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How May New Energy Investments Change the Sustainability of the Turkish Industrial Sector?

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Abstract: Utilization of renewable energy in the Turkish industrial sector is becoming more important nowadays. The tendency toward renewable energy can be clearly seen with newly planned energy investments. The energy appearance of the Turkish industrial sector for past two decades and ongoing energy projects are discussed in this study with the help of sustainability indicators. The sustainability index is based on advanced exergy analysis and shows the environmental impact of production processes and measures the transformation of energy resources in the Turkish industrial sector. This index was approximately 2.03 in 2000 and it improved to 2.25 in 2008, and then remained constant with minor fluctuations until 2019. Depending on the fulfillment of the continuing fossil, nuclear, and recommended renewable energy investment scenarios, the sustainability index may change to between 1.96 and 2.17 by 2023. None of the ongoing investments will make a major improvement in the sustainability of the industrial sector; therefore, a major shift toward the use of more renewable energy is urgently needed. Establishing solar or wind energy microgrids plants may improve the sustainability indicators drastically, therefore, encouragement of their investments is very important.

Keywords: fossil energy; microgrids; nuclear energy; renewable energy; sustainability indicators; Turkish industrial sector

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1. Introduction

Nowadays, Turkish industry sector has changed its attitude towards renewable energy and are willing to invest in renewable energy. This situation can be considered unique because it is mainly driven by the Turkish economic environment. Steadily increasing currency exchange rate and energy prices have forced producers to invest in renewable energy. In this study, the reason for this change is sought in the history of energy utilization of Turkish industry sector and we aim to assess the future targets of renewable energy utilization.

Renewable energy brings lots of opportunity and challenge to society. Ntanos et al. [1] investigated the relation between renewable energy consumption and economic growth. Al-Mulali et al. [2] examined the relation between renewable energy consumption and economic growth for high-income, upper-middle-income and lower-middle-income countries. Karimi and Chashmi [3] discussed the green entrepreneurship in sustainable development for the case of Tehran. Similar research was conducted by Skordoulis et al. [4] for Greece. Yang [5] investigated the effectiveness of single European electricity markets and effect of the European Union Emission Trading Scheme (EU-ETS) on the greenhouse gas emission of European Union countries. Yang [6] also discussed the connectedness between economic policy uncertainty and oil price shocks.

In 2020, 30.6% of the total energy used in Turkey was allocated to the industrial sector and followed by the transport (24.5%), residential (21.4%), commercial and public services sector (12.9%), non-energy use (6%), agriculture/forestry (4.5%) and fishing (0.1%) [7]. Determination of the sustainability level of energy utilization may be achievable by using exergy-based evaluation. Exergy analysis makes it possible to take full advantage of the available energy [8]. Such analyses were already carried out for many sectors including construction [9], food [10–12], manufacturing [13], chemical [14] and agricultural industries [15]. In sector-wise assessments, Bühler et al. [16] reported that the exergy efficiency of the processes in the Danish industrial sector was in the range of 12–56%. In 2013, Ghandoor et al. [17] estimated that the average energy and exergy efficiency of the Jordanian small and medium-sized enterprise sectors were 78.3% and 37.9%, respectively, and the embodied energy and inefficiencies were 58.9% and 21.2%, respectively. Using component-based process analyses, Mascarenhas et al. [18] estimated that in Brazil, the most energy-intensive equipment was industrial air compressors, and their exergy efficiency ranged from 5.27% to 21.94%. While conducting exergy analysis for the medical drug production process in Turkey, Yavuztürk et al. [19] made a similar observation. Air compressors have numerous moving parts subject to a high level of friction, therefore producing a high level of irreversibility. Miranda et al. [20] stated that in the industrial sector of Mexico, exergy consumption increased from 1350 PJ in 2000 to 1591 PJ in 2015, and in this country, the average energy and exergy efficiencies were 78% and 23%, respectively. Similarly, Dincer et al. [21] estimated that the exergy efficiency in the industrial sector of Saudi Arabia was approximately 40%. After conducting advanced exergy analysis in the industrial sector of Bangladesh, Chowdhury et al. [22] found that the depletion numbers ranged from 43% to 45%, and the sustainability index was in the range of 2.21 to 2.32.

There are already excellent sector-based exergy analyses focusing on the Turkish industry available in the literature [23–27]. However, this study will carry this knowledge one step further by integrating with the sustainability indicators and try to discuss the effect of the international and national fluctuations (global crisis, subsidy mechanism, price variation, etc.) on the industry sector needs and its energy demand. These fluctuations affect energy investment and policy decision making.

New renewable energy investments are important because they have a key role in Turkey's plan for fulfilling its commitments to the Paris Agreement.

Sustainability indicators may help to measure and enhance the understanding of transformation of energy utilization in the Turkish industry sector. The changes of sustainability indicators in the last two decades are analyzed to offer policies to improve the energy resource utilization and reduce emissions. New energy investments require new assessment of the Turkish industrial sector. In conclusion, five possible future scenarios that cover planned and ongoing renewable energy projects are evaluated by using sustainability indicators. The next section covers the methods used. Insight and results are shown in Section 3. Concluding remarks are presented in Section 4.

2. Methods

Renewable energy recourses (solar, wind, biomass, etc.) are very important [28–33], not only for the environment, but also for sustainable development. Exergetic evaluation of sustainability indicators provides helpful information about the environmental impact of human activity. Sustainability indicators are used to measure the environmental impact of renewable energy investment in the Turkish industry sector. Depletion number (D), Sustainability Index (SI), Renewable Fraction (RF), Non-renewable Fraction (NRF) and Exergy Destruction Coefficient (EDC) are evaluated by using the exergy concept of thermodynamics.

