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ORIGINAL PAPER

Comparison of energy transition of Turkey and Germany: energy policy, strengths/weaknesses and targets

Azime Telli[1] · **Selma Erat**[2,3] · **Bunyamin Demir**[3,4]

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Abstract

In present study, energy transition from fossil-based to renewable energy of Turkey was compared with Germany, which is one of the world leaders, in order to analyze for which points Germany is a good model for Turkey. The renewable energy policies, strengths/weakness and targets of Germany and Turkey were examined and compared. Germany has the 4th largest economy whereas Turkey, which is a developing country has the 18th largest economy in of the world. Germany declared to have the renewable energy in the energy mix by 65% in 2030 and set the long-term targets as: to reach at least 60% of final energy and 80% of electricity consumption from renewable sources by the year 2050. Turkey is expected to reach ~ 63 GW installed renewables in 2023, which was 42 GW. Germany and Turkey have similarities for the energy security since both are fossil-based and import-dependent countries. The import quotas of Germany are 99% for oil and 96% for natural gas and quotas of Turkey are 93.2% for oil and 99.2% for natural gas. Turkey with "*More Domestic, More Renewable*" policy wants to reduce the foreign dependency rate and reduce the primary energy consumption by 14% by the year 2023. Germany aims to reduce the greenhouse gas emission by 40% by the year 2020 and in long-term by 80–95% in 2050 as compared to the level of 1990. Turkey declared an intention to decrease the emission by 21% by the year 2030. One of the differences between Germany and Turkey is that Germany aims to shut down the nuclear power in 2022 whereas Turkey, for the first time, is going to have nuclear power in the energy mix in 2023.

Graphic abstract

Keywords Turkey · Germany · Energy policy · Renewable energy · Solar energy

Introduction

The world had gone into a new energy conversion process since the beginning of the twenty-first century. The fossil age, consisting of coal, oil and natural gas, respectively, started to become a challenge upon energy revolution that started with the discovery of steam. Two sources, namely as

✉ Azime Telli
azimetelli@gmail.com

Extended author information available on the last page of the article

nuclear energy and renewable energy, stand out instead of fossil fuels during the search for diversification of resources that accelerated after the 1973 Petroleum Crisis. These two energy sources in the energy mix have low carbon emissions. Thus, the share of these sources in the energy mix is continuously increasing and probably will bring about the end of the fossil age. There is a rapid increase particularly in the share of renewable energy sources although the share of fossils in the world energy consumption is still 80%. There are several factors triggering the energy transition from fossil-based to renewable energy sources. Some countries have come to the forefront by acting fast and decisively upon the transformation process in which the factors such as global warming, cost, technology and geopolitical crises were effective. Germany, also known as the world leader in renewable energy transformation, has introduced the term "energiewende" into energy literature. The energy transformation process of Germany was initiated in 1970s and it was accelerated after the Fukushima disaster in 2011. Germany aims to meet electrical energy need of the country from 100% renewable sources by the year 2050. As an industrialized country, Germany has acquired long-standing experience upon the energy transformation process. Thus, the experience in the process has already become a model for the other countries.

In order to determine for which points Germany was a good model for Turkey, Turkey and Germany were compared with respect to energy conversion considering the peculiar conditions of the German experience. The advantages and disadvantages of both countries were evaluated and the 2030 and 2050 targets were examined. The energy conversion of Germany is largely based on moving away from conventional sources such as nuclear and fossil fuels. On the other hand, the energy conversion of Turkey has more complex perspectives. Turkey has not yet had nuclear in energy mix, but already started energy transformation process that includes renewable energy sources and nuclear primarily in order to reduce the dependency on fossil-based fuels.

The European Union (EU) has initiated several environmental legislations and programs since the beginning of 2000s because of the growing concerns about climate change. The EU Circular Economy is known as the latest legislations and programs binding the economy and energy within the scope of low-carbon world and it points out the important role of energy and renewables to improve the efficiency and environmental performance of energy-related products. It is known that Germany did not have sufficient space to produce sufficient solar energy. Therefore, it was considered that Africa and Australia could be potential solar fuel suppliers of Germany in exchange of solar fuel production technology to be developed in Germany. The project of "Sunrise" was selected by the European Commission at the beginning of 2019 (Abbott 2019) and supported by Horizon 2020. Mersin University in Turkey is one of the supporters of Sunrise project. Such a support was considered as a motivation to work on the comparison of energy transformation of Germany and Turkey.

The energy transformation models of Germany with technological superiority and Turkey with significant potential for renewable energy were analyzed and presented in this study. The EU's energy targets were partly discussed because Germany is a member of the EU, but the process in the accession negotiations of Turkey to the EU is still on going. Energy policies of Germany and Turkey are compared in Sect. 3; renewable energy potential of both countries is discussed in Sect. 4; structural characteristics of German model and Turkey are evaluated in Sect. 5. Finally, the strengths and weaknesses of both Germany and Turkey in the energy transformation were discussed considering their own unique conditions and the future projections were presented in the conclusion section.

Literature review

Availability of renewable energy sources in Turkey was assessed by taking current situation, potential, government policies and the European Union (EU) perspectives into consideration (Baris and Kucukali 2012). Kilickaplan et al. (2017) analyzed Turkey's energy transition toward 100% renewable energy (RE) until the year 2050 by using an hourly resolved model and concluded that the transition could be separated in two major phases as of: (1) from 2015 to 2030 as the first phase, in which the electricity generation base for the power sector would be mainly switched from fossil coal and gas-based electricity to solar PV and wind power supply and (2) from 2030 onwards as the second phase, which was more related to an increased ramp up of storage capacities for a better balancing of continuously rising renewable energy supply share (Kilickaplan et al. 2017). It was also concluded that a 100% renewable energy supply was possible for Turkey with competitive costs in the remaining time till 2050, which fully matches the Paris agreement (Kilickaplan et al. 2017). It was reported that Turkey would be one of the renewable energy technology and equipment supplier countries in its region (Bayraktar 2018). Reen and Marshall (2016) worked on coal, nuclear and renewable energy policies of Germany and reported that the conservative government announced the Energiewende ('energy transformation') in 2011 and decided to reduce the amount of fossil fuels from 80% of the energy supply to 20% by the year 2050. Schmid et al. (2015) worked on the German Energiewende upon the energy transformation into practice. It was mentioned that the Energiewende was not only a national project for Germany, but a global endeavor with lessons to be learned for many countries. Hansen et al. (2019) also worked on Germany's energy transition toward

100% renewable energy in 2050 and demonstrated that it was possible to carry out the transition from a technical and economic perspective with some measures being vital for achieving the ambition in a cost-effective manner. It was reported that the energy transformation was well on the way toward Germany's long-term aim of de-carbonization despite its drawbacks and slow pace (Uyanik 2018). Cheng et al. (2019) compared the energy transitions of Germany and China including synergies and recommendations. It was reported that although Germany and China had different characteristics, international-level strategic cooperation was essential for meeting the goals of both local and global energy transition.

