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A COMPREHENSIVE ANALYSIS OF STRATEGIES, CHALLENGES AND POLICIES ON TURKISH SUSTAINABLE ENERGY DEVELOPMENT

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Abstract

Turkey's rapid population and economic growth have caused a significant increase in energy demand over the last two decades. As a result, a process of evaluating alternative energy strategies and policies was required to be formulated carefully along with the country's longer-term decarbonisation aims. Although Turkey's considerable renewable energy potential exists, its dependency on foreign energy and its dramatically depreciating currency have been the main drivers of revisions to these renewable energy-related policies. This paper aims to demonstrate and evaluate all the strategies and challenges of Turkey's green steps toward a sustainable future. Sustainable developments of many developed countries have been examined and compared to assess Turkish strategies and significant policies that have been taken. As findings, it has been revealed that policy revisions regarding the use of domestic technology in green power plants decelerate investments for a short time. However, it has been found that renewable energy patent applications have declined, although domestic technology in green energy plants has been promoted through these policy revisions. As a result of this dilemma, the quality and effectiveness of green research and development (R&D) in Turkey have been investigated and then benchmarked with most leading countries. It has been observed that there is no correlation and relation between the patent application and the articles on renewable energy. Therefore, the paper has provided insight into new policies and strategies to enhance the productivity of R&D for both Turkey and developing similar countries. Consequently, potential measures to increase Turkey's green energy use and production are discussed and proposed systematically, considering those findings.

Keywords: Sustainable development, renewable energy, energy policy, project management, energy strategies

1. Introduction

Energy demand growth is often linked to the increase in global well-being and prosperity. Regardless of the energy source, global energy demand is often observed to grow exponentially

over decades, and this trend is likely to continue. With improving living standards and the considerable increase in the global population, it is projected that electricity generation is expected to rise by nearly half of the current users over the following two decades [1, 2, 3]. As a result, it might be highlighted that the increase in the energy demand will pave the way for changes in energy consumption by energy source. To supply enough energy, various sustainable developments (materials recycling, waste reduction, increased use of renewable resources, phasing out extraction of non-renewable resources) and technological measures (improving the efficiency of energy use and energy conservation) have been planned globally. [4, 5, 6].

The Turkish energy industry has long played a critical role in employment and economic growth by being the main driver of the country's development [7]. As a natural result, the country's most recent budgetary planning was prepared to provide allocations of funds (more than 5% of the country's budget) to new renewable, nuclear, and fossil fuel energy plants across the country and various energy innovation funds in general, supporting sustainable developments through the commercialisation of innovative, emerging renewable energy technologies [8]. Therefore, general politics might be said to be focused on reducing Turkey's energy imports. Although the dependency rate on energy imports does not follow a straight-line year after year, an alarming pick of 77.9% in imports was observed in 2017. Subsequently, the energy politics of the country have shifted towards aiming to benefit more from sustainable sources, mainly solar and wind power. As a result, the share of renewable energy sources in electricity production increased during the pandemic resulting in renewable energy sources accounting for more than 12% of Turkey's generation in 2020 [9]. On the other hand, the share of coal in the electricity mix in Turkey increased by almost 40% from 2015 to 2020 and might threaten the country's green targets [10, 11, 12].

To understand the outcomes of Turkey's energy policies aiming to diversify the energy mix of the country and increase energy security, this study is established by:

i. Investigating whether the country's desire for self-sufficiency is achievable.
ii. Identifying whether the green targets can match the energy demand.
iii. Addressing policy and initiative problems and, finally.
iv. Underlying the learning gained from Turkey's challenges for other countries that strive to mitigate climate change, build resilience to volatile prices, and lower energy costs.

2. The development of Turkey's sustainable energy policies

2.1 Renewable energy policies

The generation capacity and cost of variable sources of renewable energy are dependent on geographical characteristics [13]. Due to its geographical location offering high levels of solar irradiance, wind speed and geothermal activity, Turkey has the opportunity to benefit from almost all renewable energy resources [14, 15, 16]. Especially when compared with EU countries in terms of hydraulic, geothermal, wind and solar energy potentials, it is seen that Turkey has a highly favourable position [17]. However, the utilisation rate from these resources appears to be at low levels [18, 19]. Many factors, such as costs and deficiencies in legal regulations, lie behind the gap between potential and benefit [20, 21]. Considering the country's foreign dependency rates on energy, the use of existing renewable energy potentials becomes very important for Turkey in the long run [22, 23]. Many successive laws have sought to introduce renewable energy incentives, significantly reducing Turkey's dependence on foreign energy and its energy bill as renewable energy use is promoted. [24].