In the present study, the methodology used by Chowdhury et al. [22] is followed to evaluate energy and exergy utilization in the Turkish industrial sector. First, energy and exergy consumption data are used to determine a weighting factor, i.e., the ratio of energy or exergy supplied by the individual energy source to the total energy or exergy supplied to the sector. Then, the weighted mean energy or exergy efficiencies are determined by multiplying the weighting factor with operation ratings of each energy source. Finally, the overall energy and exergy efficiencies are calculated by summing up the weighted mean energy or exergy efficiencies of each source.

Mass, energy, and exergy balances for the thermodynamic analysis are established in Equations (1)–(3), respectively:

$$\sum m_{in} = \sum m_{out} \tag{1}$$

$$\sum (mh)_{in} - \sum (mh)_{out} = \mathrm{W} - \mathrm{Q} \tag{2}$$

$$\sum (m \cdot ex_c)_{in} - \sum (m \cdot ex_c)_{out} + \sum \left(1 - \frac{T_o}{T_k}\right) \cdot \mathrm{Q_k} - \mathrm{W} = Ex_{loss} \tag{3}$$

where m represents the mass, T_o is the ambient temperature, W is work and Ex_{loss} is the exergy loss. Chemical exergy, ex_c, is calculated at the ambient temperature and pressure with Equation (4):

$$ex_c = \gamma_{ff} H_{ff} \tag{4}$$

where H_{ff} represents the higher heating value (kJ/kg) and γ shows the exergy grade function. The values of γ for the energy sources analyzed in this study are provided in Table 1.

Table 1. Exergy factors of energy sources (adapted from Koroneos et al. [34]).

Energy Source	Exergy Factor (γ)
Waterfall energy	1
Electrical energy	1
Natural gas	1.04
Coke	1.05
Oil and petroleum products	1.06
Coal	1.06
Bagasse	1

Exergy is the maximum theoretical work that can be achieved from a system. It is evaluated against a fixed environment and viewed as an indicator highlighting the departure of the system from the standard environment. This study is conducted with the environmental conditions of T_o = 10 °C and P_o = 1 atm, which were also used by Utlu and Hepbasli [35]. Energy and exergy efficiencies of different processes can be expressed using the expressions given in Equations (5) and (6), respectively:

$$\text{Energy efficiency, } \eta = \frac{Energy\ output}{Total\ energy\ input} \tag{5}$$

$$\text{Exergy efficiency, } \varphi = \frac{Exergy\ output}{Total\ exergy\ input} \tag{6}$$

Equations (7) and (8) are used to calculate overall energy and exergy efficiencies:

Overall energy efficiencies = (Energy weighting factor) (Average operation ratings) (7)

Overall exergy efficiencies = (Exergy weighting factor) (Average operation ratings) (8)

Table 2 shows the weighted mean energy or exergy efficiencies for the different industrial processes. Exergetic sustainability index and environmental impact factor are calculated following the same methodology used by Rosen et al. [36], Aydin et al. [37] and Midilli and Kucuk [38]:

$$\text{Depletion number, } \mathrm{D} = \frac{Exergy\ destroyed}{Exergy\ input} \tag{9}$$

$$\mathrm{D} = (1 - \varphi) \tag{10}$$

$$\text{Sustainability index, SI} = \frac{1}{Depletion\ number} \tag{11}$$

The renewable fraction was calculated as shown by Gong and Wall [39]:

$$\text{Renewable fraction, RF} = \frac{Renewable\ exergy\ consumption}{Total\ exergy\ consumption} \tag{12}$$

The non-renewable fraction of the exergy is expressed as shown by Zisopoulos et al. [10]:

$$\text{Non} - \text{renewable fraction, NRF} = \frac{Non - renewable\ exergy\ consumption}{Total\ exergy\ input} \tag{13}$$

Similarly, the exergy destruction coefficient can be defined as the ratio of the total waste exergy in the outlet and total exergy input and the reciprocal of the exergy efficiency as:

$$\text{Exergy destruction coefficient, EDC} = \frac{1}{Exergy\ efficiency} \tag{14}$$

Sustainability indicators are evaluated between 2000 and 2019. Data for 2020 and later are not included in the study because of the pandemic effect and some incomplete data. Figure 1 shows the system boundaries of the present study and the directions of the information outflow and the inflow of the results of the thermodynamic analyses.