There are many studies about renewable energy of both Turkey and Germany separately in the literature. However, there are few studies for comparison of energy transformation of Turkey and Germany and most of them focused on either solar energy or de-carbonization.

Energy Policies of Germany and Turkey: Similarities and differences

Germany, the 4th largest economy in the world, is among the countries with quite a high energy consumption per capita depending on the level of industrialization and urbanization. Turkey with the rate of increase in the energy demand due to developing economy and high urbanization became the 1st country in the order of energy demand among the OECD (Organization for Economic Co-operation and Development) countries in the last decade. One of the common point of Germany and Turkey that follow common energy policies under the EU umbrella is that both of them take a place in the prominent countries in the field of energy transformation in the world. Turkey giving the priority to energy transformation seriously has received much attention because of high capacity for the transformation over the last decade. The amount of energy consumed in Germany was equivalent to 335.1 million tons of oil (mtoe) while it was 157.7 mtoe in Turkey in 2017. In other words, the energy consumption of Germany was twice as much of Turkey.

Germany energy policy regarding "Energiewende"

Germany with a land area of 357,114 km^2 is the largest country in the EU (IEA 2018). Germany with 83.78 million population is estimated to be the most populous country of EU in 2020 and will rank 19th in the world. It is known that the gross domestic product (GDP) of Germany grew 0.6% in 2019 as compared to 2018 and became the 4th greatest economy among 196 countries (Country Economy 2020). Germany contributed to the energy literature with the term of "energiewende" that was formed by combining the words energy and transformation for the first time in 1980s. This term "energiewende" including targets for phasing out coal and nuclear energy and developing renewable energy has been at the center of the energy policy of Germany. German political systems are based on federalism, thus all energy legislations are planned and adopted at federal level (Reen and Marshall 2016). Germany has already started a long-term initiative to switch to a low-carbon and efficient energy mix. The primary target of this long-term initiative is to reach at least 60% of final energy consumption and 80% of electricity consumption via renewable energy sources by the year 2050. It was expected to disable the remaining nuclear power plants, which were introduced in the 1970s, by the year 2022.

Germany was ranked as the 1st in Europe concerning to energy consumption and was the 7th largest country in 2015. The year 2011 played an important role in the energy transformation process of Germany that aims to switch to a low-carbon economy. For the first time in 1996, Germany started to implement a model including only the *recycle* and *waste management* regarding the circular economy. The circular economy concept also includes "*Reduce*, *Reuse*, *Recycle* and *Recover*". Yet, the scope of this study does not include all. Germany decided to withdraw gradually from the nuclear energy after the nuclear disaster in Japan and adopted the target of 100% renewable energy. In other words, Germany has determined short-, medium- and long-term goals along the roadmap of renewable energy transition and have many firsts in these fields. The support policies, which are based on the feed-in tariff, implemented by Germany in the development of renewable energy, are accepted as an example and a model by the other countries around the world. Almost 80% of world countries (110 countries in total) that support renewable energy have been using this model (Maatsch 2014). Besides, Germany was among the most successful leading countries in the innovative technology production required for the implementation of this model. Additionally, Germany has taken an active role in international diplomacy; particularly in bilateral renewable technology transfer issues and initiatives for climate change thanks to pioneering role in this field (Uyanık 2018). The energy transformation of Germany has four main objectives covering almost every area of the economy (Pescia 2017):

- to combat climate change by reducing carbon emissions
- to improve energy security by decreasing the imports of fossil fuel
- to finish gradually the use of nuclear energy
- to guarantee the competitiveness and growth of the economy by supporting technology, industry and employment development

Fossil fuels still have the highest share (80% in primary energy mix) in energy mix of Germany similar to the rest of the world. However, coal, the largest source for power generation today, is planned to fully phase out by the year 2038 (IEA 2020). Besides, the share of renewable energy sources is 14.7% and that of nuclear sources that is expected to be completely disabled in 2022 is 6.4%. The target of Germany for 2020 is to increase the share of renewable energy in final consumption to 18%. In fact, Germany has put an emphasis on energy conversion. One of the reasons for why energy conversion is so important is that dependence on fossil fuels is still very high despite 20-year effort (Wettengel 2019). The share of energy sources in primary energy consumption in the energy mix of Germany in 2019 and the share of energy sources in primary energy consumption in the energy mix of Turkey in 2018 are presented in Fig. 1. For Germany, the share of oil is 35.3%, which the highest value in the energy mix followed by 25% natural gas. Among the renewables (14.7%), biomass is the highest share of 7.6% followed by wind (3.6%) and solar energy (1.6%).

Germany still generates the two thirds of the electric energy from conventional energy sources (BMWİ 2018). Besides, Germany plans to withdraw nuclear power, coal and lignite in the future. Thus, natural gas that remains the last traditional source for power generation will also be a transitional source of energy because Germany has targets

