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Current Status of Renewable Energy in Türkiye

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Reviews

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ABSTRACT

The usage of renewable energy has an increasing trend to replace fossil fuel or other forms of energy that have damaged the environment in the last decades. Many countries have realized the need for clean energy to reduce the greenhouse effect and carbon emissions. Turkey signed the Paris Agreement in 2016, ratified it in 2021, and set a net-zero carbon target by 2053. The objective of the Paris Agreement is to limit global warming to 1,5-2°C compared to pre-industrial levels. However, the high demand for energy for industry or high installation fees of renewable energy can be limiting factors for developing countries like Turkey. Turkey is rich in renewable energy sources such as solar, wind, geothermal, hydropower, and biomass. Even though Turkey is considered to have one of the highest hydropower, wind, and geothermal energy potential among European countries, the installed capacity is much lower than its potential. The current status of renewable energy sources and the technical potential of renewable energy in Turkey are evaluated in this review study.

Türkiye'de Yenilenebilir Enerjinin Mevcut Durumu

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ÖZ

Son yıllarda yenilenebilir enerji kullanımı, çevreye zararlı fosil yakıtlar veya diğer enerji türlerinin yerini almakta artan bir eğilim göstermektedir. Birçok ülke, sera etkisini ve karbon emisyonlarını azaltmak için temiz enerjiye olan ihtiyacın farkına varmıştır. Türkiye Paris Anlaşması'nı 2016 yılında imzalamış, 2021 yılında onaylamış ve 2053 yılına kadar net sıfır emisyon hedefi belirlemiştir. Paris Anlaşması'nın amacı, küresel ortalama sıcaklık artışını sanayi öncesi seviyelere kıyasla 1,5-2°C ile sınırlı tutmaktır. Ancak, sanayi için yüksek enerji talebi veya yenilenebilir enerjinin yüksek kurulum ücretleri gibi faktörler Türkiye gibi gelişmekte olan ülkeler için sınırlayıcı olabilmektedir. Türkiye güneş, rüzgâr, jeotermal, hidroelektrik ve biyokütle gibi yenilenebilir enerji kaynakları açısından zengin bir ülkedir. Türkiye, Avrupa ülkeleri arasında en yüksek hidroelektrik, rüzgâr ve jeotermal enerji potansiyeline sahip ülkelerden biri olarak kabul edilse de kurulu gücü sahip olduğu potansiyeline göre çok daha düşüktür. Bu derleme çalışmasında Türkiye'nin mevcut yenilenebilir enerji kaynakları ve yenilenebilir enerji teknik potansiyelinin güncel durumu değerlendirilmektedir.

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1. Introduction

The greenhouse gas emissions of renewable energy are very limited. Also, renewable energy continuously renews itself based on the characteristics of the region and climate (Erdin and Ozkaya, 2019). The total energy production of Türkiye increased from 51.44 million metric tons of oil equivalent in 1990 to 128.8 million metric tons of oil equivalent in 2015. According to the latest resources available, total production reached 147.1 million metric tons of oil equivalent by 2020 (IEA, 2020). Official data states that domestic production rates on energy supply in 1990, 2015, and 2020 are 47%, 24%, and %30, respectively. However, energy usage increased from 42,2 million metric tons of oil equivalent in 1990 to 99,5 million metric tons of oil equivalent in 2015 and 113.7 million metric tons of equivalent in 2020. While the energy usage of Türkiye increased 2.7 times (42.2 million metric tons to 113,7 million metric tons), the domestic energy production increased only 1.2 times (25.8 million metric tons to 32.2 million metric tons). Although the total energy supply meets the demand, at the point where the domestic production does not meet the demand, the shortcoming is provided by energy imports (MENR, 2020). In Türkiye, fossil fuel energy consumption is approximately 86% of the total energy usage (Figure 1) (IRENA, 2021). In addition, the carbon dioxide emission levels increased from 75 to 350 million metric tons from 1980 to 2014 (TWB, 2022). Based on the Paris agreement, a global agreement created to restrict the global temperature increase of 1.5°C, every country will be evaluated for the climate performance program every five years. Türkiye signed the Paris Agreement in 2016, ratified it in 2021, and set a net-zero carbon target by 2053. Türkiye needs to take severe measures not only for economic sustainability and the environment but also to fulfill sustainable development goal number seven of the United Nations, which states affordable and clean energy.