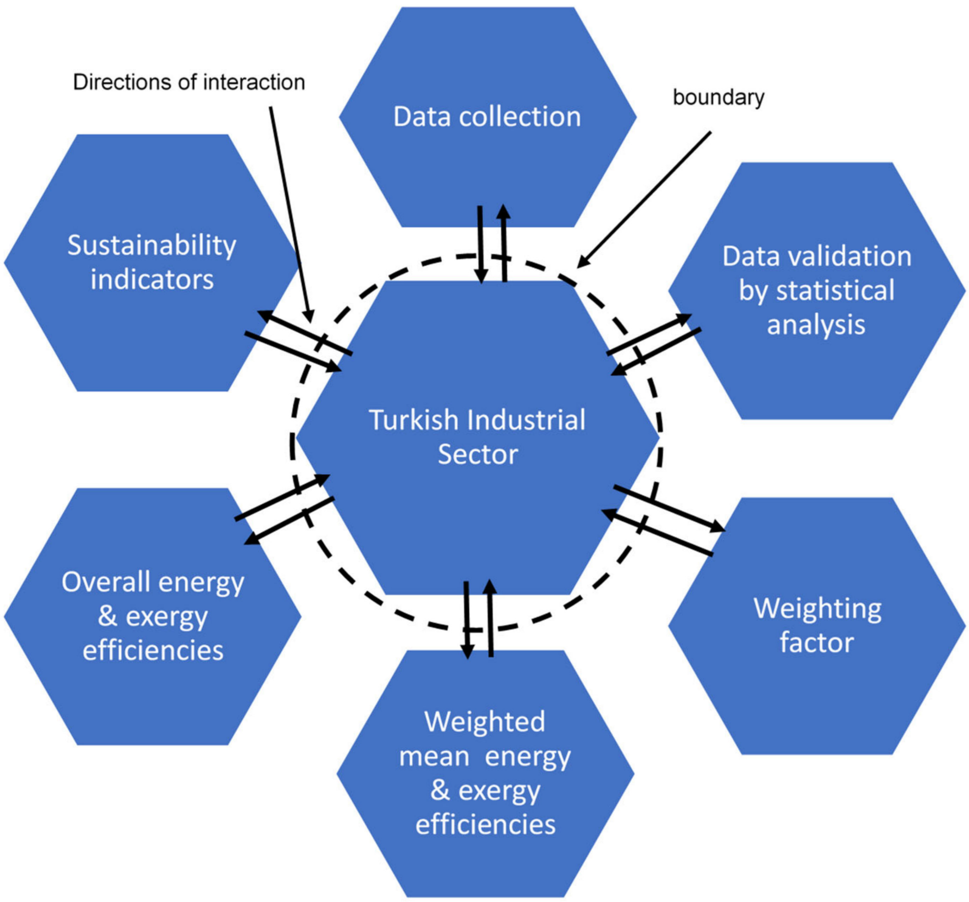


Figure 1. System boundary for the industrial processes (outbound arrows from the industrial sector describe the direction of the data flow, and the inbound arrows describe the implementation of the results of the thermodynamic analyses).

Table 2. Process and operation data of the Turkish industrial sector (adapted from Koroneos et al. [34]).

Industrial Process	Coal	Renewable Fuel	Oil	Gas	Electricity	Average
Process heat, low and medium temperature	0.54	0.62	0.67	0.66	0.91	0.68
High-temperature heat, electrolysis	0.36	-	0.45	0.58	0.67	0.52
Mechanical energy			0.23	0.26	0.70	0.40
Other industrial uses	0.55	0.72	0.53	0.59	0.56	0.59
Average	0.48	0.67	0.47	0.52	0.71	0.55
Industrial use divided by the exergy factor of each fuel						
Process heat, low and medium temperature	0.51	0.61	0.62	0.64	0.91	0.66
High-temperature heat, electrolysis	0.34	-	0.42	0.56	0.67	0.50
Mechanical energy			0.21	0.25	0.70	0.39
Other industrial uses	0.52	0.71	0.50	0.56	0.56	0.57
Average	0.46	0.66	0.44	0.50	0.71	0.53

3. Results and Discussion

3.1. Energy Insight of Turkey

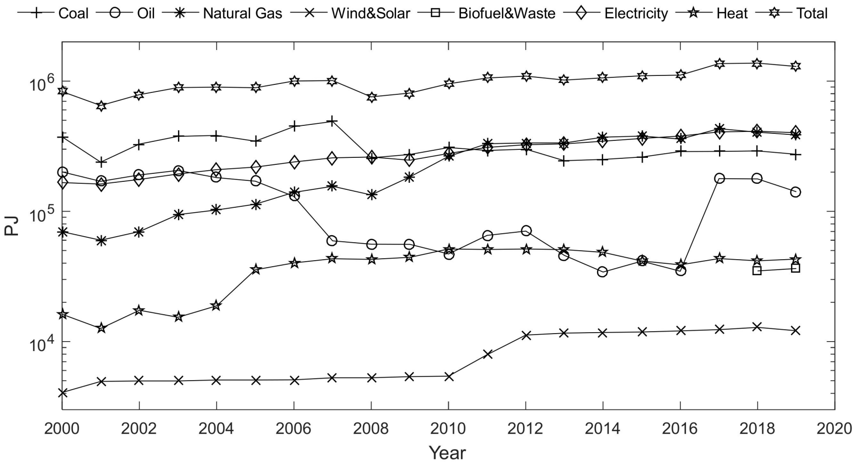
In Turkey, total energy utilization of the industry sector increased between 2000 and 2019 (Figure 2a). However, the increment is not always continuous due to national and international fluctuations such as the 2008 crisis and devaluation of the currency exchange rate in addition to the variations of energy prices affecting the energy utilization composition of the Turkish industry sector. Except for natural gas (NG), consumption of other fossil energy resources has declined, and utilization of renewable energy resources has remained almost constant. This is also verified by the consistent increase in electric power utilization, which reached 4.01 PJ in 2019. Natural gas was one of the most used energy and exergy resources in the industrial sector and it reached the level of 3.8 and 4.01 PJ, respectively, in 2019, as seen in Figure 2a,b. The first law of thermodynamics is used to evaluate energy efficiency and the second law is employed to calculate exergy efficiencies in the dataset. Figure 3 shows the energy and exergy efficiencies of the Turkish industry for the period 2000–2019.