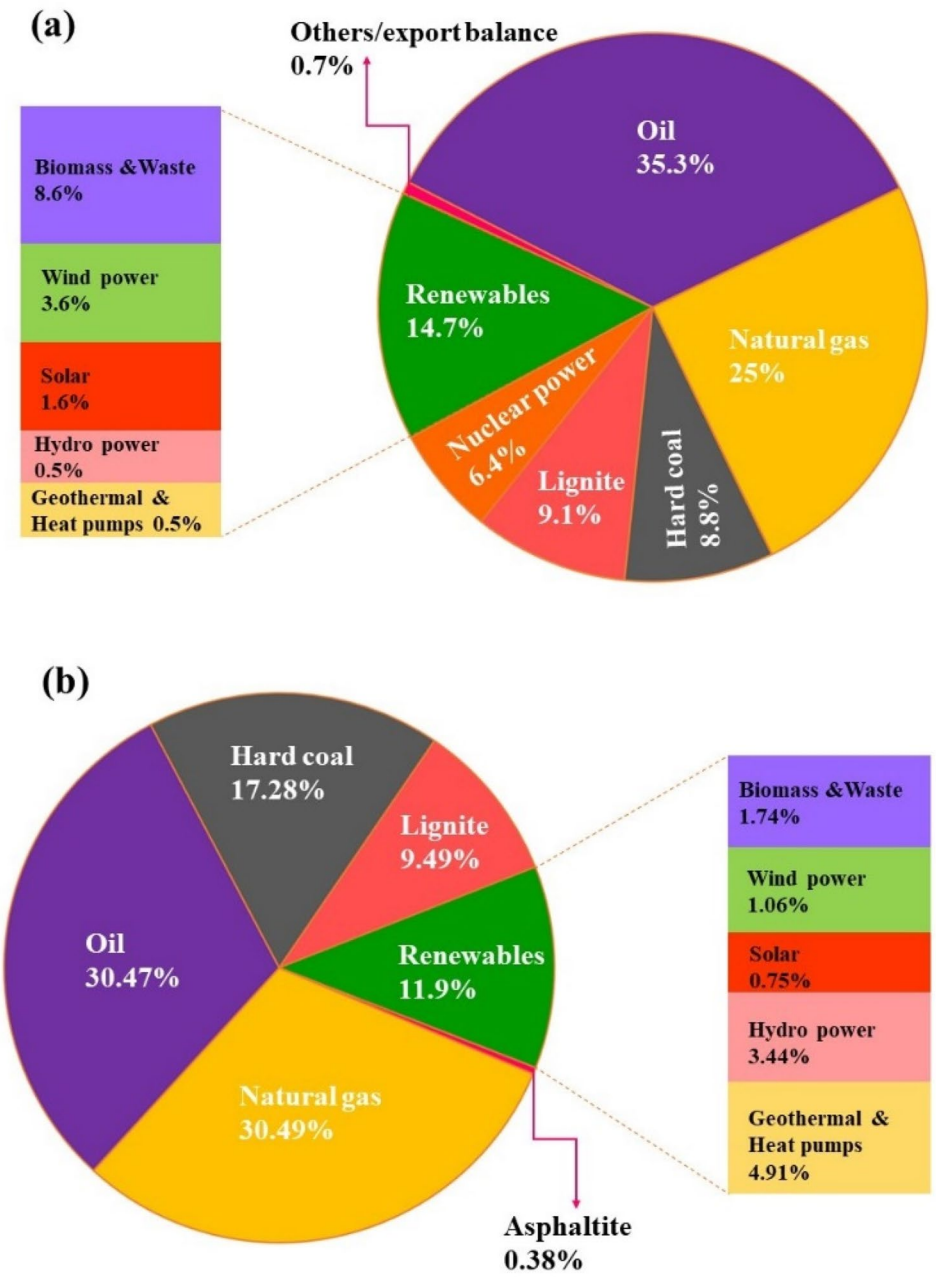

Fig. 1 The share of energy sources in primary energy consumption in German energy mix in 2019 (Appunn et al. 2020). **b** The share of energy sources in primary energy consumption in Turkey energy mix in 2018 (The graph is modified using TMMOB 2019 Report)

to complete climate neutrality by the year 2050 (Auer 2019). Net energy imports of Germany declined by 12% within the years of 2000–2018. Net natural gas imports are becoming more popular while oil and nuclear energy imports have been decreased since oil heating is getting less popular and Germany has already decided to give up nuclear energy and stop it by the year 2022. With regard to coal imports, until 2016, the imports did not start to decrease. The imports were still considerably higher in 2018 than in 2000 since domestic coal mining was abandoned. Germany imported almost 71% of the necessary energy commodities in 2018 (Appunn et al. 2020). For the first time, Germany determined guidelines under "Energy Concept" that was adopted in 2010 for an eco-friendly, reliable and affordable energy supply and made a roadmap for the age of renewable energy (BMWi 2011). Then, it was followed by a specific action plan of Germany which includes a set of targets and measures published in 2011. The implementation of pivotal political objectives for future energy system in Germany is quite important. In future energy system, Germany is to become one of the world's most energy-efficient, sustainable and low-carbon energy systems along with maintaining a secure and reliable power supply. In other words, the aims of Germany in the long-term are to have a high level of energy security, efficiency, environmental and climate protection, and an economically viable energy supply. It is obvious that, over the time, the rising energy demands will lead to an increase in energy prices all over the world. For this reason, Germany wants to strengthen the industrial competition and market orientation in energy markets in order to secure sustainable economic prosperity and future jobs to support technical innovation (IRENA 2015). On the other hand, 80% of greenhouse gas (GHG) emissions are due to energy use. Thus, Germany aims energy transformation in medium-to-long term. The share of renewable energy for final energy consumption in Germany between 1990 and 2014 and 2020 targets are presented in Fig. 2.

One of the aims of Germany is to increase the share of renewable energy in electricity generation (27.4% in 2014) up to 80% and in total energy up to 60% by the year 2050. The aim concerning the energy efficiency is to reduce total primary energy demand by 20% by the year 2020 and 50% by the year 2050 as compared to the demand in 2008. The rate of energy intensity improvement needs to be increased by 2.1% per year, which is about 1.6% between 2008 and 2014, in order to reach the targets. In addition, to double the yearly rate of building renovations from ~ 1% of the building stock per year to 2% by the year 2050 is also aimed in "Energy Concept" (IRENA 2015).

Low-carbon emission goal of Germany

Germany has already completed the industrial revolution and now considers fighting against global warming within the scope of priorities of energy policy. Germany agreed ambitious climate policies in the early 2010s with "Energiewende". In addition, Germany signed Paris Agreement in 2015 in order to reduce the CO_2 emissions and global temperature increase (Hansen et al. 2019). Germany has also committed in Kyoto protocol to reduce GHG emissions by at least 21% as compared to the level of 1990. The aim is to reduce GHG emissions by 40% by the year 2020 as compared to 1990. According to the "Energiewende" targets, Germany aims to reduce the emissions by 80–95% in 2050 as compared to 1990. Germany wants to increase the share of renewable for the final energy up to at least 60% and for only electricity demand up to 80% in 2050. In addition, Germany has targets to reduce primary energy demands, electricity heat and transport demands, as well (Hansen et al. 2019).

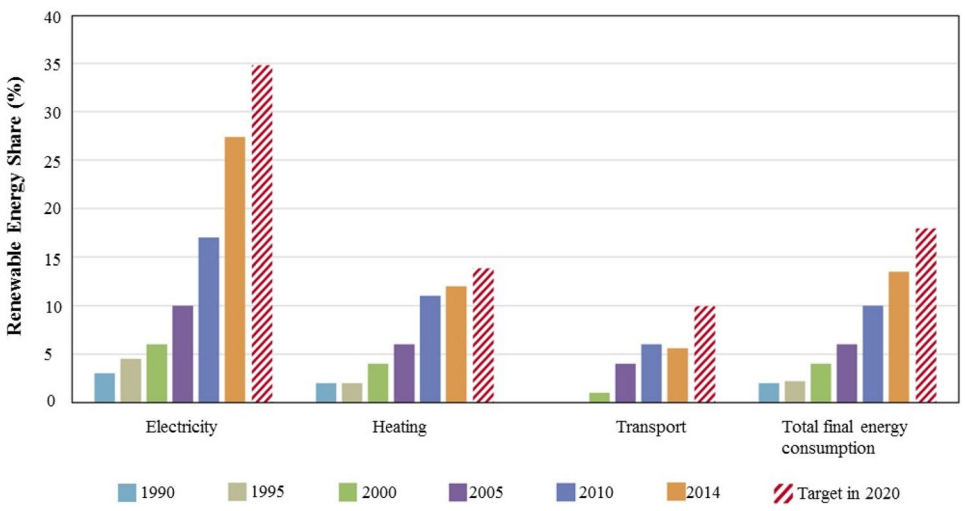

Fig. 2 The share of renewable energy for final energy consumption in Germany between 1990–2014 and 2020 targets (IRENA 2015)

