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A Retrospective Assessment of Türkiye's Recent Energy Policy in Terms of Energy Security and Climate Change Mitigation

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Abstract: Countries prioritize secure and cheap energy over clean energy in their energy policies, and Türkiye is no different. The Strategy Plan 2015–2019 of the Ministry of Energy and Natural Resources emphasizes the exploitation of domestic coal for energy security, while Türkiye intends to curb its emissions by 41% by 2030. These two targets contradict in terms of climate change mitigation. In retrospect, this study aims to determine the role of coal, wind, and solar power in energy policy-making through scenario analyses. The results indicate that if Türkiye continued its pre-2020 energy policy, its use of domestic coal would be important for energy security. On the other hand, both wind and solar have the capacity to contribute to the country's efforts towards energy security and climate change mitigation.

Keywords: Türkiye; energy policy; energy security; climate change mitigation; electricity

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1. Introduction

At the crossroads of the Balkans, the Caucasus, the Middle East, and the eastern Mediterranean, Türkiye, with its unique geographic position, is both a bridge and a barrier between Asia and Europe [1]. Having a population of 85.8 million with a USD 11,938.8 per capita GDP as per 2023, Türkiye is an upper-middle-class country with specific economic vulnerabilities [2]. Global environmental uncertainties in connection with climate change and Türkiye's highly import-dependent energy system exacerbate these risks for the wealth of the country.

Inefficient and below-global-average per capita electricity consumption, high demand increase, and foreign dependency with limited suppliers define Türkiye's energy profile [3]. Challenges that Türkiye is facing to securing energy include the large share represented by imported fuel in its economy, risks related to suppliers, high energy consumption, and the need for investments in the energy sector. The country's fossil reserves can only meet a small amount of demand. Türkiye imports 92% of its required oil and 99% of its natural gas [4], which means the country depends on foreign sources and suppliers. Russia (19% of oil, 53% of gas) and Iran (18% of oil, 17% of gas) [4] are the two biggest suppliers to Türkiye, and this heavy dependence on such politically, socially, and economically unstable countries creates vulnerabilities for Türkiye [4,5].

Based on the Development Plans, Türkiye has followed three major approaches to energy security in the past 60 years. The first four Development Plans describe energy security as "access to appropriate and accessible energy resources at low cost". The focus

during this period was engineering solutions and infrastructure development with the intention of increasing energy efficiency and sustaining economic activity. The second energy security approach is based on Türkiye's geostrategic position. The last four reports are concerned with energy security concerning international politics and energy markets. The final approach to energy security is shaped by environmental concerns. Specifically, since the 1992 United Nations Conference on Environment and Development, i.e., the Rio Conference or Earth Summit, sustainability has been consistently emphasized [5].

Nevertheless, local, regional, and global events change priorities. The 1973 oil crisis diverted attention towards the importance of domestic reserves. Türkiye accepted this stance, and coal became important for the country because it was used in electricity generation, steel, and cement industries. However, in the 1990s, Türkiye gave up reliance on domestic reserves and started importing energy sources. Thus, the share of imported fuel increased, and the country has since become energy dependent [6].

As a response to the aforementioned import dependence and global climate talks, Türkiye released its Supply Security Strategy in 2009. In particular, coal is prioritized, with the commitment being to exploit all reserves that were known by 2023. Besides this, renewables are emphasized, with the target being to reach a minimum 30% share with 20 GW wind in 2023. Finally, the strategy intends to lower dependence on natural gas for electricity generation below 30% [7]. Similarly, the Strategy Plan 2015–2019 of the Ministry of Energy and Natural Resources (MENR) focuses on energy supply security, and includes production and import, enhancing storage and distribution infrastructure, and demand management as fundamental elements of the concept. The Strategy Plan emphasizes the role of domestic sources in supply security and commits to increasing the contribution of domestic coal to electricity generation to 60 TWh by 2020. Along with coal, the utilization of wind and solar power is also emphasized [8]. Türkiye has adopted an energy policy similar to that from the pre-1990 period, but with the prime difference that environmental stresses are on the agenda. Despite the high fossil fuel dependence, Türkiye intends to reduce its greenhouse gas (GHG) emissions by 41% through 2030 in its updated Nationally Determined Contribution (NDC) (Türkiye's INDC: https://unfccc.int/sites/default/files/NDC/2023-04/T%C3%9CRK%C4%B0YE_UPDATED%201st%20NDC_EN.pdf, accessed on 15 April 2023). Moreover, National Renewable Energy Action Plans, prepared in response to the (2009/28/EC) European Commission Directive, accelerated the deployment of wind and solar power [9].

All forms of energy use create environmental problems. In today's world, the most challenging problem is climate change. The Fifth Assessment Report (AR5) Synthesis Report of the Intergovernmental Panel for Climate Change (IPCC) indicates that atmospheric CO_2 emissions between 1750 and 2011 were 2040 $\pm$ 340 $GtCO_2$, and about 40% of these, 880 $\pm$ 35 $GtCO_2$, remained in the atmosphere. The contribution of fossil fuel combustion and industrial processes to CO_2 emission increases was 78% in this period, and the increasing use of coal has changed the long-term trend of the reduced carbon intensity of the energy supply. Since 1970, CO_2 emissions from these sectors have tripled. In the ten years after 2000, the increase in GHG emissions was about 10 $GtCO_{2\text{-eq}}$, and 47% of this rise was related to the energy sector. In 2010, the energy sector was alone responsible for 35% of GHG emissions. Electricity and heat production alone was responsible for 25% of 49 $GtCO_{2\text{-eq}}$ in 2010 [10].

Other than GHG emissions, traditional fossil-fueled power generation is associated with substantial environmental degradation, such as air pollution, water pollution, land degradation, and habitat loss. Fossil fuel combustion releases harmful gases that impact air quality and public health [11–13]. Additionally, the extraction and transportation of fossil fuels may lead to habitat loss [12,13], as well as degradations in soil and water quality.

In contrast, renewable energy sources, such as wind and solar, generally have a lower environmental impact. For instance, wind and solar energy generation produce minimal emissions during operation, and have a significantly reduced carbon footprint compared to fossil fuels [14]. However, the production and installation of renewable energy technologies can still have environmental consequences, such as land use changes, habitat disruption, and resource extraction for materials. For example, large-scale solar farms may require significant land areas, which can lead to habitat losses for local wildlife [14,15]. Wind energy, for instance, can affect local bird and bat populations due to turbine collisions [12,13].