3.1.1. Fossil Energy

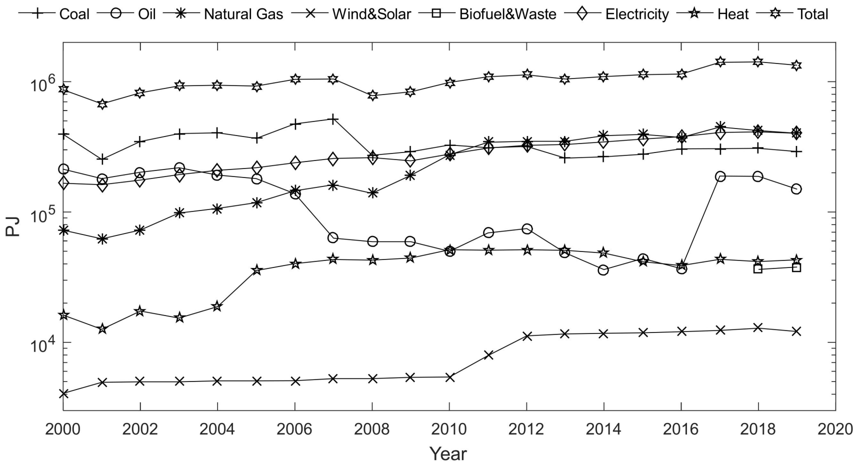
Fossil fuels (coal, oil and natural gas) are the backbone of the Turkish industry sector. Especially heavy industries which supply essential raw materials and semi-product to the whole economic system are driven by fossil fuels. Energy-intensive industries such as petrochemicals, cement and steel production have a high demand for fossil fuels because of the nature of the process. For example, coal cannot be easily replaced by any energy resources in the steel industry which utilizes blast furnaces.

Coal consumption reach its peak in 2007 and nearly halved in 2008 (Figure 4). Although coal prices are fairly stable, a significant drop in coal consumption can be explained by 2008 financial crisis [40]. The effect of the 2008 financial crisis can be observed in the Turkish industry production index (Figure 5). Yearly variation of the index between 2008 to 2009 reached −20.8% for general industrial performance and −24.4% for manufacturing industrial performance. Decrements in industrial performance have been observed by decrement in coal energy consumption.

Crude oil is another essential energy resource used in the Turkish industry sector. The comparatively low price of oil and the suitability of storage and transportation makes it a reliable energy source for the Turkish industry. It is worth noting that the consumption of oil is mainly affected by its price (Figure 6). Crude oil prices continuously increased between 2002 and 2008 and reached a peak level in 2008. In response to this, oil consumption has been continuously reduced by the Turkish industry sector. This might be explained by natural gas replacing oil (Figure 7) due to the burning efficiency of a new gas burner and the diffusion of the gas pipeline into Turkish cities. On the other hand, low prices of crude oil in 2016 lead the attention of industry back to oil again and oil consumption in the Turkish industry sector increased by 4 times.



(**a**)



(**b**)

Figure 2. (**a**) Data regarding energy utilization in the Turkish industrial sector, data adapted from the IEA [7]. (**b**) Exergy utilization was calculated after multiplying the energy with the exergy factor presented in Table 1.

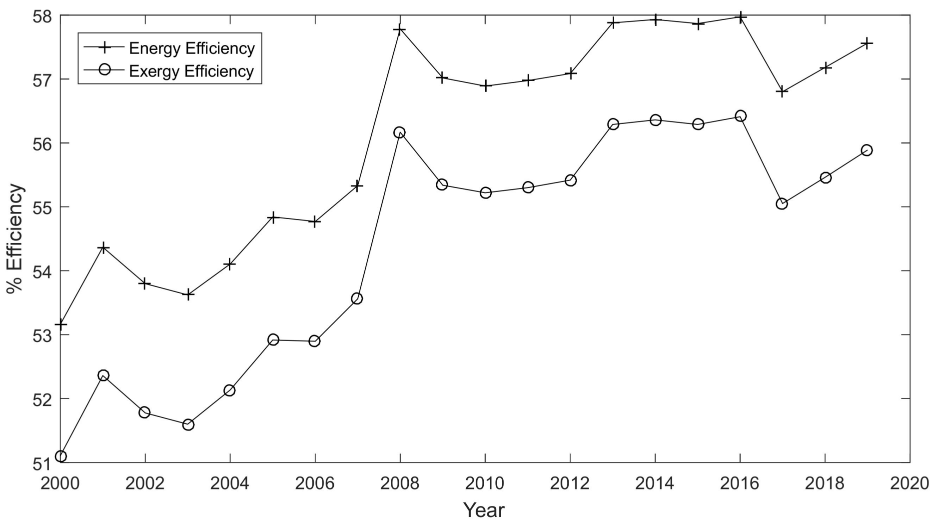


Figure 3. Energy and exergy efficiencies for Turkey between 2000 and 2019.

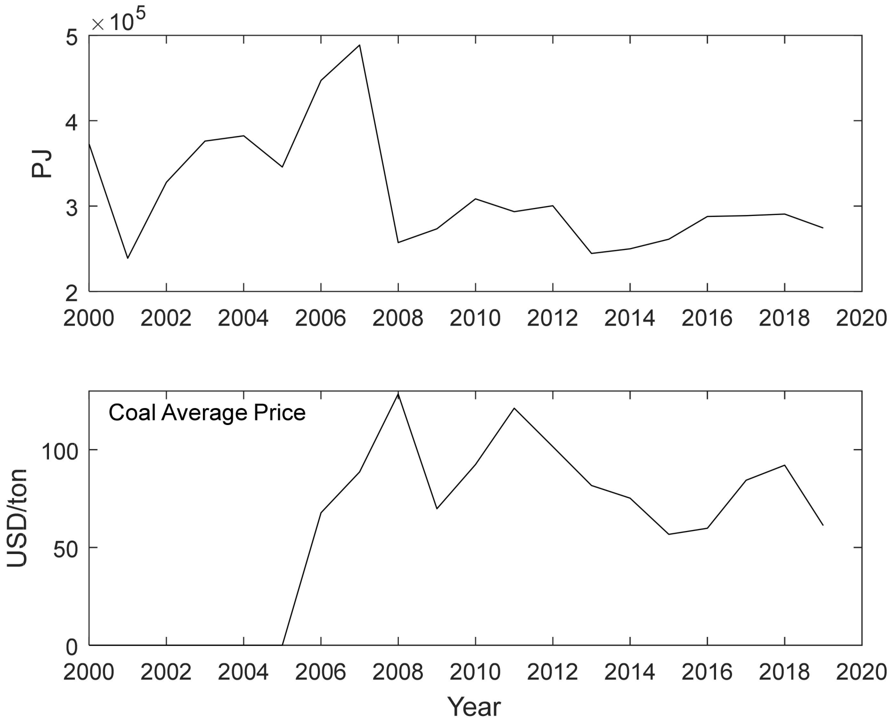


Figure 4. Coal consumption in Turkish industry between 2000 and 2019 and average coal prices between 2005 and 2019.