Concerning to GHG emissions reduction, the EU has a goal to reduce the emission by 20% by the year 2020 (Appunn and Wettengel 2020). It seems that Germany has more ambitious goals than that of the EU. These goals with respect to climate protection have put renewable energy along with energy efficiency at the center of Germany's energy debate. On the other hand, the controversial debate about nuclear power in 2000 as well as the oil crisis in the 1970s has encouraged transition toward renewable energy in recent decades. Germany decided to phase out nuclear power in 2000 and the decision was re-enforced in 2011 because of Fukushima nuclear accident in Japan. Although the decision about phasing out nuclear power was controversial in German politics between 1980 and 2000, the "Energiewende" has gained broad political consensus. Thus, Germany has decided to phase out nuclear power gradually and stop it by the year 2022. As aforementioned above, the decision supports energy efficiency improvements and the expansion of renewable energy. The report of Energy Concept for an Environmentally Sound, Reliable and Affordable Energy Supply (BMWi 2011; Kuittinen and Velte 2018) presents the guiding principles of Germany's "Energiewende" as follows:

- Restructuring fossil fuel power plants
- More rapid expansion of renewable energy and its integration into the energy system
- Wind energy as a central component
- Expansion of electricity grids
- Smart grids and storage facilities
- Energy-efficient buildings

The European initiatives for energy efficiency include efficient procurement and cost efficiency (IRENA 2015). Germany has a goal introduced in January 2019 to phase out all coal electricity generation by the year 2038. Both of the decisions of phasing out nuclear power and coal electricity generation would turn out further changes in electricity generation mix of Germany. Thus, the use of renewable energy and natural gas has increased in the mix. For example, electricity generated by coal-fired plants declined by 46 MWh between 2000 and 2017 whereas electricity generated from wind and solar increased by 95 MWh and 40 MWh, respectively. However, coal still remains the main source in Germany. The share of coal in total generation reduced from 50% in 2000 to 36% in 2017. But, there was a slight increase in 2012 and 2013, which was related to the decision of Germany to move away from the nuclear power (EIA 2019).

For the first time in 2018, renewable energy competes with coal to become the biggest source of electricity generation in Germany supported by a surge in solar panel installations and coal-plant closures. According to the Fraunhofer Institute, wind, solar, hydro and biomass generated over 40% of Germany's electricity in 2018 whereas coal had a share of 39%. It was announced that an almost 20% increase in solar energy capacity, the shuttering of older coal plants and favorable weather conditions conspired to help green sources edge ahead (Wilkes and Parkin 2019).

Import dependency of Germany

Germany decided to have a goal with "Energiewende" to produce energy independent of fossil fuels in 2010 in order to reduce CO_2 emissions drastically via phasing out oil, coal, and natural gas. It was known that between 2000 and 2018, net energy imports decreased by almost 12% in Germany. While oil and nuclear energy imports are reduced, the net natural gas imports are increased. Coal imports did not start to decrease until 2016 and were still higher in 2018 (39%) than in 2000. This was due to the fact that domestic coal mining has been steadily reduced at the end of 2018 whereas electricity generation by coal has been reduced much more slowly. Thus, coal imports increased accordingly in order to close the gap encountered. Net energy imports of Germany with respect to energy sources are shown in Fig. 3 by years.

The energy commodity imports dependence of Germany has not decreased much over the years. For instance, almost 71% of the necessary energy commodities were imported in 2018 while the share of that was 72.6% in 2000. On the other hand, there was a decline in oil imports by ~ 17% between 2000 and 2018. However, oil imports had the largest share in German total net energy imports (47.5%) in 2018. Among German total net energy imports, oil imports are followed

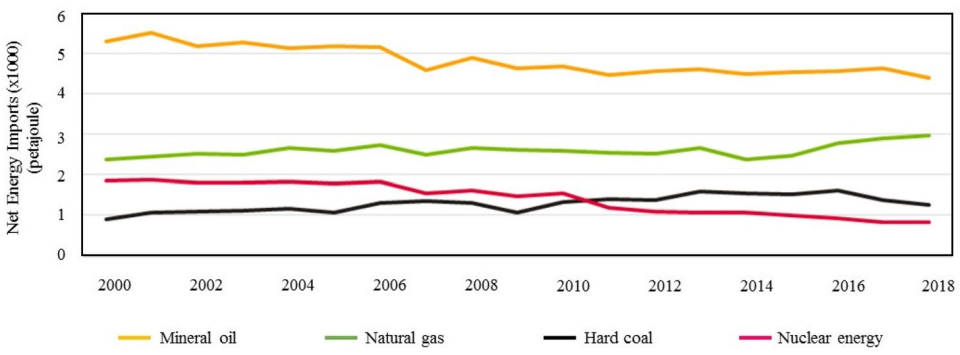

Fig. 3 Net energy imports of Germany with respect to energy sources (Heymann and Auer 2019)

by natural gas imports. The share of natural gas imports was 32% in 2018, which meant that net imports were increased by 25% as compared to 2000. Germany is the biggest natural gas consumer in Europe. Besides, it is expected that present demand will rise by ~ 1% over the next five years (Heymann and Auer 2019). In 2017, Germany used 53 billion cubic meters (bcm) of Russian gas, which was ~ 40% of total gas consumption in Germany. Due to the fact that Germany had very few reserves of natural gas, half of natural gas is imported from Russia by pipeline. Germany increases natural gas exports since it is an important transit country for new pipelines (Heymann and Auer 2019). On the other hand, Germany announced a plan to build a (€420-million) liquid natural gas (LNG) terminal on the Elbe River in northern Germany. Thus, Brunsbüttel would be the first LNG plant in Germany, which is expected to be on-line by the end of 2022 and to be able to import as much as 5 bcm per year that is 10% of annual imports from Russia (Wettengel 2019). Next, Germany declared a goal to complete and operate Nord Stream II, which is more environment-friendly than LNG (Heymann and Auer 2019). Excluding nuclear energy, the import quotas are 99% for oil and 96% for natural gas. Germany has renewables and lignite as domestic sources of energy (Heymann and Auer 2019).

Turkey's energy policy regarding "More Domestic, More Renewable"

Turkey with a land area of 785,350 km^2 is nearly 2.2 times larger than Germany, which is the largest country in the EU. The population of Turkey is around 83 million which is similar to Germany. The national income per capita was around 8.811 USD in 2019 (TSI 2020) in Turkey, which is a developing country. The aim of Turkey is to increase it up to 12.484 USD in 2023. The growth rate of Turkish economy is 3% in the last 30 years and it became 18th largest economy in the world. Turkey includes two priorities in energy policy. The first one is development of renewable energy sources and the second one is promotion of energy efficiency measures. Turkey with 76% energy dependency realizes that energy security was also important. The main elements of current energy strategy of Turkey are listed below (MFA 2015):

- to diversify the routes and countries of energy supply
- to increase the share of renewable energy and also include the nuclear energy into the energy mix
- to take care of energy efficiency and increase the efficiency,
- to contribute to the EU's energy security.