Türkiye's emission profile is presented in Figure 1. As shown, Türkiye's total carbon emission shows an increasing trend with GDP increases. However, Türkiye's population does not exhibit a sharp increase as carbon and GDP increase. According to the data from the World Development Indicators Database (WDI), Türkiye's total carbon dioxide emissions were 27,388.82 kt in 1965, and reached 345,981.45 kt in 2014. In almost 50 years, the country's emissions increased more than 10 times, GDP less than 10 times, and population 2.5 times.

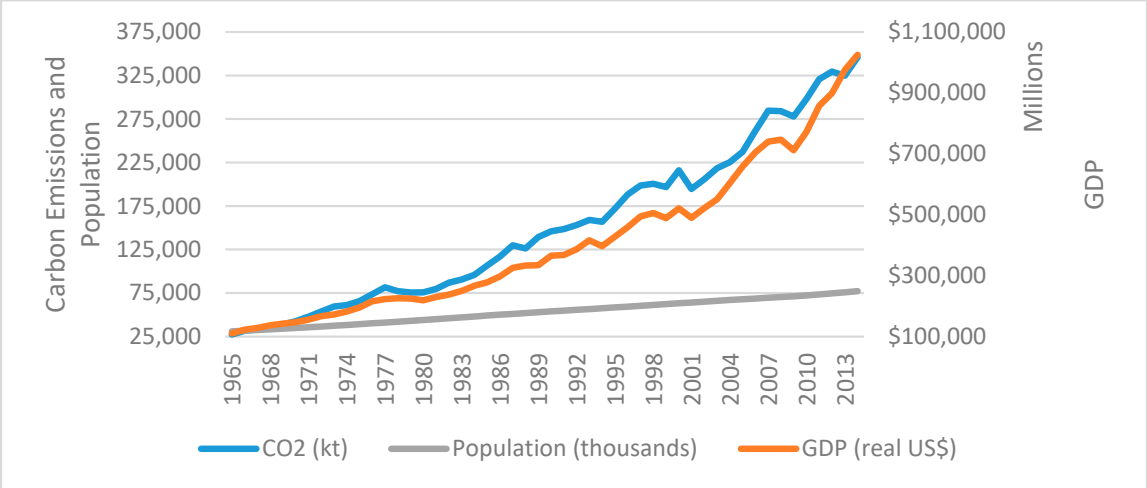


Figure 1. Türkiye's carbon emission profile (data source: WDI).

Energy security is a recently emerging concept in the Turkish literature. Energy security analyses for Türkiye have been undertaken by [16–21], which employed index analyses or models to quantify energy security. All these studies referred to Türkiye's historical energy security index and indicated the vulnerability of the country, but did not analyze the future. The following studies used econometric methods to analyze the issue. Refs. [22–26] investigated the determinants of supply security for Türkiye and emphasized the country's import dependence.

The relationship between carbon dioxide emissions and the Turkish electricity sector is a relatively hot topic, and is analyzed by [27–38]. These studies use economic or econometric models, and show that the fossil reliance of the country challenges it ability to meet mitigation targets, while also discussing renewables' potential role in emission reduction.

In light of the above discussion, the main objective of this study is to assess whether domestic coal utilization is a viable solution in the long term for addressing the energy security of Türkiye in the context of climate change discussions. This study also questions the role of solar and wind power in Türkiye's energy policy. It is based on scenario analyses that prioritize these domestic energy sources. The main contribution of this study to the literature is that it combines two seemingly unrelated research topics, energy security and climate change mitigation, and analyzes their interdependence, which is not evaluated in the referenced literature. Thus, the aim is to contribute to the evaluation of opportunities

for the Turkish power sector to address climate mitigation, as emphasized by [39]. After portraying the pre-COVID-19 world, and Türkiye in particular, the study provides a basis for comparing the outcomes of energy policies before and after COVID-19 and the Russia–Ukraine war. In other words, the study stops time in 2019, and forecasts a future following the prevailing conditions of that time.

2. Materials and Methods

2.1. Methodology

This study uses three panel equations (PE), constructed by [40], and conducts scenario analyses based on these equations. A panel of data is formed by the combination of cross-sectional units, e.g., people, households, firms and countries, who are observed over time. In other words, panel data are obtained by "pooling time-series of cross-sections" [41,42]. To form the panel data set, socioeconomic and energy-related data from 47 countries were gathered from the WDI Database, the BP Statistical Review of World Database, and the Data Explorer of International Energy Agency (IEA) [40].

The panel equations forming the basis of the analyses are given below.

$$PE1: lnCO2 = -2.42 + 0.21lnCTP + 0.03lnGTP - 0.005lnSP - 0.015lnWP + 0.439lnINDUSTRY + 0.042lnGDP + 0.64lnPOP$$

$$PE2: lnEI = 5.82 + 0.32lnCTP + 0.09lnGTP - 0.022lnWP - 0.698lnENERGYINTENSITY + 0.578lnGDP - 2.81lnPOP$$

$$PE3: lnEI = 0.16lnCTP + 0.12lnGTP - 0.016lnSP + 0.684lnGDP - 2.057lnPOP$$

Equation PE1 is used to forecast the carbon emissions of Türkiye. This equation explains the impacts of the independent variables (on the left) on carbon emissions, lnCO2. Equations PE2 and PE3 are used to forecast the energy imports, lnEI, of Türkiye. Due to the collinearity between lnWP and lnSP [40], the impacts of wind power and solar power on net energy imports are separately estimated by PE2 and PE3, respectively.

There are three business-as-usual (BAU) cases, which differ in terms of GDP increase, and four energy mix scenarios. Each scenario is repeated using two different population estimations: Turkish Statistics Institution (TUIK) and Organization for Economic Cooperation and Development (OECD).

For the forecast, Microsoft Excel TREND function (Microsoft 365 (Office)) is used to extend the data from 2017 to 2050.

2.2. Data and Forecast

The details of the data set used in the estimation of the panel equations given in the previous section are provided by [40]. The WDI Database, the BP Statistical Review of World Database, and the Data Explorer of the International Energy Agency (IEA) are used to obtain data for Türkiye. The descriptions of the variables used in this study are listed in Table 1, and Table 2 gives descriptive statistics. Except for population and GDP, the data set covering the 1990–2017 period is used for the forecast up to 2050. Population estimations are gathered from the TUIK and OECD forecasts for 2050. Future GDP is calculated with 4%, 4.5%, and 5% annual increase estimations based on the 2017 real value. The data set and forecast analysis as a Microsoft Excel file is available by the link provided by Supplementary Materials heading of this text.