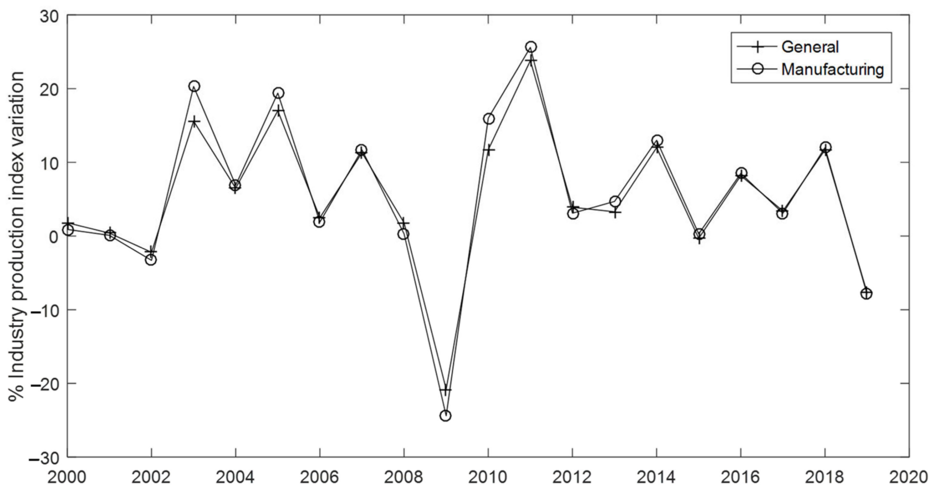


Figure 5. Yearly variation of Turkish industry production index.

Natural gas market law entered into force in 2001 and starting from that date, natural gas became important for Turkish industries [41]. A pipeline network of 18 321 km in length was operating in 81 cities in Turkey in 2019. Natural gas consumption in the Turkish industry sector has steadily increased between 2000 and 2019 despite natural gas prices. Natural gas prices reached nearly 8 USD/MMBtu between 2004 and 2008 and then fell to 3–4 USD/MMBtu. Long-term contract between Turkey and producer country (Russian Federation, Republic of Azerbaijan and the Islamic Republic of Iran), installation of new gas pipelines (Blue Stream Pipeline, The Trans-Anatolian Natural Gas Pipeline, etc.), LNG terminals (Ereğli, Aliağa, Dörtyol, etc.) and underground natural gas storage facilities (Silivri and Tuz Gölü) have encouraged the Turkish industry sector. In addition, numerous cogeneration plants and thermal power plants based on natural gas have been established with help of government subsidy.

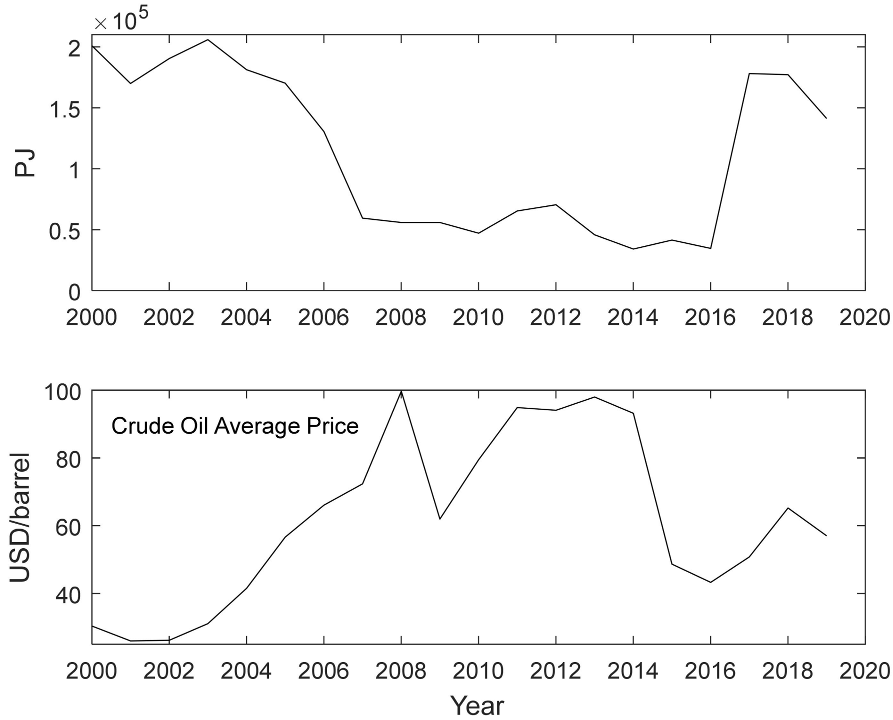


Figure 6. Crude oil consumption in Turkish industry between 2000 and 2019 and average crude oil price between 2000 and 2019.