Turkey has an approach of "*More Domestic, More Renewable*" within the scope of the National Energy and Mining Policy. Thus, with respect to national energy policy, Turkey expands electricity capacity using domestically sourced coal. The goal is to nearly double the power generation from domestic coal in 2019 as compared to 2012 levels according to the latest strategic plan (Timberly 2018). The main priority of Turkey is to diversify the energy sources as mentioned in the Ministry of Energy and Natural Resources (MENR) Strategic Plan (2015–2019). Turkey has an advantage of geographic position for energy transportation since it is located in between Europe and Asia. Turkey wants to be a regional energy hub particularly for natural gas followed by oil and also wants to reduce the share of fossil fuels in accordance with long-term energy strategies. Between 2008 and 2018, energy consumption increased from 198.085 up to 300.109 GWh in Turkey. It is also expected that the energy demand will increase in the future. Thus, the Turkish government put the energy security on top its political agenda because of increased consumption. Turkey strongly depends on imported energy supplies that are mainly based on fossil fuels. Turkey released a Renewable National Action Plan (NREAP), which was prepared according to the EU's targets in 2014 (MENR 2014).

Low-carbon emission goal of Turkey

Turkey declared an intention to decrease GHG emissions level at a rate of 21% by the year 2030 with the long-term energy strategy via signing Kyoto Protocol and Intended Nationally Determined Contribution (INDC) to the United Nations Framework on Climate Change Convention (UNFCCC) before the Paris Conference of the Parties (COP 21) (MFA 2015). However, the Paris Climate Agreement has not been ratified by Turkey, which is a member of G20. It is known that, only if Turkey receives financial support from the EU, then it will ratify the agreement. On the other hand, Turkey has already decided for clean technology transition. Thus, the investments in the renewable energy field have been increased. It is expected that Turkey will become the 5th biggest renewable energy country in Europe by the year 2024, and the 11th in the world with such progress (Anadolu Agency (AA) Energy 2019). Turkey produced 46% of electricity from renewable energy sources in 2019 and became one of the largest potential for renewables expansion especially for wind and geothermal power in between the European countries. The share of renewable energy resources in total installed capacity reached to 42 GW in 2018. It was expected that the installed renewable power with an increase of 50% would reach to ~ 63 GW from 2019 to 2024 (IEA 2017). The share of renewable energy in the electricity generation mix has been estimated as 30% and 10% of the estimated value will be used in transportation sector by the year 2023 (MENR 2014). Turkey's mitigation measures focus on increasing the share of renewable energy, integrated

waste management, energy efficiency, and establishment of an emission trading mechanism. Expansion of the policy instruments is considered to provide cost effectiveness in undertaking mitigation measures (Turhan et al. 2016).

Import dependency of Turkey

Turkey's energy dependency is 76% and the energy demand is mostly supplied from fossil energy sources. Among the consumed energy sources, oil, natural gas and coal still keeps their importance. On the other hand, significant investments have been made in the field of renewable energy sector recently (Presidency of the Republic of Turkey Investment Office 2019). According to the report (TMMOB 2019), Turkey's total energy consumption accounted for 30.49% natural gas, 30.47% oil and 17.28% coal in 2018. Turkey is only able to produce 24% of total energy, thus has to import 76% (particularly oil and natural gas) from the other countries including Russia, Iran, Iraq and Azerbaijan. Namely, Turkey imports 93.2% of oil and 99.2% of natural gas consumption (TPAO 2018). About 23% of oil is imported from Iraq, 19% from Russia and 17% from Iran. In addition, 53% of natural gas is imported from Russia, 17% from Iran and 14% from Azerbaijan (TPAO 2018). Turkey decelerated the National Energy Policy along with "*More Domestic, More Renewable*" approach to decrease the foreign dependency rate.

Renewable energy policies, potentials and targets

It is observed that there were outstanding differences as well as similarities between Germany and Turkey regarding energy transformation. Germany has achieved significant cost advantage in the field of renewable energy. Thus, Germany is a role model for Turkey. It is important for both Germany and Turkey to increase the share of the renewable energy in the energy mix due to the problem of import dependency as explained in Sect. 3. Therefore, the renewable energy policies, potentials, targets of Germany and Turkey are presented in this section in detail.

Renewable energy policy of Germany

Germany that is the biggest economy in Europe aims to have 65% renewable energy in energy mix by the year 2030. Furthermore, Germany has a target to produce 60% of total energy and 80% of electric energy by renewables by the year 2050. Germany decided to phase out nuclear energy by the year 2022. It was also decided to phase out coal in long-term. Thus, renewable energy sources such as wind and solar power have been playing important roles. It is known that Germany was the largest electricity producer and consumer of the EU. Among the EU countries, Germany is also the largest electricity producer from wind, solar and biomass energies (BMWi 2018). Germany is the third country in the world with the highest installed power with respect to wind energy, according to 2018 data (Morris 2018). In addition, it is one of the countries that use solar energy most effectively with successfully determined and implemented renewable energy strategies.

Germany has outperformed its goal of generating 35% electricity from renewable energy which was set for 2020, with 36% electricity production in 2017 (BDEW 2019). It is expected to increase this percentage. It is predicted that Germany could increase renewable energy installed power by 5% each year and obtain nearly 100% of the electricity consumption in 2030 from renewable sources (Morris 2018). Germany has dropped the fossil fuels for energy generation since the priority was given to green power. Besides, the power demand has decreased due to mild weather and ongoing efficiency drives. Germany in conventional energy mix has 48.7 TWh energy generated by the plants run on imported hard coal and 54.1 TWh by gas-to-power generation, and 71.2 TWh by nuclear energy (Reuters 2020). *Wind power* Germany has been using wind energy for more than 30 years. It is reported that wind energy was the second important source of electricity and produces more electricity than nuclear or coal (BWE 2018). Further, according to the report of IEA in 2020, wind power surpassed both nuclear and natural gas to become the second-largest source of electricity generation in 2017 (IEA 2020). In addition, Germany has the highest installed wind capacity (59.3 GW) in Europe, and the third one in the world in 2018 (Unwin 2019). On the other hand, Germany started offshore wind energy after 2010 because offshore wind is cost-efficient, consistently reliable and competitive. Around 1500 turbines with a capacity of over 7.5 GW were installed after ten years. With 1078 MW and 325 turbines, the gross expansion of onshore wind turbines in 2019 will reach its lowest level since the introduction of the Renewable Energy Act (EEG) in 2000 (Uyanık 2018). *Solar energy* Germany is one of the largest solar energy producer around the world although it takes a place among the countries with the least sunshine hours in the world. Germany reached to 47.72 GW cumulative solar power capacity at the end of May 2019 and ranked 4th in the world. Germany has successfully supplied over 50% of the nation's daily energy demand from solar power (Chowdhury 2019). *Hydro power* Hydroelectric power plants have been operated in Germany for more than 100 years. Thus, Germany is good at hydroelectric power plant technology. At least half of all hydroelectric power plants around the world are based on German technology (BMWi 2016). Although the share of hydropower in the energy mix of Germany is quite low, it will remain a system cornerstone due to its