Although the panel equations given in Section 2.1 can all be used to determine the variables, each has its own function. CO2 and EI are the dependent variables. CO2 is included because it is the prime concern in climate change, as it is a by-product of energy generation. EI is accepted as a proxy of energy security, meaning that the larger the net energy imports of Türkiye, the greater its dependence on energy imports. In spite of its associated air pollution and carbon emissions, coal will be used in electricity generation

in the coming decades because it already has a place in the energy mix and is able to generate constant power, and Türkiye still has large coal reserves, which the MENR aims to exploit. Therefore, CTP is included in the analyses. Noting that natural gas is imported by Türkiye, GTP is taken due for the same reasons that CTP is taken. SP and WP are included because they are the prime independent variables of this study, along with CTP, since these technologies offer hope for climate change mitigation. Moreover, their role in energy security is of interest. Sectoral energy consumption data are included since different sectors substantially contribute to climate change, play critical roles in energy security, and are affected by development. Energy intensity is a measure of energy efficiency, the "fifth fuel", and an indicator of a nation's commitment to climate change mitigation.

Table 1. Description of variables.

Variable	Label
CO2	Carbon dioxide emissions, millions of tonnes
EI	Net energy imports, million tonnes of oil equivalent
CTP	Electricity generation by coal, TWh
GTP	Electricity generation from natural gas sources, TWh
SP	Electricity generation by solar pv, gross output, TWh
WP	Electricity generation from wind power, gross output, TWh
NP	Electricity generation from nuclear power, TWh
INDUSTRY	Total final energy consumption by industry sector, ktoe
RESIDENTIAL	Total final energy consumption by residential sector, ktoe
ENERGYINTENSITY	Total primary energy supply by GDP, tonne per 2010 constant USD
GDP	Current billion USD
POP	Total population, million

Scenarios are run for Türkiye based on the three equations, PE1, PE2, and PE3, given before. Figures 2–4 show the trend equations used to forecast lnCTP, lnGTP, lnSP, lnWP, lnINDUSTRY, lnRESIDENTIAL, and lnENERGYINTENSITY.

Table 2. Descriptive statistics.

Variable	Obs	Mean	Std.Dev.	Min	Max
lnCO2	1292	4.81	1.618	0.693	9.133
lnEI	989	3.2	1.522	0	6.601
lnCTP	1188	3.117	2.242	−6.908	8.409
lnGTP	1232	2.248	2.33	−6.804	7.257
lnSP	785	−3.213	3.121	−11.513	4.769
lnWP	959	−1.226	3.108	−11.744	5.687
lnINDUSTRY	1292	9.316	1.568	5.864	13.837
lnRESIDENTIAL	1292	9.079	1.558	5.609	12.718
lnCARBONINTENSITY	1292	−1.12	0.695	−2.813	0.924
lnGDP	1292	5.631	1.587	1.388	9.877
lnPOP	1292	3.054	1.763	−1.367	7.234

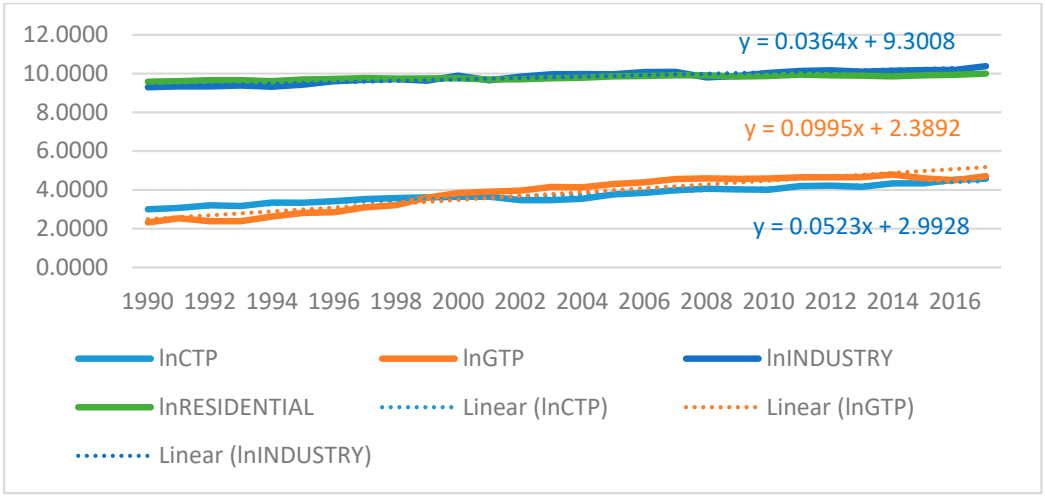


Figure 2. Trend equations used in forecast.

Figure 2 shows the pattern of independent variables, lnCTP, lnGTP, and lnINDUSTRY, over the period of 1990–2017. As seen, all variables increase smoothly in this period. The assumption is that this behavior continues for the forecast period until 2050.

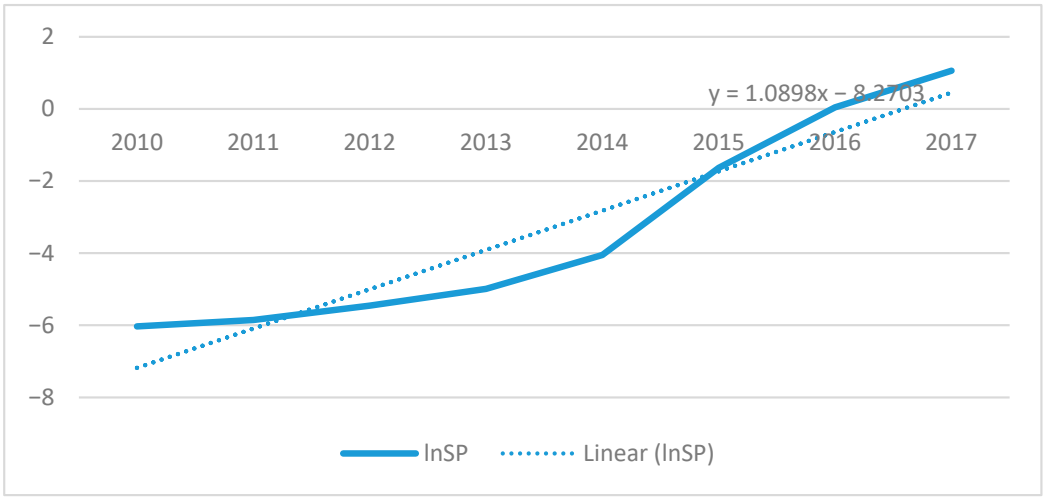


Figure 3. Trend equation for natural logarithm of solar power used in forecast.