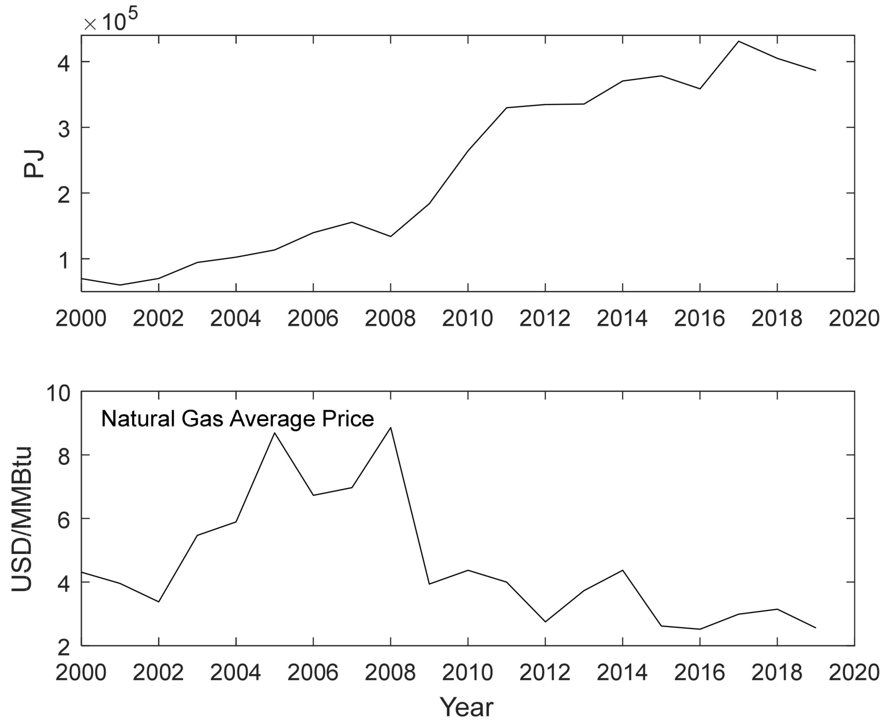


Figure 7. Natural gas consumption in Turkish industry between 2000 and 2019 and average natural gas price between 2000 and 2019.

3.1.2. Renewable Energy

Renewable energy resources have become important for the Turkish industry in recent years. Renewable energy (solar, wind, biofuel and waste) usage in Turkey's industrial sector increased from 0.4 PJ in 2000 to 4.8 PJ in 2019 (Figure 8). The main increment is observed between year 2017 and 2018. There are several reasons for that. First of all, roof-top solar energy legislation was effectuated in early 2018. That legislation enabled the installation of roof-top solar energy systems in factories for self-usage and to sell surplus electricity to the national grid. Secondly, a new renewable energy subsidy mechanism called YEKA (Yenilenebilir Enerji Kaynak Alanları—Renewable Energy Resource Areas) in 2016 paved the way for installing big-scale solar and wind energy power plants. The government launched a USD $1 billion wind power investment in five projects in Turkey. In addition to that, YEKA led to the stimulation of the national solar and wind energy sector. Thirdly, the anti-damping tariff for imported solar panels from China in 2016 encouraged the solar panel manufacturer to boost their investment. Turkey became a solar panel exporter instead of an importer in 2018.

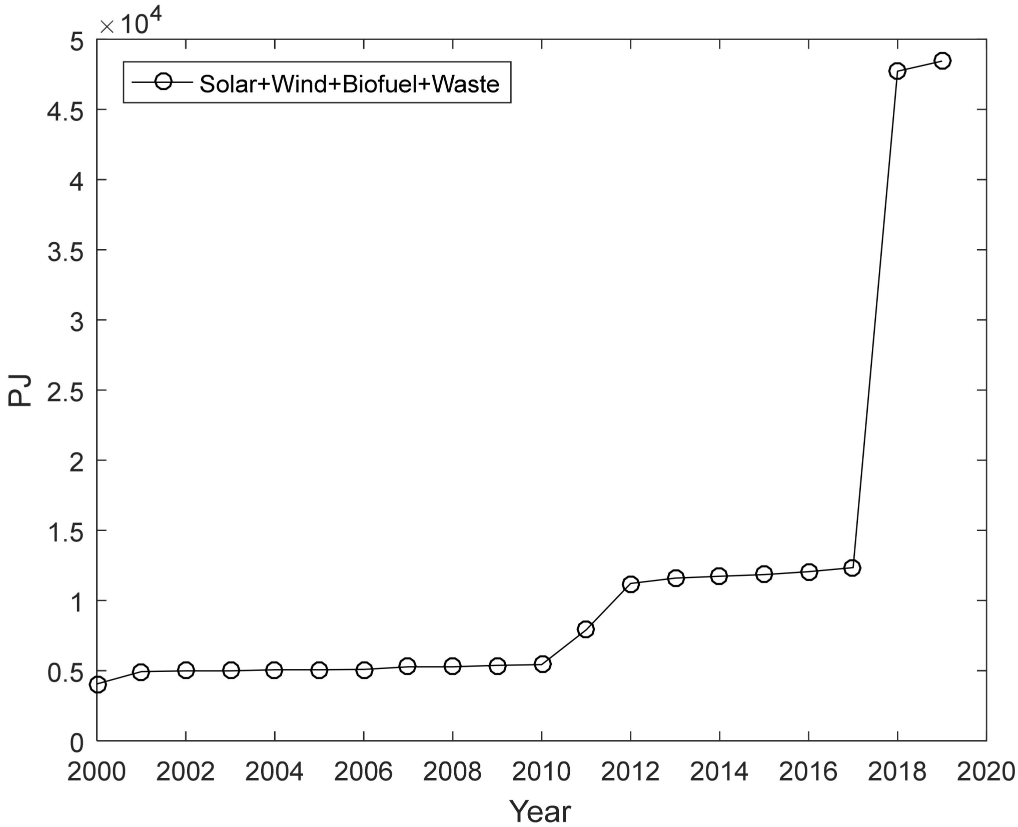


Figure 8. Renewable energy consumption of the Turkish industry sector.

