWh/year corresponds to 50,2% of total electricity production in the 50% RES scenario, while 96,2 TWh/year accounts for 31,6% of total power generation in the reference energy scenario.

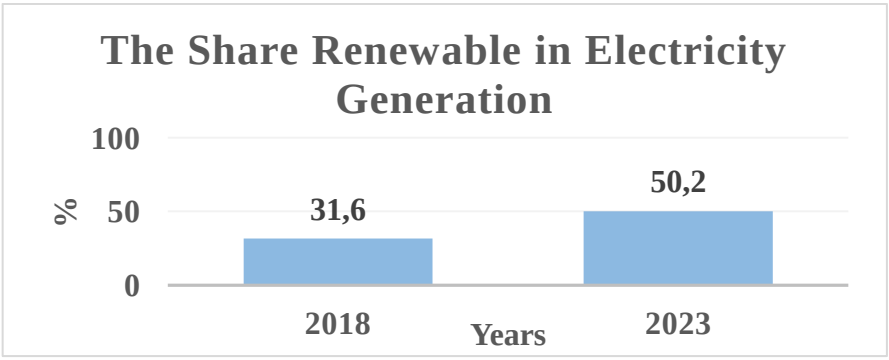

Figure 3. The share of renewable in electricity production.

CO_2 emission mitigation is one of the main goals of the Paris Agreement and global clean energy targets. To decrease the adverse effect of global warming, CO_2 emissions in the power generation should be reduced. That is why this parameter is a significant result of this study. Annual CO_2 emission

in 2018 and 2023 can be seen in Figure 4 below as a result of EnergyPLAN analyses of two scenarios.

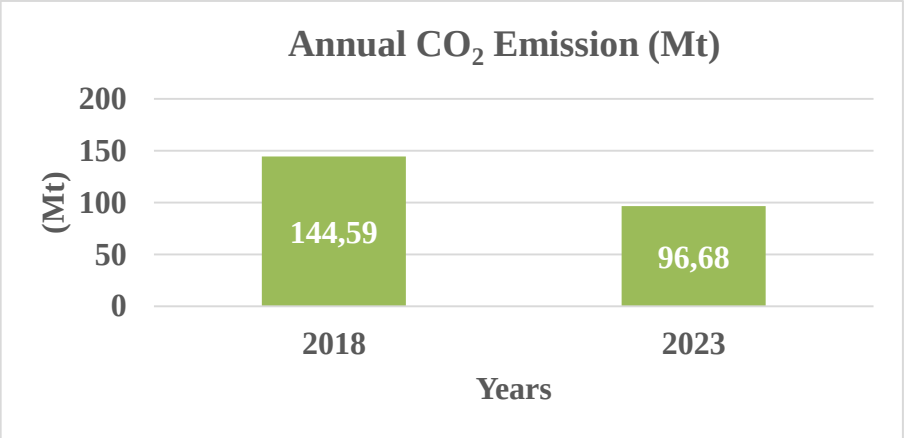

Figure 4. Annual CO_2 emissions.

As can be seen in Figure 4, CO_2 emission was decreased from 144,587 Mt to 96,683 Mt between 2018 and 2023 as a result of scenario analyses of EnergyPLAN.

5.1. Economic Analyses of Scenarios

Power plants have some expanses from the installation to the variable and fixed O&M costs. In this study, the scenarios have costs to perform and to maintain. High renewable energy penetration requires considerable investments. Higher RES share and more capacity expansions mean higher investment costs. This section shows the required investment costs to achieve the 50% RES scenario. The total investment cost of capacity expansions is the cost to achieve the 50% RES scenario.

The investment costs by type of power plants can be seen in Table 11. The total investment cost for the 50% RES scenario is 100357 M USD. Furthermore, there is 5 years time range between the two scenarios in 2018 and 2023. Then the total investment cost is divided by 5 and the annual total cost is obtained. In this calculation, the total annual cost is 20071,4 M USD.

This means, yearly 20071,4 million USD should be invested to perform the 50% RES scenario until the year 2023.

Table 11. Costs comparison between the reference energy scenario and the 50% renewable energy scenario.

Sources	**Capacity Expansions for 2023**	**Unit Costs (MUSD/MW)**	**Total Investment Cost (MUSD)**
Solar PV	8886	1,33	11827
Wind	8400	1,32	11080
Geothermal	1190	2,68	3189
Hydropower	6932	2,75	19077
Biomass	2454	4,08	10012
Indigenous Coal	4451	3,66	16295
Natural Gas	0	0,95	0
Nuclear	4800	6,02	28877
		Total	100357

CO_2 taxes and electricity transmission costs were not considered in this study. Costs of power plants were used to carry out the economic analysis of the scenarios.

The total investment cost is determined 100357 MUSD for achieving the 50% RES scenario. Nevertheless, Akkuyu nuclear power plant makes up more than a quarter of this amount by 28877 MUSD. When the nuclear power plant is ignored in the calculation, the cost of indigenous and renewable power plants is 71480 MUSD.

6. CONCLUSION

In this study, the 50% renewable energy system of Turkey for the year 2023 was performed. The results show that due to the time limitation, to achieve this scenario in 2023 is not a dream but challenging. A significant amount of investment is needed to implement this scenario. Akkuyu Nuclear Power Plant should be 100% operational till 2023 to assist in corresponding the energy demand. Furthermore, the installed capacity of renewable power plants should be increased more than the energy targets.

While the share of fossil fuels in the reference energy scenario was 68,4% in the electricity production, this share was decreased to approximately 40% in the 50% RES scenario. For this reason, the CO_2 emission was reduced from 144,587 Mt to 96,683 Mt. This fall is significant in the aspects of health, environmental and economic. Furthermore, this study shows that reducing a huge amount of CO_2 emission is possible by decreasing the share of fossil fuels in electricity production.

In the 50% scenario, the imported coal was ignored in the electricity share and the share of natural gas was decreased from 30,3% to 20%. This means, the energy dependency of Turkey was also reduced and a considerable amount of money was saved. The cost of lower CO_2 emission and 50% renewable share was obtained as 100357 MUSD. This value can be directly considered as the total cost of the 50% RES scenario.

Due to the time limitation and political targets, energy storage systems were not integrated into the 50% RES scenario. Because the storage integration to the power plants needs a considerable amount of money and time. However, the energy storage systems are needed for scenarios with a higher RES share.

To sum up, although performing a high rate of RES at the national level provides many benefits, it also causes a high amount of costs. However, this should be considered in many aspects such as health expenses,

environmental problems, which are caused by CO_2 emissions. Then the real cost of clean energy transition can be determined.

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