Table 1. Major Turkish Legal Regulations and Policy Supports for Renewable Energy[1]

Renewable energy-oriented law, regulation or policy	Date	Type	Target[2]
The use of renewable energy sources for electric energy generation	2005	Policy support-strategic planning	All renewable sources
Supporting geothermal projects	2008	Economic and political	Geothermal
Climate change action plan 2011–2023	2011	Strategic planning	Solar[3], hydra and geothermal
Revision of renewable energy resources support mechanism	2011	Economic and political	All renewable sources
10 years-tariff guarantee application for renewable energy	2013	Economic and strategic planning	All renewable sources
10th development plan (2014-2018)	2014	Economic and strategic planning	All renewable sources
Turkey national renewable energy action plan	2015	Strategic planning	Solar and biomass
11th development plan (2018-2022)	2018	Economic and strategic planning	All renewable sources
Arrangement for organised industrial zones (oiz)	2019	Economic	Solar and wind

Table 1 shows the significant development of Turkish policies on renewable energy use. The enacted law in 2005 aimed 1) to expand the use of renewable energy resources for electricity generation, 2) to bring these resources to the economy in a reliable, economical and high-quality way, 3) to increase the diversity of resources, to reduce greenhouse gas emissions, 4) to evaluate wastes, 5) to protect the environment and 6) to develop the manufacturing sector needed for the realisation of these goals. Non-fossil energy sources such as hydraulic, wind, solar, geothermal, biomass, biogas, and tidal were included as green resources. However, the policy has been criticised as an unsuitable way to develop green technologies since some parts were not well-defined for the energy industry [25]. Although a regulation was later made regarding the determination of renewable energy resource areas, this regulation remained limited. The use of renewable energy resource areas in public lands was only determined. The procedures and principles regarding the determination, protection and use of geothermal resource areas for electrical energy production were also disregarded. Moreover, Turkey also introduced the country's first tariff scheme for the introduction of renewable energy resources in 2005 (YEKDEM)[4]. Moreover, Turkey also introduced the country's first tariff scheme for renewable energy resources in 2005 (YEKDEM). The scheme of the FiT, valid between the years 2005 and 2011, failed to promote investments in renewable energy, as anticipated due to the Turkish Lira-denominated FiT and the inexperienced Turkish energy industry. [26]. It was decided to make changes in the YEKDEM formulas related to calculation methods by changing the regulation in 2016, 2019 and 2020. The changes made mainly cover the details based on reconciliation.

[1] Source: Self-prepared using Official Gazette of the Republic of Turkey.
[2] Targets have been highlighted concerning only renewable energy.
[3] For occupants' own land and buildings
[4] Law on Utilization of Renewable Energy Sources for the Purpose of Generating Electrical Energy (No: 5346).

In 2008[5], significant amendments to the legislation on the electricity market were made for geothermal and biofuel power plants. In 2011, the promotion law was amended (YEKDEM)[6]. The tariff rate for the feed-in tariffs is based on the US dollar instead of the Turkish lira. The rate is also increased and differentiated for certain renewable technologies [27]. Incentives are also introduced for the local production of mechanical and electrical equipment to promote local production in Turkey [28].

A plan[7] on energy to reduce carbon emissions from buildings was implemented in a better policy environment, created by the National Climate Change Action Plan (NCCAP), launched in 2011. It has mainly two parts: the Control of greenhouse gas emissions (e.g., energy, forestry, construction, waste, agriculture and land use) and the adaptation to climate change [29]. The 10th development plan (2014-2018)[8] provided the basis for most of the renewable policies and was measured to address climate change in Turkey. The new plan consisted of three components: the security of the supply, the integration of energy and the formation of an energy market that is foreseeable. Turkey also planned to prioritize domestic resources and increase the use of renewable energy in the local economy, research and development, and the renewable energy resource zone (YEKA). The policy targeted to 1) increase the proportion of renewable resources in the total production of energy by a minimum of 30%, 2) increase energy efficiency, 3) ensure the full operation of the free markets and enhance the investment environment, 4) transform Turkey into a hub and a terminal of energy. Therefore, the country would be aimed to increase its influence on the region and the global energy market [30].