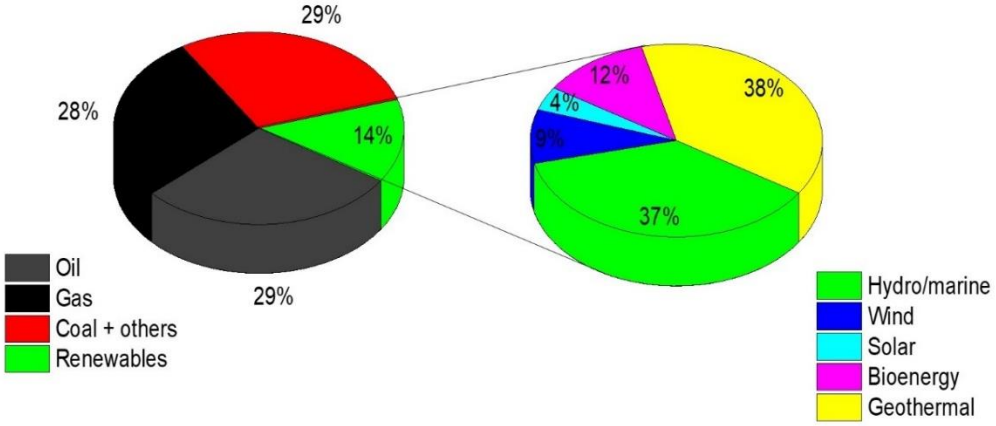

Figure 1. Total primary energy supply and renewable energy supply in Türkiye in 2018.

Capital investment in renewable energy plants is tremendous, but once the initial expense is paid, the energy cost is less than the cost of energy generated from fossil fuels. Renewable energy is an

excellent opportunity for Türkiye due to its significant geographical location regarding renewable energy capacity (Erdin and Ozkaya, 2019). Türkiye has a variety of renewable energy sources, such as solar, wind, geothermal, hydropower, and biomass. While hydropower plants had a share of 87% in renewable energy sources in 2013, this rate decreased to date to 60%. That mainly results from wind and solar energy investments. By 2021 Türkiye has 53 GW installed power capacity in renewable sources (TSKB, 2021). Figure 1 shows that hydropower and geothermal were the two most used renewable energy sources in Türkiye. According to an official report, the highest renewable energy consumption in Türkiye was by electricity in 2018. Similarly, households consumed the highest amount of renewable energy in 2018 (Figure 2) (IRENA, 2021).

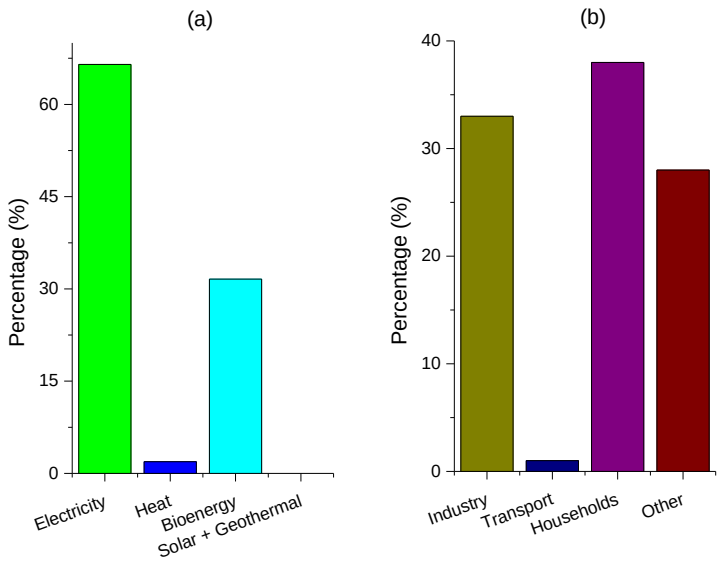

Figure 2. Renewable energy consumption by source (a) and by sector (b) in 2018 in Türkiye.