relative reliability and predictability (IHA 2019). Electric energy generation from hydropower was 24.9 billion kWh in 2000, 17.7 billion kWh in 2003, and 16.6 billion kWh in 2018 (Statista 2019a). *Biomass energy* Biomass energy came to the third largest renewable source in Germany after onshore wind and solar power because about 7% gross power was produced from biomass in 2018. It is pointed out that biomass was reliable and weather-independent source (Eriksen 2019). The share of biomass in renewable electricity generation is 24% (BMWi 2020). Germany ranks 5th in the world with respect to biomass energy according to 2018 data (Statista 2019b). *Geothermal energy* The geothermal electricity development in Germany is quite slow. It is mentioned that geothermal power played only a marginal role in the German electricity market (BMWi 2016). Despite legal incentives, the share of geothermal resources in Germany's electricity generation from renewable energy represents the lowest rate with 3% (167 GW, 2018) because of its high cost as compared to the other energy sources (BMWi 2018).

Renewable energy Policy of Turkey

Energy transition from fossil based to renewable energy sources is in the priority of Turkey's energy policy. Turkey has increased the renewable investments since 2000s. The share of renewable energy sources in the total capacity of Turkey was 42 GW in 2018. Turkey aims to add the capacity of 20 GW, 5 GW, and 1 GW for wind, solar and geothermal by 2023, respectively. The installed renewable capacity is expected to increase by 50% and reach to ~ 63 GW from 2019 to 2024 (IEA 2017). Turkey aims to produce 30% of total electric consumption from renewable sources in 2023. *Geothermal energy* Turkey is ranked 4th in the world in 2019 regarding geothermal energy (Think Geoenergy 2020). The share of the installed capacity in electricity generation was 0.06% in 2006 and increased to 0.20% in 2010 and to 1.6% in 2018 while the share of the world was 0.21%. The capacity has increased by 21% in 2018 with adding 219 MW of new capacity (REN 21 2019). Turkey has already exceeded the 2023 targets (1.000 MW) with installed capacity of 1.526 MW and increased the 2023 targets up to 4.000 MW (Topbas 2020). *Wind power* Turkey used wind energy in the energy mix for the first time in 1998. The installed capacity was ~ 3.760 MW in 2014 and ~ 8.000 MW in 2019 (TUREB 2020). The improvement in the installed capacity (2009–2019) is presented in Fig. 4.

The 2023 target is to reach 20.000 MW installed capacity (Cebeci 2017). Turkey is ranked 7th in Europe and 11th in the world (MENR 2016). In 2018, Turkey is ranked 8th in the world (Unwin 2019) for wind power. *Solar energy* The geographical position with electricity production potential from solar energy as 380 TWh-year and total installed capacity of 56 GW solar energy gives advantages to Turkey. In 2014, the installed capacity was 40 MW that is expected to be 5 GW until 2030 (Cebeci 2017). Konya-Karapinar solar power plant with 1.000 MWe is one of the largest solar power plants in the world (MENR 2018). In 2013, the concentrated solar energy plant (with 5 MW thermal power capacity) that is a new technology was established in Mersin for the first time in Turkey by Greenway a Turkish company (Esen 2018). *Biomass* The number of firms licensed on biodiesel production is 8, for bioethanol is 5 and 199 biomass energy power plants are actively producing electricity from bio-materials (MENR 2019). In Turkey, 147 biomass power plants are actively producing 658 MW/year electricity that is 0.74% of Turkey's total electricity generation according to the February 2019 data (TEIAS 2019). *Hydro power* Turkey has hydropower potential in renewable energy and technically viable potential is 216 billion kWh/year (MENR 2015). In 1902, the first hydroelectric power plant of Turkey was established in Mersin. It was reported that the 659 (streaming + dam), which set a bar for more than 40 million tons of CO_2 emissions were approximately producing 28,378.1 MW hydroelectric power (TEIAS 2019). Although CO_2-free nuclear energy is one of the conventional energy sources and not in the list of renewable energy, the nuclear situation of Turkey is given in following section because it is going to have a significant role in the energy mix of Turkey. *Nuclear energy* The first nuclear power plant (Akkuyu Nuclear Power Plant, Akkuyu NPP) of Turkey has been established in

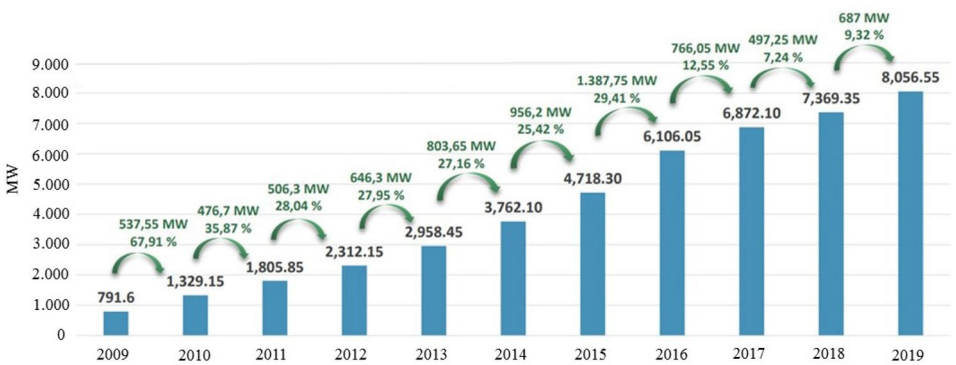

Fig. 4 Changes in installed capacity of wind power of Turkey between 2009–2019 (TUREB 2020)

Mersin in accordance with the agreement signed with Russia in 2010. Akkuyu NPP has been established along with the model of Build-Own-Operate (Telli 2016). Akkuyu NPP has four units and 4800 MW total capacity and the lifetime of 60 years. The first unit is expected to become operational by the year 2023. The 2nd NPP of Turkey was planned to be established in Sinop with an agreement signed with Japan in 2013. The feasibility studies were already completed in 2018. The 3rd NPP of Turkey is also under consideration and possibly will be built on Thrace region of Turkey.