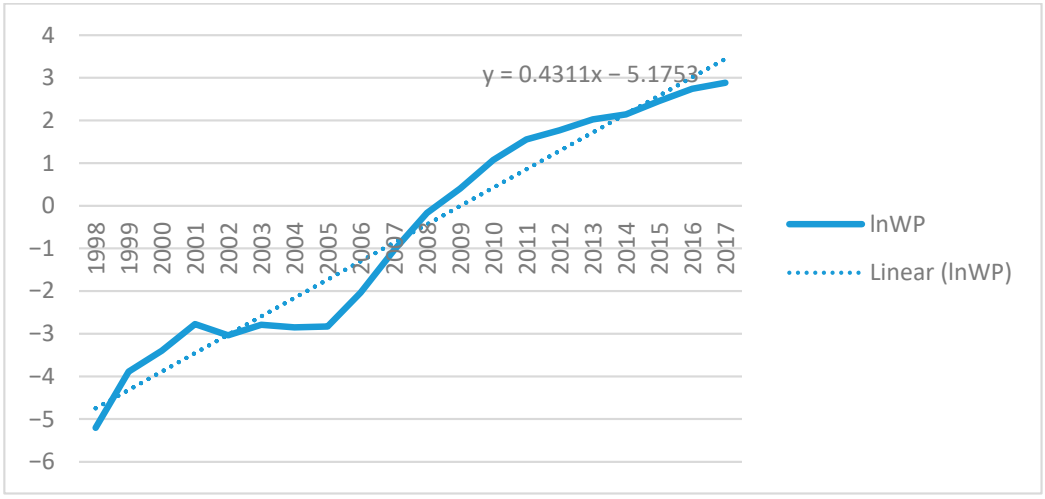


Figure 4. Trend equation for natural logarithm of wind power used in the forecast.

Figures 3 and 4 show the behaviors of lnSP and lnWP. Both variables show a sharp rise during their sampling periods. As for the other independent variables, lnSP and lnWP are assumed to follow these trends from 2019 till 2050.

3. Scenario Results and Discussion

As indicated before, there are three BAU scenarios determined by different degrees of GDP growth. There are four energy mix scenarios that are concerned with the maximum utilization of coal, solar, and wind. The Table 3 below is a summary of scenarios detailed by the preceding sections.

Table 3. Summary of scenarios.

Scenario	Assumptions	Determinant Variable
Business-as-Usual1 (BAU1)	All variables except GDP and POP increase according to historical trends.	GDP
Business-as-Usual2 (BAU2)	All variables except GDP and POP increase according to historical trends.	GDP
Business-as-Usual3 (BAU3)	All variables except GDP and POP increase according to historical trends.	GDP
60 TWh Domestic Coal (60TWhDC)	Electricity generation and GDP variables are real values. Domestic coal-based generation is 60 TWh by the end of 2019.	CTP
Full Domestic Coal (FullDC)	All domestic coal potential is used until 2033. The additional capacity is 13,670 MW. The annual increase in installed domestic coal capacity is 1000 MW. CF is taken as constant at the 2019 value for all years. WP, SP, GTP, and imported coal are kept constant at 2019 values.	CTP
45 GW Installed Wind (45GWWind)	All wind potential is used until 2050. The annual increase in installed wind capacity is 1200 MW. CF is taken as constant at the 2019 TEİAŞ value for all years, 38%. The average daily generation is 20 h. CTP, GTP, and SP are kept constant at their 2019 values.	WP
Maximum Solar Power (MaxSP)	Total solar potential is 46.8 GW, utilized until 2050. The annual increase in installed solar capacity is 1300 MW. The average net daily solar generation is 4 h. CTP, GTP, and WP are kept at their 2019 values.	SP

3.1. Business-As-Usual (BAU)

The BAU scenarios are run with the forecasted data described above for three GDP increase alternatives, 4%, 4.5%, and 5%. Future carbon emissions and energy import data are calculated by use of the equations given in Section 2.1.

As the TUIK and OECD population forecasts are almost equal, there is no significant difference between the two figures. Also, different GDP increases do not result in significant

distinctions. With a 4% GDP rise and TUIK population forecast, $lnCO2_{2018}$ is 6.367 and $lnCO2_{2050}$ is 7.305. With a 5% GDP rise and TUIK population forecast, $lnCO2_{2018}$ is 6.368 and $lnCO2_{2050}$ is 7.330. Therefore, for brevity, further results are shared only via the TUIK data.

lnEI with wind power in the energy mix is calculated by PE2. With a 4% GDP rise and TUIK population forecast, $lnEI_{2018}$ is 2.191, and $lnEI_{2050}$ is 3.512. With 5% GDP rise and TUIK population forecast, $lnEI_{2018}$ is 2.194, and $lnCO2_{2050}$ is 3.622.

lnEI with solar power in the energy mix is calculated by PE3. With 4% GDP rise and TUIK population forecast, $lnEI_{2018}$ is 1.745, and $lnEI_{2050}$ is 1.673. With 5% GDP rise and TUIK population forecast, $lnEI_{2018}$ is 1.754, and $lnEI_{2050}$ is 1.961.

As expected, both carbon emissions and energy imports, i.e., energy dependency, increase under BAU scenarios.

3.2. 60 TWh Domestic Coal-Based Generation

This scenario is actually a target designated in the 2015–2019 Strategic Plan [8], which aims for 60 TWh electricity generation from domestic coal by the end of 2019. The purpose here is to assess whether the target is attained and to evaluate its impact on emissions and energy security in 2018 and 2019. Unlike BAU scenarios, real data are used, except for in the lnINDUSTRY, lnENERGYINTENSITY, and lnPOP variables. Electricity generation data are obtained from the TEİAŞ electricity statistics webpage (TEİAŞ, 2020, Elektrik İstatistikleri Türkiye Elektrik Üretim–İletim İstatistikleri, https://www.teias.gov.tr/tr-TR/turkiye-elektrik-uretim-iletim-istatistikleri, last access on 27 May 2021), and GDP is taken from the World Bank database (The World Bank Group, 2021, GDP (current USD)–Türkiye, https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=TR, last access on 27 May 2021). The 2018 and 2019 carbon emissions and energy import data are calculated by use of the equations given in Section 2.1.

The electricity generation information from TEİAŞ does not provide distinct data for all domestic coal types. Therefore, from the installed capacities given by TEİAŞ, electricity generation from domestic coal is estimated. The calculation results are tabulated in Table 4, revealing that 60 TWh by the end of 2019 was not attained.