As shown in Figure 3, China has the largest installed renewable energy capacity, with 643 GW, followed by the US, with 193 GW in 2020. It is followed by Brazil, Japan, India, Canada, Germany, the Russian Federation, Italy, and Türkiye. Türkiye ranks tenth in the world and third in Europe regarding the installed renewable energy capacity, with 41 GW by 2020 (IRENA-a, 2020). The share of renewable energy in Türkiye's installed power is reported as 54% by January 2022 (MFA, 2022). The share of renewable energy in the overall production is 8% in China (IRENA-c,2022), 13% in the USA (EIA, 2021), and 46% in Brazil (IRENA-d).

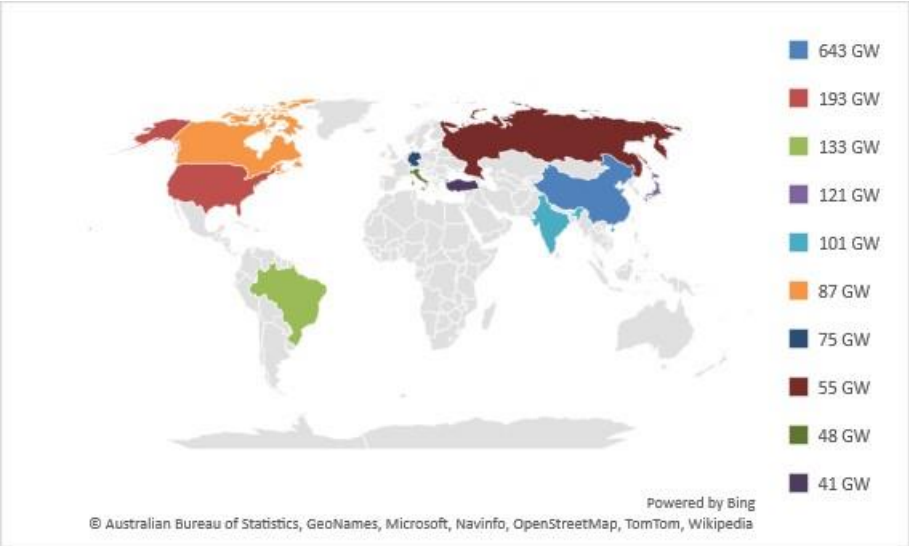

Figure 3. Installed renewable energy capacity of the leading countries worldwide in 2020.

Considering the enormous increase in electrical consumption in Türkiye, increasing the domestic production rate as fast as the government can be crucial. For example, the Turkish government should subsidize sales tariffs or extend the incentive period to spur the demand for renewable energy and create a mass of renewable energy in the market (Nesta et al., 2014; Bulut et al., 2017). This study aims to evaluate the current status of renewable energy sources and the technical renewable energy potential of Türkiye.

2. Renewable Energy Potential of Türkiye

2.1. Solar Energy

Solar energy, divided into direct and indirect categories, is generated directly from sunlight. It is a clean energy source, and there are no harmful gas emissions during energy generation. Photovoltaic power plants generate electricity directly from sunlight and are examples of direct solar energy-using systems. Hydropower, wind, and biomass are examples of indirect solar energy-using systems. Radiation that reaches the earth is energy generated by the reactions in the sun. The solar energy system converts this radiation into electrical energy by using solar panels. The representation of a simple solar energy process is shown in Figure 4. The sunrays deliver a vast amount of energy to earth in an hour compared to fossil, nuclear, or other renewable sources combined in a year (Aydin and Cunkas, 2019). However, solar energy is not as challenging as wind energy because of the high accuracy of sunlight prediction than wind patterns (Kok, 2015).