Comparison of energy transition of Germany and Turkey

Once the electricity consumption of Germany and Turkey is compared, it was observed that Germany was the 7th whereas Turkey was the 17th. Same holds for primary energy consumption; Germany is the 7th whereas Turkey is the 16th on top of 20 countries in 2018. Germany, in addition to the targets announced by the EU, has set national priorities that exceed these targets regarding the renewable energy transition. The regulations in the EU in the field of energy have to be taken into account by Turkey because of ongoing process of EU accession. The renewable energy targets of the EU were determined in the "Renewable Energy Directive" published in 2009. Accordingly, the target for 2020 is to make the ratio of renewable energy to be at least 20% in the energy mix. Countries are free to set their own targets above this rate. In addition, it is aimed in the directive that 10% of the energy used in transportation to be meet from renewable energy by the EU members (Bayraktar and Kaya 2016).

The European Commission published a proposal for a revised Renewable Energy Directive on 30 November 2016 in order to make the EU a global leader in the field of renewable energy. The new target is to meet at least 27% of the final energy consumption in the EU by 2030 from renewable energy sources (FNR 2020). Furthermore, the directive was revised once again in December 2018. The revised directive (2018/2001/EC) requires the EU members to supply at least 32% of their total energy needs from renewable energy sources by the year 2030 (EC 2019). Thus, both Germany and Turkey announced their national action plans and many mechanisms have been created to support energy transformation.

There are three similar goals regarding the energy transition of Germany and Turkey: reducing GHG emissions, expanding renewable energy use and increasing energy efficiency. Indeed, affordable and secure energy supply is also a clear strategic goal for both countries (Wu and Hann 2013). It is obvious that such common ground and differences made it potentially possible and profitable for the two countries to cooperate in diverse ways (Cheng et al. 2019). Although there are significant differences between Germany and Turkey in terms of socio-economic indicators, they have common points in their long-term energy policy. Accordingly, the cooperation between two countries in the energy field, especially the information and technology transfer from Germany to Turkey is constantly developing. Both countries shape their national energy policies in line with the EU's goal, which is to make zero GHG emissions by the year 2050 (EC 2020).

The main difference between Germany and Turkey is that Turkey follows a strategy to meet rising energy boost whereas Germany follows a basic strategy to reduce the energy demand. The goal of Germany for 2030 is to reduce primary energy demand by 30% to 2008 level (Xinhua 2019). Since the economic growth and energy consumption were closely interrelated, such a situation is normal for Germany, which has completed economic development. However, it is different for Turkey, which is a developing country. Even in the conservative scenario, the energy demand of Turkey is expected to be double of the current state. This constitutes serious pressure on Turkey regarding energy supply security. The energy demand of Germany started to decrease after 2010 and it maintains this trend except for the quite low increase observed in some years. The electricity consumption per capita in Germany was 6668 kWh in 2018 (Index Mundi 2020). It is also important to mention that the demand of fossil and nuclear energy declined between 2005–2019. As a result of the "Energiewende" policy, the share of renewable resources in the energy mix of Germany is increasing steadily.

The share of renewable energy in the primary energy mix of Germany has reached ~ 17%. Although the target of the EU is to reach 20% renewable energy. Germany has set the national target as 18% and is quite close to this goal. Regarding electric energy generation from renewable sources, the aim is 35% in 2020, which was already exceed in 2019 with the value of 38.5%. Besides, the aim is to increase this rate up to 65% by the year 2030. The share of renewable energy in energy supply in final consumption of energy was increased from 2% to 10% in Germany from 1990 to 2009 (Federal Republic of Germany 2012). It is estimated in the German National Action Plan that the share of renewable energies in gross final energy consumption will be 19.6% in 2020. The share will be 38.6% for electricity sector, 15.5% for heating/cooling sector, 13.2% for transportation sector (Federal Republic of Germany 2012). The present Renewable Energy Act (Erneuerbare-EnergienGesetz – EEG) encourages the further development of the production of renewable energies in the electricity sector involving the production of combined power and heating/cooling systems. The priorities of electricity generated from different sources will be connected to the national grid as defined with the

EEG adopted in 2000. In addition, electricity producers are given a certain fixed price guarantee by the law for electricity supplied to the grid. It is also planned to reduce the supports over the time in order to make new technologies more efficient and less costly (Uyanık 2018). Germany started to search for a new mechanism since it was already more than 20 years that the EEG supports in progress. Germany has been in a transition process of procurement system which is similar to the model of Renewable Energy Resource Area (YEKA) that is already in practice in Turkey.

Germany decided to reduce the imports significantly by renewables and improve energy efficiency and increase the energy security. It was also decided to phase-out nuclear, which is at the central part of the energy transition of Germany because Germans view it is unnecessarily risky, too expensive, and incompatible with renewables. Germany has already planned how to fill the gap to be created by nuclear phase-out: with renewables, natural gas turbines, energy efficiency and conservation, demand management, existing conventional power plants (Morris and Pehnt 2018). Another step to be followed in accordance with Germany's transformation strategy is to reduce the installed coal power plant of 41 GW down to 17 GW in 2030. Thus, the annual carbon emissions by the energy sector can be reduced by 60% that supports to achieve the target of carbon reduction by the year 2030. The German Coal Commission's 2030 forecast is that renewable energy sources will increase to 65% and current coal production will decrease by two thirds (Agora Energiewende 2019).

Despite the global economic crisis, the energy demand of Turkey is increasing due to developing country economy. Namely, in the last 30 years, the Turkish economy was grown by 3% and became the 18th largest economy in the world. Between 2002 and 2018, the average annual growth rate of the economy was about 5.6% and the total energy demand increased more than 90%. The demand was supplied by energy investments and energy imports (Taranto and Dincel 2019). The electricity consumption per capita in Turkey was 2844 kWh in 2018 (Index Mundi 2020). The share of renewable energy in the primary energy mix of Turkey is about 11%, which can be increased rapidly by evaluating the capacity. The share of renewable energy in electricity production of Turkey is 47.3% which is higher than that of Germany. The energy transition of Turkey is similar to trends around the world. The first regulations in the field of renewable energy were made in Turkey at the beginning of the 2000s. The transformation process was accelerated by the Renewable Energy Sources for the Support Mechanism (YEKDEM) that came into force in 2005. The YEKDEM incentives are shorter as compared to Germany's 20-year planning. The producers are supported with a 10-year fixed-price purchase guarantee (pwr 2015). The Law of YEKA was enacted in 2013 in order to support the YEKDEM mechanism. The aim of the regulation, which is used in many countries, is to increase the licensed production capacity. Although Turkey has high potential, it was not able to increase the investments in renewable energy fast due to high costs. Recently, the investments have been increasing thanks to the developments in the renewable energy technology that reduces the investments costs. Besides, the sensitivity regarding global warming has been increasing and energy security has become one of the most important issues for Turkey. According to 11th Development Plan (SBB 2019), Turkey has a target to increase the share of renewable energy up to 38.78% for 2023. It was reported that among the European countries, Turkey has the largest potentials for renewables expansion especially in wind and geothermal power (Carbon Brief 2018). Turkey with quite a high geothermal potential (60 GW for heat and 2 GW for electricity) is among the world leaders. Regarding wind potential, Turkey is the largest (114 GW) and for solar potential (56 GW) it is the second largest in Europe (Yeldan and Vovyoda 2015).