The Eleventh Development Plan[9] of Turkey, covering the years 2019-23, sets out several key targets for the renewable energy sector. The plan mainly aims 1) the reduction in the proportion of gas in the production of electricity from 29,9 % to 20,7 %, 2) to increase the proportion of renewable sources in the production of electricity from 32,5 % to 38,8 %, 3) to increase the electricity produced by local sources of energy from 150 Terawatt Hours (TWh[10]) to 219,5 TWh.

To make Organized Industrial Zones (OIZs) in Turkey become more efficient, environmentally sustainable, and competitive, an arrangement was issued in 2019. Thus, energy efficiency and renewable energy use associated with OIZs were targeted [31].

2.2 Renewable energy production

The policies mentioned in Section 2.1 aim to encourage renewable energy sources in electrical energy production. In this regard, the obtained energy production through green sources will be examined in this section, considering the development of renewable sources.

With the start of the renewable energy resources support mechanism in 2011, the number and capacity of power plants participating in the grid increased annually. As seen in Figure 1, there has been a noticeable increase in participation since 2015. On the other hand, a considerable fluctuation was observed between 2012 and 2014. This can be addressed by changes in the Turkish lira against the exchange rate. The average dollar rate in 2012 was 1.79 TL; in 2013, it

[5] Amendments to the Electricity Market Law (No: 5784)
[6] Amended law on Renewable Energy Law (No: 6094).
[7] Link: https://webdosya.csb.gov.tr/db/iklim/editordosya/iklim_degisikligi_eylem_plani_EN_2014.pdf
[8] Link: https://policy.asiapacificenergy.org/node/3168
[9] Link: https://www.sbb.gov.tr/logo/eleventh-development-plan-2019-2023/
[10] A unit of energy that is equal to 10 raised to the power of 12 watt-hours.

was 1.90 TL; at the end of 2014, it was 2.33 TL. Investors, who had gotten used to the dollar's stability, faced an unusual TL depreciation during these three years. As a result, the entire renewable investment sector had to turn to imported solutions for parts supply and project design. For instance, the turbines used to establish the wind power plants in Turkey were the turbine brands that still dominate the world market. Most wind turbines and their components (turbine, generator, hub, gearbox, etc.) were imported from abroad; therefore, a renewable energy resources support mechanism was left. Investors preferred to sell the energy they produced from the wind in the free market, instead. The main reason is the higher electricity market prices than the incentive system. In other words, it is the fact that producers with a RES certificate preferred to sell their products to the market at market prices, which are more attractive than the upper limit of the support mechanism.