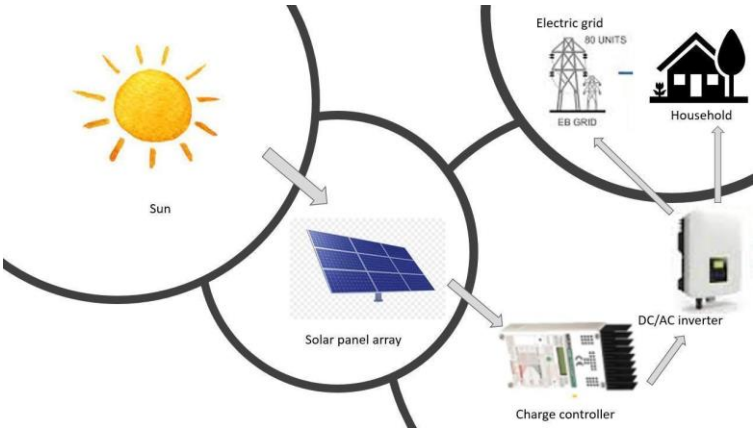

Figure 4. Solar power generation.

While the Southeast Anatolia and Mediterranean regions are the most productive regions of Türkiye in terms of solar energy, the Black Sea Region is the least productive. Türkiye represents one of the largest developing solar markets. A 1 GW photovoltaic solar power station is being constructed in Konya-Karapınar and is expected to be completed in 2023, which will be the largest solar power plant in Türkiye. (Erdin and Ozkaya, 2019; NSE, 2021). Türkiye has an annual 380 billion kWh solar-based renewable energy potential with an annual insolation time of 2741 hours. In Türkiye, the annual solar energy value is 1527 kWh/m^2.year (Aydin and Cunkas, 2019; Erdin and Ozkaya, 2019). Türkiye is expected to increase solar-based renewable energy capacity by 10 GW by 2024, which will be the highest capacity increase among renewable energy sources. (AA, 2019).

2.2. Wind Power

Wind energy is the movement of air relative to the earth's surface. Wind energy is generated by the heat from the sun and modified by the earth's rotation and surface topography (Erdin and Ozkaya, 2019; Yilmazulu and Dombayci, 2018). Approximately 2% of solar energy is converted into wind energy (Yilmazulu and Dombayci, 2018). Wind power is potentially accessible on the top of mountains, coastlines, high ridges, or open spaces based on the location. As shown in Figure 5, wind power systems convert the wind's kinetic energy into electrical energy through wind turbines.

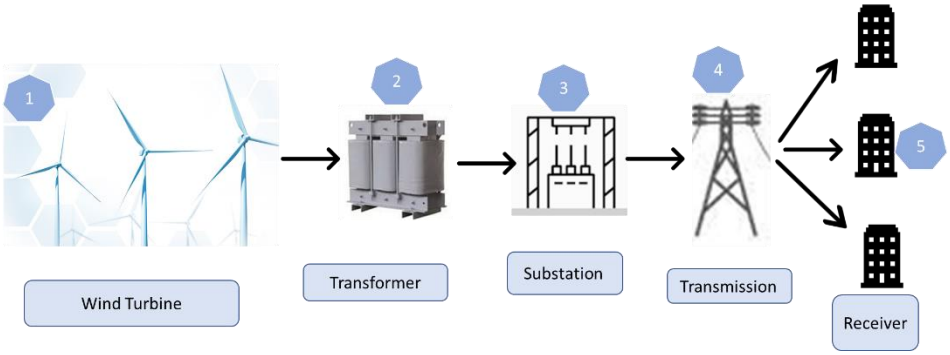

Figure 5. Wind power generation.