The main differences between Germany and Turkey upon the energy transition are about coal power plants and nuclear energy. Turkey with "*More Domestic, More Renewable*" policy, decides to give priority to domestic coal-fired power plants and also to renewable energy sources in order to reduce natural gas import dependency while Germany is about to phase-out the use of coal. Besides, Turkey aims to have the share of 20.7% in electricity generation from natural gas in accordance with the 11th Development Plan (SBB 2019). Nuclear energy is another prominent point of the policy of Turkey for energy diversification. Turkey has ambitious targets regarding nuclear energy. Although Germany is going to shut down the last nuclear plant in 2022, Turkey is going to produce energy from nuclear power gradually in 2023. Germany as being one of the first countries to start the energy transition has made serious progress for this transition. This reliable regulatory framework, which aims to remove investors' income risk by providing purchase guarantee and priority grid access, has been effective in reducing wind and solar energy costs by 50–90% in ten years. Therefore, wind and solar power have become the cheapest sources for electricity generation (Saygin and Godron 2018). Germany maintains its position among the most important renewable energy countries in the world despite the decreased the rate of capacity increase. Thanks to significant technological advantage, Germany produces solar energy approximately 46 times more than Turkey although it receives 60% less sunlight as compared to Turkey (Gözlem 2019).

In the last decade, Turkey started to take into account the high capacity of solar radiation and to increase the investments in the solar energy sector. In 2017, Turkey made more solar energy investments as compared to Germany. Yet, Germany is ranked 4th in the top ten list of the world regarding

the total installed capacity in 2017 whereas Turkey was out of the list. The countries are in following order: China (131 GW), USA (51 GW), Japan (49 GW), Germany (42 GW), Italy (19.7 GW), India (18.3 GW), UK (12.7 GW), France (8 GW), Australia (7.2 GW), Spain (5.6 GW) (Clean Energy Wire 2018). It is noticed that Germany and Turkey had different preferences for base load resource upon the energy transformation. They are two largest exporter of natural gas from Russia whereas they have different strategies for the future. The natural gas remains the important role for Germany because it consumes natural gas at hub prices and has the largest storage capacity of the EU.

On the other hand, Turkey set a target to reduce the electricity generation from natural gas because it consumes natural gas at higher prices than the European countries. This problem is due to natural gas agreements signed by Turkey under the condition of *take or pay*. Turkey aims to cover the gap left behind natural gas by coal-fired power plant in the short term and renewable and nuclear in the medium and long term. It seems that Germany and Turkey have different pathways for energy transformation because of their unique circumstances which also affect their targets for reducing GHG emissions. Germany reduced the GHG emissions by 30.8% in 2018 as compared to 1990 levels. The government has been criticized for years due to missing the target. Germany with 33% reduction of emissions in 2020 is edging closer to reach to the target of 2020 which is 40% as compared to 1990 levels (Clean Energy Wire 2019). Germany with "Energiewende" policy has rapidly increased the share of renewable energy in energy mix and decided to stop nuclear power and leave fossil fuels. However, emissions have remained stubbornly high for years, mainly due to the continued use of coal power. The use of coal and lignite decreased by more than 20% in 2019 as compared to 2018 levels because power production from renewables and natural gas increased and the use of hard coal by the steel industry reduced. In addition, old lignite plants were transferred into a reserve and several others were overhauled which meant that they were shut down for a long time (Clean Energy Wire 2019).

Turkey is expected to become the 5th biggest renewable energy country in Europe by the year 2024, and the 11th in the world with such progress (Anadolu Agency (AA) Energy 2019). Turkey declared a intention to decrease GHG emissions level at a rate of 21% by the year 2030 in the 2015 Paris Agreement (MFA 2015).

Conclusion

Energy transformation process becomes quite important issue around the world due to the global warming and energy security problem. There is no doubt that the renewable energy sources will play a key role for the transformation from fossil-based to renewable energy. Many countries, especially developed countries, have taken considerable steps for the energy transformation and developed long-term strategies. These strategies consist mainly of supply security, cost (affordability) and environmental factors. Both Germany and Turkey have determined their own unique strategies. Their ambitious expansion concerning to renewable energy is in line with international trends. Germany is one of the countries to adopt the energy transformation both politically and socially at the earliest time and has achieved great success. Germany aims to produce 80% of its electricity needs from renewable sources by the year 2050 and for this purpose has declared short-term targets in 2010 for every ten years. Germany has become the world leader in wind and solar energy and in the last 40 years, achieved 50% improvement in the field of energy efficiency.

Although Turkey does not explain long-term targets for renewable energy, with right steps, has a great potential to achieve the success what Germany had. Hydropower has a significant importance in the energy mix of Turkey and the share of wind, solar and geothermal energy also increases depending on the investments. In the last decade, Turkey, who increases the share of renewable energy 3 times in the installed electricity generating capacity, has possibility to increase this rate in accordance with "*More Renewable, Domestic More*" policy. Although the utilization rate of renewable energy for electricity generation increases quite fast both in Germany and Turkey, the utilization of the renewables does not improve significantly in the heating and transportation sectors. Both Germany and Turkey aim to increase the number of vehicles working with electricity due to the fact that transportation sector is mainly responsible for GHG emissions. There are various projections for meeting the energy supply from 100% renewable energy in 2050. However, approximately 80% of the world energy demand is still met from fossil fuels. The fossil prices are in a downward trend due to excess supply and such situation can negatively affect the renewable energy investments in the future. In addition, the fact that renewable energy storage technology is not yet compatible with the 100% target is one of the obstacles to the energy transition process.

The energy transition from fossil to renewable energy of Turkey was compared with Germany, the world leader, with respect to energy policy, strengths and weakness, and targets considering their own unique conditions. Germany has acquired long-standing experience upon the energy transformation process with the help of "energiewende" policy, which was introduced to the literature in 1980s. For this reason, the transformation model of Germany that has technological superiority is a role model for Turkey with significant potential for renewable energy as well as for the other countries.

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Affiliations

Azime Telli[1] · Selma Erat[2,3] · Bunyamin Demir[3,4]

Selma Erat
selma.erat@mersin.edu.tr

Bunyamin Demir
bd@mersin.edu.tr

[1] Department of International Relations, Faculty of Economics and Administrative, Mersin University, 33340 Mersin, Turkey

[2] Department of Medical Services and Techniques, Program of Opticianry, Vocational School of Technical Sciences, Mersin University, 33340 Mersin, Turkey

[3] Advanced Technology, Research and Application Center, Mersin University, 33340 Mersin, Turkey

[4] Department of Mechanical Engineering, Faculty of Engineering, Mersin University, 33340 Mersin, Turkey