Today, renewable energy plant installations are continuously increasing. New regulations, briefly explained above, are the main driver. In addition, the transformation from fossil fuels to green energy has established a new market and investment opportunity for companies. Additionally, the increasing awareness of environmental problems in Turkey leads to increasing demand for renewable energy.

3.1.3. Sustainability Indicators

Variation of the sustainability indicators, including the Sustainability Index, of the Turkish industry for the period 2000 to 2017 is shown in Figure 9. The Kyoto Protocol was signed in the United Nations framework convention on climate change in 1997 and was ratified by the Turkish parliament in 2009 to combat global warming and climate change; thus, Turkey, along with other countries, has agreed to reduce the emission of greenhouse gases. However, there is significant criticism that Turkey has signed the treaty but then ignored it and has not accomplish the commitments [42]. To achieve this goal, Turkey should make more use of renewable energy resources.

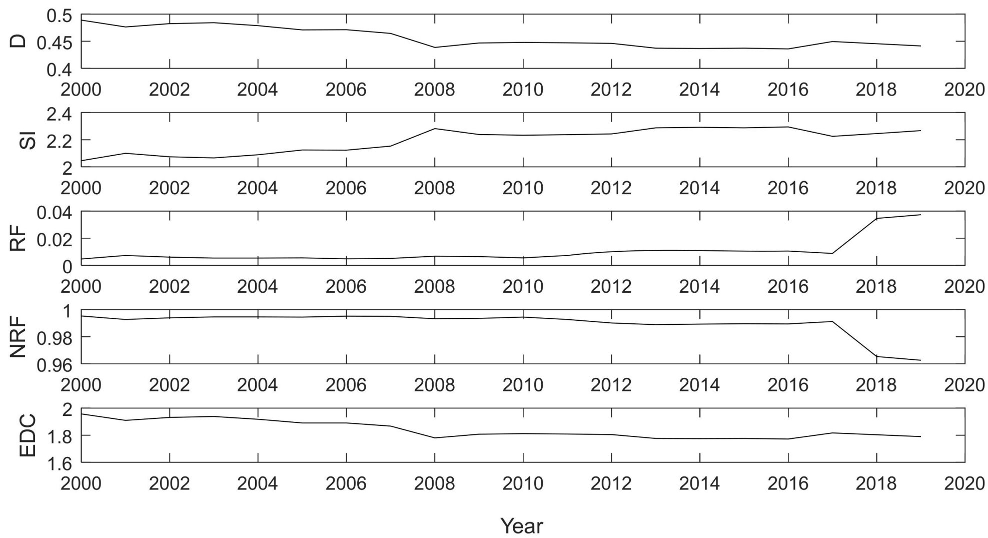


Figure 9. Sustainability indicators.

A fraction of the total emission of greenhouse gases results from energy utilization, mainly from the utilization of conventional fuels [43]. Therefore, any improvement in energy and exergy efficiency will reduce environmental costs as well as energy utilization [44]. Implementing the results of the "advanced exergy analysis model" may be the key component in achieving sustainable development. Advanced exergy analysis was employed to calculate the sustainability indicators for the period of 2000 to 2019, and the results are presented in Figure 9. The Sustainability Index (SI) shows the environmental impact of the production process. A high SI means that the production process is more environmentally friendly. The SI was approximately 2.04 in 2000, then improved to 2.28 in 2008, and then remained constant with minor fluctuations until 2019. Energy-intensive industries such as petrochemicals, cement and steel production have been developed in recent years in Turkey. Electricity use in the energy-intensive sectors of the Turkish industry is very high, and a large part of it is produced from fossil-based energy sources. Exergy losses are high in the industrial use of fossil-based energy sources, such as coal and natural gas, compared to that of the other sources [45]. Between 2000 and 2006, the depletion numbers of the Turkish industry were high, while the exergy efficiencies and the SI values were low. The low SI values were mostly caused by high fossil-based exergy consumption. To achieve a high SI in the Turkish industry, the RF of the total energy use must improve and the NRF should decrease. The minimum RF value for the Turkish industry was 0.47% in 2000, but it improved to 1.11% in 2012 and then remained constant with minor fluctuations until 2019. The NRF of exergy use in the Turkish industry was between 99.5% and 96.3% during these years. To improve the SI of the Turkish industry, it is important to produce electricity mainly from renewable energy sources. In Turkey, the EDC was between 1.95 and 1.78 between 2000 to 2019. A high EDC reduces the SI of the Turkish industry. In industrial applications, EDC may be reduced by improving exergy efficiency. To achieve improving exergy efficiency, some technical precautions can be described. For example, machines used in the industry must have a low level of irreversibility, or low-temperature application is preferred instead of high-temperature application. Therefore, Turkish industry has to become more efficient, using less energy to achieve the same level of production.

The cost of clean energy has decreased in recent years; therefore, its use in industry is more feasible now than it was in the past [46]. The sustainability index for the Bangladeshi industry was between 2.13 and 2.32 [22]. Although numerous researchers have already emphasized that energy recovery should be evaluated to reduce energy consumption and emissions in the industry [47–50], there are very limited data available in the literature, reporting all of the sustainability indicators of industry both for Turkey and other countries.