Türkiye is a semi-island surrounded by the Aegean, Mediterranean, and Black Sea. The Marmara Sea is an inland sea in Türkiye, connecting the Aegean Sea and the Black Sea via the Bosphorus Strait and the Dardanelles. The Aegean Sea region and the Marmara Sea region have Türkiye's richest wind energy sources, followed by the Southeastern Anatolia and Eastern Mediterranean regions (Aydin and Cunkas, 2019).

Türkiye's wind-based renewable energy capacity is predicted 48 GW (Erdin and Özkaya, 2019; MFAD, 2021). The supportive instruments of the Turkish government for renewables, such as feed-in-tariff and local content support, lay a foundation for the stable growth of wind energy power plants (MFAD, 2021). Even though wind-based renewable energy has advantages like being eco-friendly, low operating and maintenance costs, simplicity of operation, and time efficiency, the initial investment cost of wind energy is relatively more expensive than solar energy (Yilmazulu and Dombayci, 2018).

2.3. Biomass Energy

Biomass refers to organic material (plant or animal material) used to release energy through a natural process cycle where organic substances are converted to biomass energy (Figure 6). Biomass energy is obtained from various plant species on land and in water, as well as from urban waste, forest residues (plant and wood), animal waste, and food waste (Topcu and Çinar, 2020; Kara et al., 2017). Mainly biomass is used for heating homes, fueling vehicles, generating electricity, and for industrial facilities to process heat (Kara et al., 2017). The energy production process from biomass can be direct, like producing electricity by burning organic substances, or indirect, like producing biofuel. The high amount of food waste can be a renewable energy resource whose cost per kWh is cheaper than fossil fuel (Ebunilo et al., 2018). Even though Türkiye's total biomass energy potential is about 33 million tons of oil equivalents, the usable biomass energy is only 17 million tons of oil equivalents (Toklu, 2017; Kara et al., 2017). It is estimated that the electricity-generating capacity of biomass will be 50 GW in 2030 in Türkiye (Kara et al., 2017).

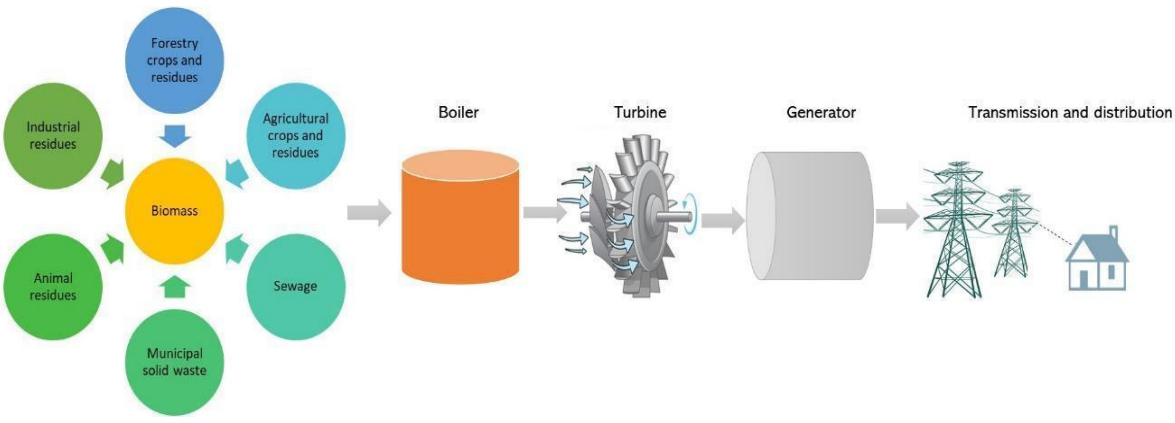

Figure 6. Energy production from biomass.