Table 4. Approximation of electricity generation from domestic coal.

Year	MENA Domestic Coal Generation Target (TWh)	TEİAŞ Hard Coal + Imported Coal + Asphaltite (TWh)	TEİAŞ Lignite (TWh)	Hours/Day Lignite Used for Electricity Generation	Hard Coal + Asphaltite (TWh)	Total Domestic Coal (TWh)	CF by TEİAŞ for Fossil Fuel
2013	32.9						
2015	40	44.83	31.34	15.93	4.39	35.73	0.622
2016		53.70	38.57	18.41	5.07	43.64	0.629
2017	50	56.78	40.69	19.02	5.43	46.13	0.642
2018		68.16	45.09	19.94	5.70	50.78	0.655
2019	60	66.02	46.87	19.26	5.50	52.37	0.669

realized; estimate.

Besides this, based on the real values and TUIK population forecast, $lnCO2_{2018}$ is 6.390 and $lnCO2_{2019}$ is 6.395. $lnEI_{2018}$ is 2.181, and $lnEI_{2019}$ is 2.145 with wind power. With solar power in the energy mix, $lnEI_{2018}$ is 1.661 and $lnEI_{2019}$ is 1.604.

Compared with BAU, the lnCO2 results are slightly higher and the lnEI results are slightly lower. The difference in lnEI is higher for the equation using lnWP.

3.3. Full Domestic Coal (FullDC)

This scenario assumes the utilization of all potential domestic coal in electricity generation, which is calculated to yield an additional 13,670 MW by [35]. The scenario is run considering a 1000 MW increase in annual installed domestic coal capacity until 2033, while keeping all other electricity generation variables constant at the real 2019 values. The capacity factor is also taken as remaining constant from 2019 (see Table 4).

Different degrees of GDP increase do not result in significant distinctions. With a 4% rise in GDP and TUIK population forecasted, $\ln CO2_{2018}$ is 6.435 and $\ln CO2_{2033}$ is 6.920. With 5% rise in GDP and TUIK population forecasted, $\ln CO2_{2018}$ is 6.436 and $\ln CO2_{2033}$ is 6.933.

Energy security with wind power in the energy mix is calculated by PE2. Different GDP increases do not result in significant distinctions. With a 4% rise in GDP and TUIK population forecasted, $\ln EI_{2018}$ is 2.274 and $\ln EI_{2033}$ is 2.756. With a 5% rise in GDP and TUIK population forecasted, $\ln EI_{2018}$ is 2.277 and $\ln EI_{2033}$ is 2.809.

Energy security with solar power in the energy mix is calculated by PE3. Different GDP increases do not result in significant distinctions. With a 4% rise in GDP and TUIK population forecasted, $\ln EI_{2018}$ is 1.818 and $\ln EI_{2033}$ is 2.066. With a 5% rise in GDP and TUIK population forecasted, $\ln EI_{2018}$ is 1.827 and $\ln EI_{2033}$ is 2.206.

Compared with the results for BAU, all the outcomes of this scenario are higher. The calculation is performed as in the 60TWhDC scenario, and it is found that including domestic coal in electricity generation reduces the total energy imports by 91.25% in 2033. However, CO_2 emissions increase almost 7-fold in comparison to the 1990 value (136.442 million tonnes).

3.4. 45 GW Installed Wind Capacity (45GWWind)

This scenario aims for the full utilization of wind potential in electricity generation until 2050. The assumption is that the annual installed wind capacity increases by 1200 MW. All other electricity generation data are kept constant at their real 2019 values. Also, the capacity factor for wind is kept as the 2019 TEİAŞ value, 38%. This scenario takes energy efficiency into account due to PE2, and makes a positive contribution to energy security.

PE1 indicates that different GDP increases do not result in significant distinctions. With a 4% rise in GDP and TUIK population forecasted, $\ln CO2_{2018}$ is 6.400, and $\ln CO2_{2050}$ is 7.124. With a 5% rise in GDP and TUIK population forecasted, $\ln CO2_{2018}$ is 6.401 and $\ln CO2_{2050}$ is 7.149.

PE2 also shows that different GDP increases do not result in significant distinctions. With a 4% rise in GDP and TUIK population forecasted, $\ln EI_{2018}$ is 2.226 and $\ln EI_{2050}$ is 3.126. With a 5% rise in GDP and TUIK population forecasted, $\ln EI_{2018}$ is 2.230 and $\ln EI_{2050}$ is 3.236.

Compared with the BAU and FullDC results, all the outcomes of this scenario are lower. In other words, investing in wind power reduces both carbon emissions and energy imports. Regarding the impact of energy efficiency, which is represented by lnENERGYINTENSITY, PE2 emphasizes that if Türkiye gives priority to wind power, it will need energy-intensive, i.e., inefficient, power technologies in order to lower its energy imports. This means that coal should be used along with wind due to the latter's intermittent character. Otherwise, the high reliance on wind power might necessitate more energy imports.

3.5. Maxiumum Solar Power (MaxSP)

This scenario aims at the maximum utilization of solar potential in electricity generation, which is 46.8 GW installed capacity, as estimated by [35]. The assumption is that the installed solar capacity increases by 1300 MW annually up to 2050. All other electricity generation data are kept constant at their real 2019 values. The average daily net electricity generation duration is taken as 4 h.

PE1 discusses carbon emissions. Increases in GDP do not yield a remarkable difference. With a 4% rise in GDP and TUIK population forecasted, $lnCO2_{2018}$ is 6.400 and $lnCO2_{2050}$ is 7.139. With a 5% rise in GDP and TUIK population forecasted, $lnCO2_{2018}$ is 6.401 and $lnCO2_{2050}$ is 7.164.

Unlike in other scenarios, PE3 reveals that GDP increases matter in Max SP. With a 4% rise in GDP and TUIK population forecasted, $lnEI_{2018}$ is 1.781 and $lnEI_{2050}$ is 2.185. With a 5% rise in GDP and TUIK population forecasted, $lnEI_{2018}$ is 1.789 and $lnEI_{2050}$ is 2.473. This result confirms those of [43] and implies that GDP is an important factor in solar deployment.

Compared with all other scenarios, the results for MaxSP are lower than those for BAUs and FullDC. However, the 45GWWind emission forecast yields results lower than those for MaxSP (see Figures 5 and 6), while MaxSP shows better outcomes in terms of energy security (see Figure 7).