3.1.4. Future of Energy Investment in Turkey

Significant energy investments are under way in Turkey at the moment. The first reactor of the Akkuyu Nuclear Power Plant in Mersin will start operating in 2023, the other three units are expected to be complete by 2025, and each reactor will generate 1200 MWe of electric power [51]. Nuclear facilities have zero carbon dioxide emissions during operation. Turkey will make important investments to improve renewable energy utilization. A solar power plant with a capacity of 1000 MW will be completed in 2023 in Karapınar, Konya. Morever, a wind power plant project with a capacity of 1000 MW was tendered in 2019; additional wind power plants with 250 MW of power output are planned to be established in Aydin, Mugla, Balikesir and Canakkale. There is an ongoing construction of large hydroelectric power projects, Ilısu, Yusufeli and Çetin, that will have 1,200,558 and 517 MW of capacity [51]. These projects will affect the sustainability indicators of Turkey positively. In addition to these investments, there are also ongoing new coal-based thermal power plant projects. Turkey, with a pre-production capacity of 31.7 GW, will be the second larger coal-using country after China. The establishment of coal-fired power plants will affect the sustainability indicators of the country negatively. In addition to 1280 PJ of established capacity in 2017, Turkey is building new power plants including 4800 MW of nuclear power, 1000 MW of solar power, 1000 MW of wind power, 2275 MW of hydroelectric power (Ilısu—1200 MW, Yusufeli—558 MW and Çetin—517 MW) and 31.7 GW of a coal-based thermal power plant. If all of these investments should be successfully finished, Turkey will have an additional 986 PJ of coal, 118.7 PJ of renewable and 149.3 PJ of nuclear energy capacity.

Assuming that a solar power plant may operate 13 h a day and the other energy sources operate for 24 h a day, and the exergy differential of nuclear energy is 0.95 [52], Turkey will end up with the limiting case sustainability scenarios, which are presented in Table 3:

Table 3. Sustainability indicators according to five different scenarios.

Limiting Case Scenarios	φ	SI	RF	NRF	NEF
(1) All energy investments are finished successfully	0.51	2.04	0.05	0.9	0.05
(2) Only renewable energy investments are finished successfully, others are stopped	0.53	2.12	0.08	0.91	-
(3) Only the nuclear power plants are finished successfully, others are stopped	0.54	2.17	0.008	0.90	0.09
(4) Only the coal-based thermal plants come into operation as a fossil-based energy investment	0.49	1.96	0.005	0.99	-
(5) Turkey achieves producing 20% additional electricity in the microgrids with renewable wind and solar energy in addition to the case described in Scenario 1.	0.54	2.17	0.20	0.75	0.04

The Nuclear Energy Factor value (NEF) presented in Table 3 represents the ratio of the nuclear exergy to the total exergy utilization. In Scenario 1, SI will decrease because of the large capacity coal-based thermal power plants. In Scenario 2, there will be less than a 4% increase in SI. In the case of Scenario 4, there will be a slight decrease in the SI. According to the predictions based on Scenarios 1, 2 and 4, the predicted SI values will not change significantly. IN the last decades, while the installed world capacity of wind and solar electric generators increased their production, costs reduced significantly [46]. In Spain, at the end of 2011, wind and solar power contribution to electric power demand was 16% and 3%, respectively, and in Denmark, wind power provided almost 26% of the electric power demand in 2011 [53]. During the last decade, microgrids operating in parallel with the national grids or as autonomous power islands in industrial plants gained popularity [54–57]. Turkey has very similar geographical specifications to Spain, surrounded by the seas, and there is a high hot plateau in the middle of the land. According to the Vision 2023 agenda [58], the Turkish government plans to produce 30% of Turkey’s electricity demand from renewable energy sources in 2023. This means that hydroelectric, wind and solar energy capacities would increase to 36,000 MW, 20,000 MW and 3000 MW, respectively [59]. With a conservative estimation, Turkey may achieve producing 20% additional electricity in the microgrids from renewable wind and solar energy. Table 3 shows that in all of the scenarios, exergy efficiency φ will remain between 0.49 and 0.54. The highest value of φ may be attained in both Scenarios 3 and 5. The value of the sustainability index will range between 1.96 and 2.17, and the highest value of sustainability index may be attained in Scenarios 3 and 5. Scenario 5 helps to improve the desperately needed renewable fraction (RF) to the highest level and brings the NRF and the NEF to the lowest values presented in Table 3.

4. Conclusions

In this study, transformation of energy resources of Turkish industry system is discussed. This transformation highlights the growing utilization of renewable energy resources. Usage of renewable energy resources depends on several reasons. Firstly, most fossil fuels consumed by industry are imported from abroad. This is the main reason for the current account deficit in Turkey's economy. In addition to that, importing fossil fuels increases Turkey's dependency on energy-rich countries. Secondly, imported fossil fuels price has risen in recent years and increasing prices lead to increased cost of industrial production. Thirdly, awareness about renewable energy in Turkey is steadily increasing. Turkish people demand more renewable energy utilization from the government and companies. As a result, the Turkish government has and continues to promote renewable energy investment in the country. In this study, the trend of renewable energy investment was discussed by using sustainability indicators.

The recent history of energy utilization transformation of Turkish industry sector is assessed by using sustainability indicators. The future of that transformation may be foreseen by the same methodology. Therefore, five different probable scenarios are considered to foresee the near future.

The first scenario is based on the consideration that all ongoing energy investments will be finished successfully, and in this case, the exergy efficiency and the sustainability index of Turkey will be 0.51 and 2.04, respectively. The second scenario assumes that only renewable energy investments are finished successfully; others are stopped. In this case, the exergy efficiency and the sustainability index of the country will be 0.53 and 2.12, respectively. The highest value of SI may be attained in this scenario where only the ongoing nuclear power plant projects should be finished successfully and the other ongoing projects are stopped, but this does not seem like a viable option. On the other hand, if Turkey achieves producing 20% additional electricity in the microgrids operating with renewable wind and solar energy, in addition to the case when all the ongoing energy investments are finished successfully, this will help to improve the desperately needed renewable fraction of the country to the highest level, 0.20, and bring the non-renewable fraction and the nuclear energy factor value to the lowest attainable values. When evaluating the ongoing projects in terms of their possible impact on the environmental indicators, the results show that it will be difficult for the decision makers to find an immediate solution.

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