The indirect biomass processes are biodiesel, bioethanol, and biogas (bio-methane) production. Because the source of the biomass varies, the quality or energy efficiency cannot be maintained consistently; hence, it is not perfect as a renewable energy source. In addition, energy production by biomass results in hazardous pollutants like volatile organic compounds, carbon dioxide, and carbon monoxide through biomass burning (Topcu and Çinar, 2020). Biomass, which contributes to air pollution, deforestation, and hydropower, dominates renewable energy sources in Türkiye. However, it is expected to decrease the share of biomass in renewable energy sources by expanding other renewable energy sources (Yuksel et al., 2017).

2.4. Hydropower

Hydropower generation can be considered as converting the energy of flowing water to electrical energy (Figure 7). Hydroelectric power plants are efficient, renewable, and environmentally friendly. Due to the low operation costs, low-risk potential, and independence of the external conditions, hydropower energy investments are attractive. Even though the hydroelectric potential of Türkiye is 433 billion kWh which is 1% of the total theoretical hydropower potential of the world, the economically feasible annual hydropower potential is 140 billion kWh (Erdin and Ozkaya, 2019; Atalay and Yilmazulu, 2018). The hydropower consumption of Türkiye was equivalent to 13,2 million metric tons of oil in 2017, and Türkiye surpassed Japan and France with 0,6 GW of hydropower plant installations in 2017 (Erdin and Ozkaya, 2019).

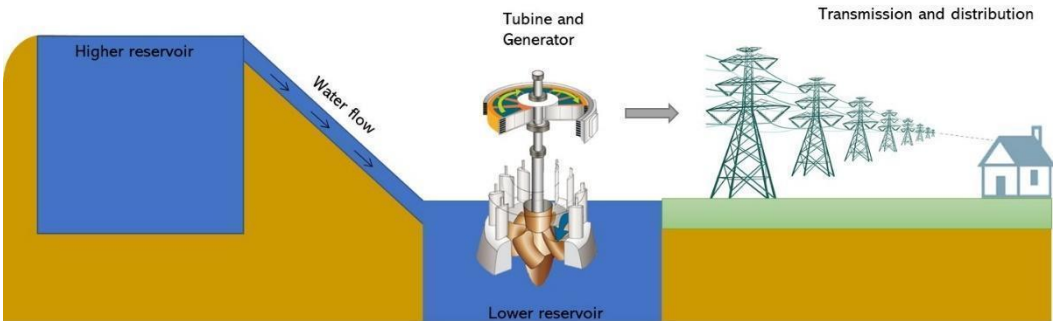

Figure 7. Hydropower generation.

2.5. Geothermal Power

Geothermal energy is the earth's internal temperature, spreading from the sub-surface of the earth (Erdin and Ozkaya, 2019). It has significant potential as a renewable energy source. The geothermal power generation process is represented in Figure 8. Türkiye has the seventh largest geothermal energy capacity globally and the largest in Europe. However, it is not among the top five countries (the USA, Philippines, Indonesia, Mexico, and Italy) producing electricity from geothermal energy. Still, it is the number fourth in the world to use geothermal energy for heating and hot springs after China, the USA, and Sweden (Kilic, 2016). Türkiye's geothermal potential is 31500 MW, and only

1500 MW can be considered suitable for electricity generation (Kat, 2011). Western Anatolia, having 78% of the geothermal sources, is the richest region of Türkiye in terms of geothermal sources. Although 90% of the geothermal sources are convenient for heating, thermal tourism, etc., due to the low and moderate temperature ranges, the rest 10% of geothermal sources in Türkiye are good enough to use for electrical energy generation (Erdin, Ozkaya, 2019). Hence, even though Türkiye has great potential for geothermal energy, only a small amount is economically feasible due to the low and moderate temperature (Yuksel et al., 2017).