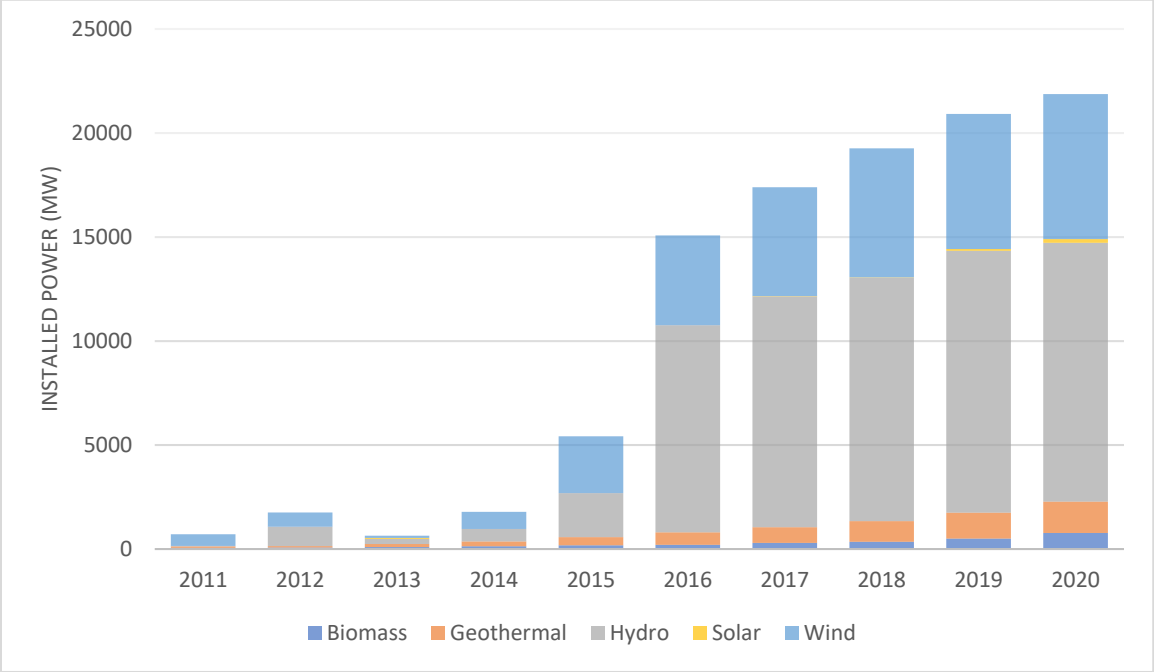

Figure 1. Installed power (MW) of licensed green energy based-participants by years[11]

The rise in 2016 was, in general, associated with the sharp revisions in the support provided by the amendments to the aforementioned laws in 2005 and 2013, as clearly shown below:

- Purchasing the electrical energy produced from renewable energy sources by the legal entity holding a RES certificate generation license, which will be operational until the end of 2015, for ten years according to the prices in given prices on energy type (briefly, amendments to the incentive price system).

- Giving the same amount of incentive for ten years for the surplus energy they give to the distribution system to real and legal persons engaged in an unlicensed generation.

[11] Source: Self-prepared using Turkish Ministry of Energy and Naturel Resources' (TMENR) databases (cross-checked through IEA).

On the other hand, 'the vision 2023'[12] for renewable energy resources has been determined within the scope of the "Electricity Energy Market and Supply Security Strategy Document", which is considered as an annexe to the decision of the High Planning Council numbered 2009/11. Table 2 illustrates the targets of the vision 2023 in this context. These goals are: (1) increasing the share of renewable energy sources in electricity generation to 30%, (2) maximising utilising of the entire hydroelectric potential across Turkey, (3) processing 600 MW of geothermal energy, (4) increasing the installed power based on wind energy to 20,000 MW, (5) making the necessary regulations for the use of solar and other renewable resources; (6) aiming to reduce the use of natural gas below 30%, and replace it with renewable energy sources.

Table 2. The vision 2023 targets for the Turkish energy sector.

Renewable energy source	Targets
Share of renewable sources in energy production	30%
Wind power installed capacity	20,000 mw
Solar power installed capacity	3,000 mw
Hydro-power installed capacity	maximum or 36,000 mw
Geothermal power installed capacity	600 mw
Biomass	2000 mw
Nuclear power plants	2 operational (3rd under construction)

As seen in Figure 2, the share of all renewable energy sources in the total installed power has increased from 33% to almost half over the last 20 years. Of the renewable generation facilities that reached a total of 50.4 GW at the end of 2020, 61.5% were hydroelectric power plants (HEPP), 17.5% were wind power plants (WPPs), and 13.2% were solar power plants (SPPs).

Therefore, the findings of the section show that Turkey has been keeping pace with the global trend in the last two decades, and significant progress has been made in renewable energy.

[12] The vision highlights the centennial of the Turkish Republic that as founded in 1923. It was first emphasised by TUBITAK to achieve advanced scientific and technological development as of that date. Its targets have been widened under many different scopes, including energy policies.