In brief, relying on domestic coal exacerbates CO_2 emissions, but wind power and solar power may be beneficial in helping Türkiye to reach its emission reduction targets (see Figure 5). These results are in line with those from the literature referred to above. According to Figure 6, among the technologies analyzed in this study, wind power is more promising in lowering carbon emissions, i.e., achieving climate change mitigation, while Figure 7 highlights the benefits of solar power to securing energy, which exceed those of wind. The former outcome is attributed to the intermittent character and smaller capacity factor of solar power, since wind can generate more power than solar. The latter outcome is attributed to the off-grid use potential of solar power. The results of the manual calculations of Türkiye's domestic coal-based power generation are positive in the context of the country's energy security, but these come at the expense of climate change mitigation efforts.

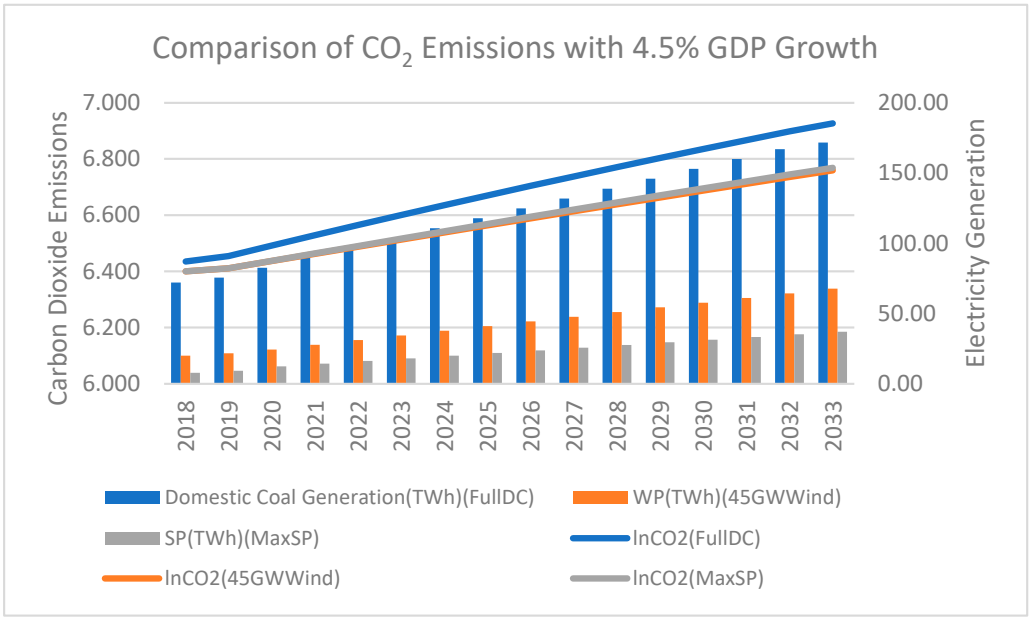


Figure 5. Comparison of carbon emissions with domestic sources.

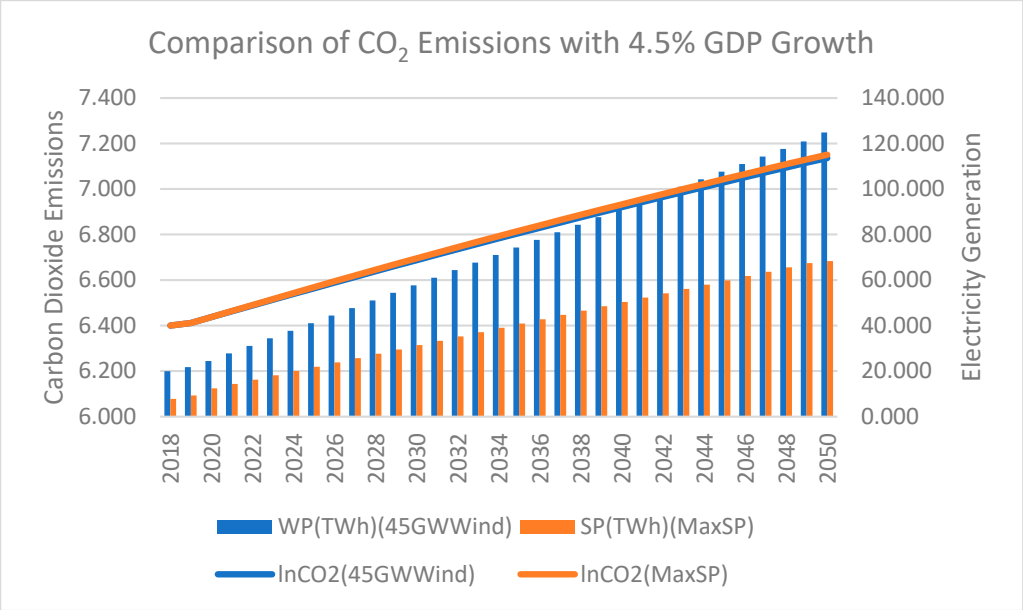


Figure 6. Comparison of carbon emissions between WP and SP.

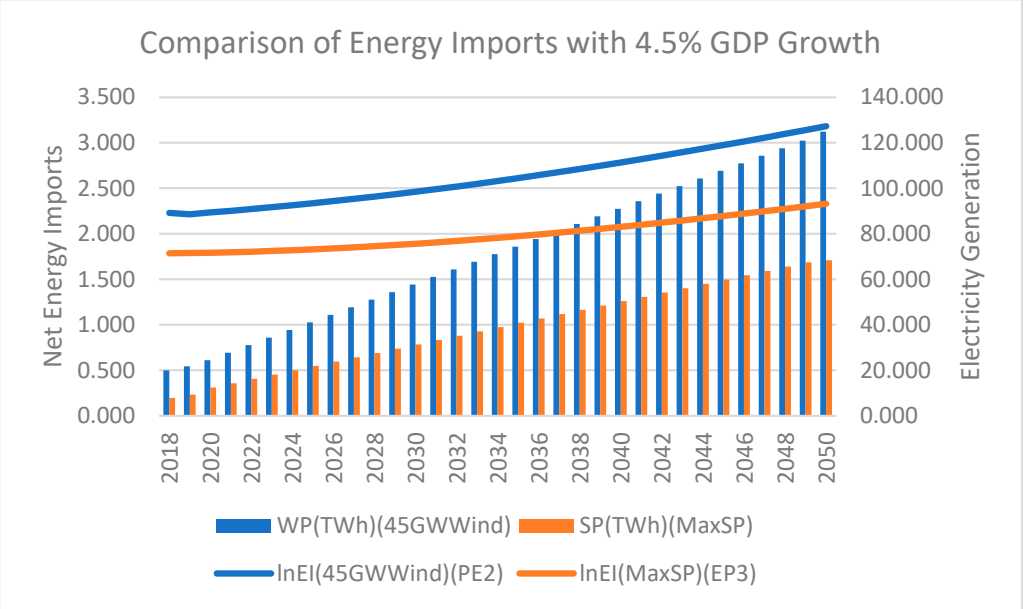


Figure 7. Comparison of levels of energy security between WP and SP.