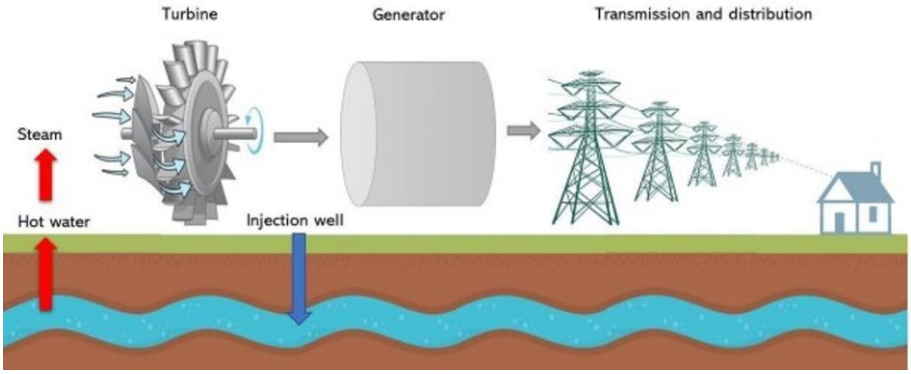

Figure 8. Geothermal power generation.

2.6. Hybrid Systems

Renewable energy sources highly depend on spatial location, such as total annual sunshine duration or wind energy potential. Therefore, it would be advantageous to use a mix of renewable energy sources (Kocaman, 2014). A hybrid system is a power generation system that combines two or more plants with different energy sources (Lee et al., 2020), which is quite flexible to implement (Yuksel et al., 2017). Hybrid energy systems have a higher return on investment than photovoltaic and wind turbines (Bulut et al., 2017), with shorter payback periods and cost efficiency in small capacities (Kok, 2015).

Floating photovoltaic systems are renewable energy generation systems that can be implemented in lakes, rivers, or even dead water spaces. In addition, it is advantageous over traditional photovoltaic systems in terms of maximizing the utility of resources and no need to use agricultural land. Moreover, floating photovoltaic systems can be easily paired with hybrid systems (Figure 9), such as hydropower (Lee et al., 2020). Turkey has power plants that can set an example for this. One of them is the power plant located in Bingöl, which has an installed power of 580 MW and incorporates solar and hydroelectric energy (AA, 2021).

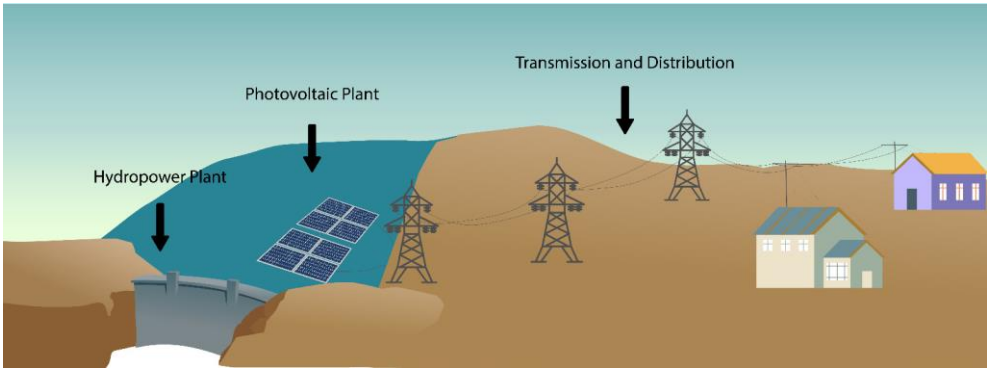

Figure 9. Hybrid power generation.

3. Current Status

The current renewable energy situation in Türkiye is given in Table 1. The total renewable energy capacity in Türkiye in 2018 was 42230 MW which is 2,43 times larger than the capacity in 2010. The solar, wind, biomass, hydropower, and geothermal capacity share was 11,99%, 16,59%, 1,39%, 66,99%, and 3,04% in 2018, respectively. Even though the hydropower capacity was the largest both in 2018 and 2010, the highest increase in the capacity was in solar energy from 2010 to 2018, with 844 times higher capacity. In addition, there has been a tremendous increase in the number of power plants increased, from 20 in 2011 to 818 in 2020. In Türkiye, the first solar-hydro hybrid system was installed in 2021 by integrating an 80 MW solar power plant into a hydroelectric unit of 510 MW. Up to now, this is the only solar-hydro system in Türkiye (Todorovic, 2021). Türkiye is on a good track in terms of renewable energy investments.