In terms of linear values, the above results are repeated (see Figures 7–9). Under the FullDC scenario, in 2033, the CO_2 emissions will increase to 1018.943 million tonnes, which is 747% higher than the 1990 value. With the 45GWWind and MaxSP scenarios, the CO_2 emissions in 2033 are forecasted to reach 861.949 million tonnes (632% rise) and 870.146 million tonnes (638% rise), respectively. These values will be 1256.726 million tonnes and 1275.693 million tonnes in 2050, respectively. Comparing energy import results, we see that the 45GWWind scenario achieves 24.077 mtoe in 2050, while the MaxSP scenario results in 10.273 mtoe, which is less than half the value of wind power. Ref. [24] gives similar results in terms of renewables' contributions to energy security in Türkiye.

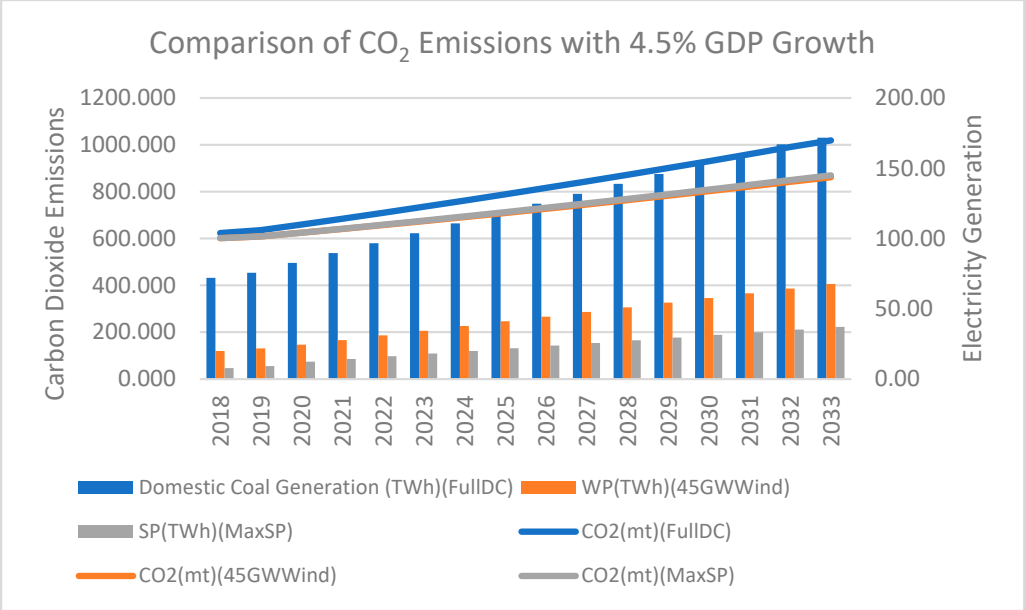


Figure 8. Comparison of carbon emissions with domestic sources.

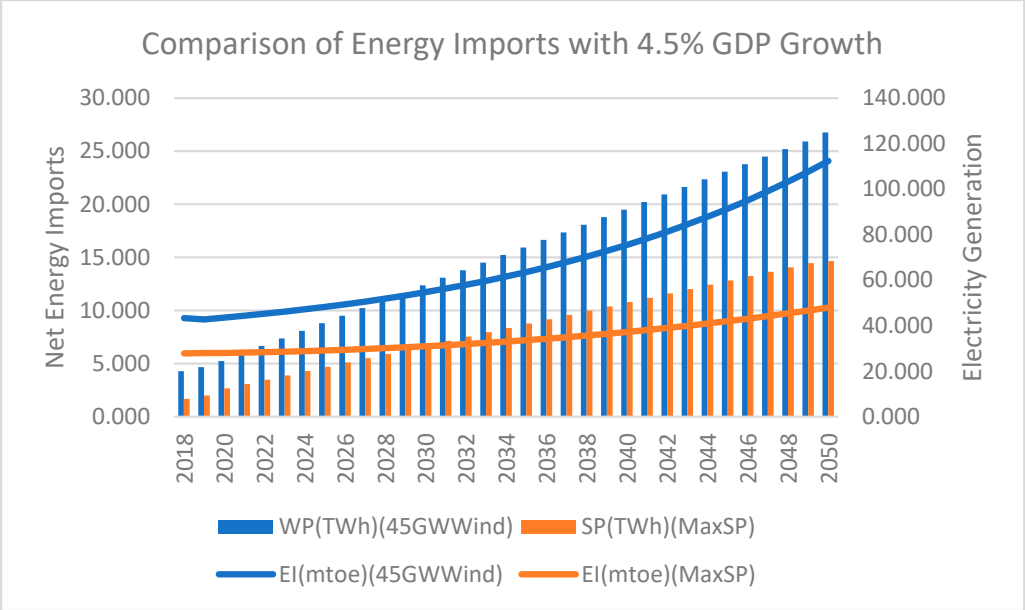


Figure 9. Comparison of energy security between WP and SP.

The updated NDC of Türkiye sets the target of "up to 41% reduction in GHG emissions by 2030". BAU scenarios show a forecasted rise of 213%, while the Full DC scenario yields a forecasted rise of 232%. The 45GWWind and MaxSP scenarios yield a doubling of emissions in 2030 compared with the 2012 values. Refs. [27,28,36] give similar results, emphasizing the role of renewables in emission reduction. It is thus safe to say that investing in renewal energy-based power generation may contribute to the attainment of emission reduction targets in Türkiye, however, only changing the electricity generation technology or fuel used will be insufficient for achieving climate change mitigation.

4. Conclusions

Although environmental pressures, along with others, dominate the daily life and perceptions of the public in Türkiye, policies in the country fail to address these realities and the expectations of the public. Energy policies are shaped by economic and/or political

priorities. For instance, the Strategy Plan of MENR [8] emphasizes electricity generation security over environmental problems related to the power sector. The Ministry's main objective in the plan for securing electricity supply is the exploitation of domestic coal rather than prioritizing investment in solar and wind power. This study is thus developed in this context.

Inefficiency, below-global-average per capita electricity consumption, high demand increases, and foreign dependence on limited suppliers define Türkiye's energy profile [3]. Challenges that Türkiye faces in securing energy include the large share of imported fuel in the economy, risks related to suppliers, increasing levels of energy consumption, and the need for investments in the energy sector. The country's fossil reserves are able to meet only a small amount of its needs. Russia and Iran are the two biggest suppliers to Türkiye, and this heavy dependence on such politically, socially, and economically unstable countries creates vulnerabilities for this country [4,44]. Despite this high level of dependence on fossil fuels in power generation, Türkiye intends to reduce its greenhouse gas (GHG) emissions by 41% by 2030, as stated in its updated Nationally Determined Contribution (NDC). Thus, Türkiye has challenged herself to not lag behind in global climate diplomacy.

There are three ways to maintain energy security: "managing energy demand, increasing domestic energy supply, and increasing the reliability of imported or domestic supplies". Nations can reduce their energy supply vulnerability by reducing demand or increasing efficiency, restructuring and arranging stockpiles, preparing plans for emergency conditions, increasing the share of alternative domestic supplies, diversifying external supplies, and taking "diplomatic, industrial and military measures" [45,46]. Similarly, Strategy Plan 2015–2019 of the Ministry of Energy and Natural Resources [8] focuses on energy supply security, and accepts production and import, enhancing storage and distribution infrastructure, and managing demand as fundamental elements of the concept. The Strategy Plan emphasizes the role of domestic sources in supply security and commits to increasing the contributions of domestic coal to electricity generation. Along with coal, the utilization of wind and solar power is also indicated.

According to the sector reports of the Turkish Electricity Transmission Corporation (TEİAŞ) (Sector Reports of Turkish Electricity Transmission Corporation: https://www.teias.gov.tr/tr-TR/sektor-raporlari, last access on 22 March 2020), the installed capacity of the country increased every year during 2015–2019; here, the share represented by fossil fuels was always the largest, and considerably increased in 2016 and 2017, as did other non-fossil sources. Regarding the latter, their share significantly increased, with solar showing the largest rise, even larger than the rise in fossil fueled-power plants. Specifically, during 2015–2019, the rise in installed capacity for solar was 5350.4 MW, whereas the same for fossil fuels was 4909 MW, and the total for non-fossil fuels was 11,877.7 MW, almost 2.5 times greater than the rise for fossil-based sources. In brief, Türkiye showed progress, although only slight, towards accomplishing its security and sustainability goals in the energy context in the pre-2020 years.

Based on this progress, in retrospect, this study aims to evaluate the role of domestic coal, solar, and wind in securing the electricity supply of Türkiye, and in fulfilling its efforts towards climate change mitigation. The results for different scenarios indicate that relying on domestic coal exacerbates CO_2 emissions, but using wind power and solar power may be beneficial in helping Türkiye to reach its emission reduction targets. Among the technologies analyzed, wind power is more promising in terms of lowering carbon emissions, i.e., achieving climate change mitigation, while solar power is helpful for securing energy. Also, Türkiye's use of domestic coal is important in securing its electricity supply.

In linear terms, the BAU scenarios forecast a rise of 213%, while the FullDC scenario forecasts an increase of 232% in carbon emissions. The 45GWWind and MaxSP scenarios reveal a doubling of emissions in 2030 compared with 2012 values. Considering the NDC of Türkiye, investing in renewal energy-based power generation may contribute to the attainment of emission reduction targets in this country, however, only changing electricity generation technology and/or the fuel used is not adequate for climate change mitigation.

If Türkiye preserved its pre-2020 energy policy approach, it would reduce its energy dependency by exploiting more domestic coal, wind and solar power. However, the results indicate that resuming the pre-2020 approach might not help the country to attain its emission reduction targets with similar success. The Strategy Plan of MENR [8] does not specify renewable targets. Thus, this study assumes a steady rise in the share of wind and solar until 2050, which is not viable, as the results prove. Therefore, Türkiye needs to define renewable installation targets in its policy documents. In the meantime, the country should renovate the grid to become resilient against the intermittency of solar and wind.

Also, each power source may contribute to the resolution of a different problem. As the scenario results indicate, investing in solar energy will be helpful to securing energy, while wind power will be more helpful to mitigating climate change. This result is attributed to the off-grid use potential of solar power. Thus, Türkiye requires more research on innovative uses of solar capacity. The building code may be revised to oblige owners to mount solar panels on rooftops and suitable façades, not only for power generation but also for hot water supply. Moreover, the development planning law and municipal laws should be amended to impose conditions that promote the use of solar power in public areas. Wind power is limited to certain locations and atmospheric conditions. Thus, Türkiye should prioritize investment in wind to improve its potential availability. To facilitate the energy transition, finance is a crucial factor. Subsidies, grants and low-interest loans are resources offered by public funding. To encourage private sector tax credits, feed-in tariffs or renewable energy certificates may be used. The government also has the choice to issue green bonds to raise funds for solar and wind investments. One other option is funding through the use of international loans.

Furthermore, the results indicate that only changing power generation technology is not sufficient to attain policy targets. Türkiye needs to manage demand via fiscal and administrative measures. Instead of a constant tariff, one that is adjusted to power consumption may reduce demand and indirectly contribute to energy efficiency. Finally, reducing working hours, accelerating automation in bureaucracy, and rescheduling energy-intensive public activities, e.g., night football games, would help to regulate demand.

This study assumes a static Türkiye after 2019. Thus, the basic limitation of the analysis is that it does not consider the impacts of global events like COVID-19, current wars, and national economic, political or social issues. Also, the study neglects to consider potential improvements in power generation technology and consumption efficiency. Global and local energy prices might be included to forecast the cost imposed on the public. The true cost of energy security might be calculated with consideration of the externalities emerging because of electricity generation. Finally, the impacts of the introduction of electric vehicles into the system on electricity demand and supply security need to be contemplated.

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Nomenclature

Abbreviation	Explanation
BAU	Business-As-Usual
CTP	Coal-fired Thermal Power
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GTP	Gas-fired Thermal Power
IEA	International Energy Agency
IPCC	Intergovernmental Panel for Climate Change
MENR	Ministry of Energy and Natural Resources
mtoe	Million Tons Oil Equivalent
NDC	Nationally Determined Contribution
OECD	Organization for Economic Cooperation and Development
PE	Panel Equation
SP	Solar Power
TEİAŞ	Turkish Electricity Transmission Corporation
TUIK	Turkish Statistics Institution
TWh	Terawatt Hours
WDI	World Development Indicators Database
WP	Wind Power

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