Table 1. Renewable energy in Türkiye.

Renewable energy	Solar energy	Wind energy	Bio-mass	Hydro-power	Geother mal	Total	References
Capacity in 2018 (MW)	5064	7005	587	28291	1283	42230	IRENA-b, 2020
Capacity in 2010 (MW)	6	1320	118	15831	94	17369	IRENA-b, 2020
Production in 2018 (GWh)	7803	19949	2650	59938	7431	97768	IRENA-b, 2020
Production in 2010 (GWh)	8	2916	252	51795	668	55639	IRENA-b, 2020
# power plants in 2020	17	165	126	461	49	818	MMO, 2020
# power plants in 2011	0	9	3	4	4	20	MMO, 2020

Due to the Turkish government's favorable regulations and incentive plans, wind and solar energies are the best choices for the market. Hydropower and biomass have a vast potential to implement due to their sources in Türkiye (Deveci and Guler, 2020). Türkiye has one of the highest hydropower, wind, and geothermal energy potential among European countries (Baris and Kucukali, 2012). On the other hand, because Türkiye will be a water-stressed country, the Turkish government needs to reduce the share of hydropower (Sahin, 2020).

While environmental awareness in Türkiye is rapidly increasing, the use of renewable energy is widespread in the markets. With the growing awareness of economic, political, and environmental issues, increasing activity in the energy sector resulted in energy cooperatives. Renewable energy

cooperatives allow the public to be involved in democratizing the renewable energy sector. For example, there were 46 renewable energy cooperatives in Türkiye in 2020 (Ozgul et al., 2020).

4. Result and Discussion

The current status of renewable energy sources and the renewable energy potential of Türkiye are evaluated in this review study. Türkiye is rich in renewable energy sources such as solar, wind, geothermal, hydropower, and biomass and is considered to have one of the highest hydropower, wind, and geothermal energy potential among the European countries. However, Türkiye has a much lower installed capacity compared to its potential. Hence, there is a significant opportunity to implement renewable energy in every sector for different regions. For example, the installed energy capacity of Türkiye was 42230 MW in 2018, with renewable electricity generation of 97768 GWh by the end of 2018. The installed capacity of solar energy, wind energy, biomass, hydropower, and geothermal in 2018 was 5064 MW, 7005 MW, 587 MW, 28291 MW, and 1283 MW, respectively.

If a country continues to supply energy by importing and using non-renewable resources, the economy will be damaged due to the increasing prices, and the environment will be destroyed due to the emissions. High demand for energy for industry or high installation fees of renewable energy can be limiting factors for developing countries like Türkiye. On the other hand, the Turkish government may face various challenges like financial challenges and technological innovation while substituting the environmental hazards created by conventional energy systems with renewable energy production and supply. The Turkish government can take several steps, like renewing the regulation for incentives because the existing regulations in the market have not fully achieved their effectiveness or supporting suitable investments for each region as every region has different renewable energy sources. For example, Southeast Anatolia and the Mediterranean regions are the most productive in terms of solar energy. In addition, The Aegean Sea region and the Marmara Sea region have the richest wind energy sources in Türkiye, and Western Anatolia has the richest geothermal sources. Because of the high demand for energy cleanly and sustainably, Türkiye needs to use renewable energy as much as possible.

Statement of Conflict of Interest

No conflict of interest was declared by the authors

Author's Contributions

Evrim Çelik Madenli conceptualized, supervised, wrote, visualized, reviewed, and edited the paper. Umut Bekçi visualized, reviewed, and edited the paper. Titah Haritul Ichwani visualized and partially wrote the initial submission.

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