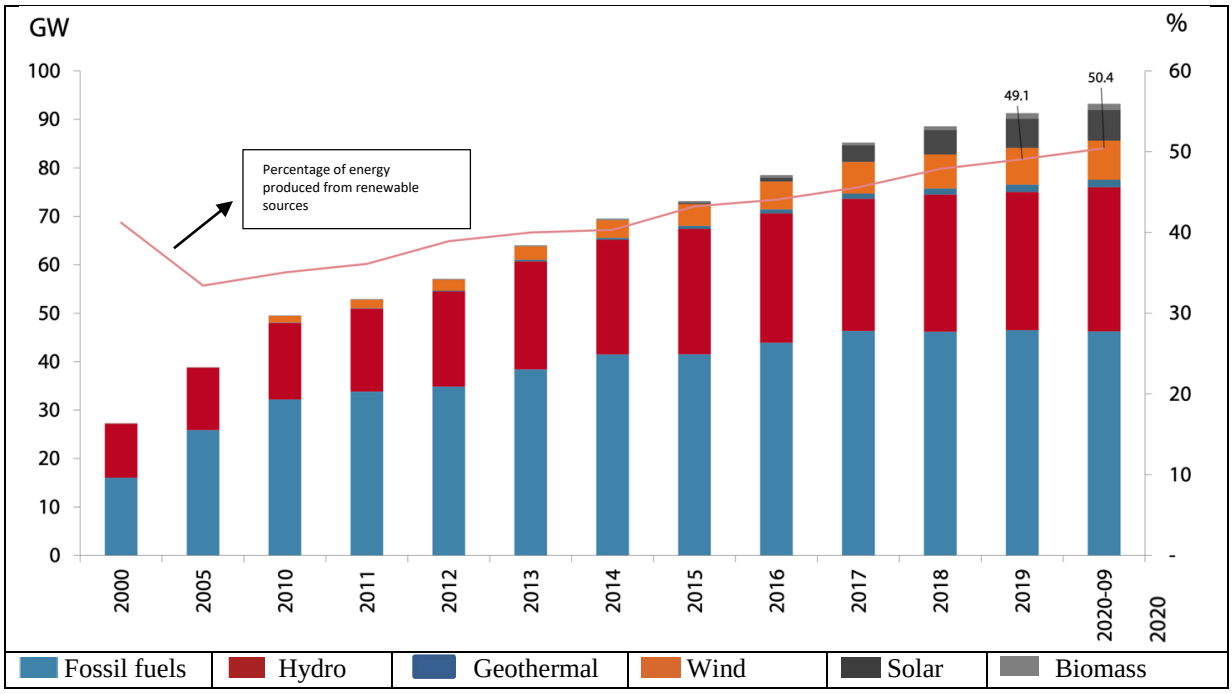

Figure 2. Installed capacity (GW) of energy sources in Turkey between 2000 and 2020 (compiled from annual reports by the Turkish Energy Market Regulatory Authority[13])

3. Evaluation of Turkey's green energy progression among G20 countries

The G20 plays an essential role in achieving global sustainable development goals as G20 members, accounting for two-thirds of the world's population, currently represent around 75% of world trade, 80% of global carbon dioxide emissions (CO2) and 85% of global gross domestic product (GDP) [32]. Therefore, this section compares Turkey's Green Energy Progression to the members of the G20.

Adopting an action plan on the 2030 agenda for sustainable development, a set of critical blueprints was settled by all members in 2016. This action enables concentrating on achieving all 17 sustainable development goals (SDGs)[14] by 2030. Thus, the members aim to increase the share of renewable energy in the global energy mix substantially by 2030 (Goal 7, 2nd clause). Four years on, G20's renewable energy targets and policies associated with green energy might be essential to consider.

Table 3 illustrates G20 countries' achievements associated with policy and target commitments to date. The targets have been categorised into four main groups. As those might have been changed according to strategies of sustainable national policy that a member country follows, the changes in existing sustainable policies are shown as either (R) or (O), revision and removal, respectively. It has also been observed that no member has included any sustainable strategy/target nationwide. On the other hand, regulatory policies[15] and 'fiscal incentives and

[13] The regulatory authority for electricity, natural gas, oil and liquefied petroleum gas markets
[14] Considering the nature of this study, only Goal 7 (Ensure access to affordable, reliable, sustainable, and modern energy for all) is discussed.
[15] About achieving government's green energy production and using related objectives through the use of regulations, laws, and other instruments.

public financing' have been investigated as nationwide and sub-national[16] new, revised, tender and removed policies.

Renewable targets on final/primary energy consumption are observed to have been set by most of the members. However, it is apparent that the Turkish authorities have not created a target about how much energy generation will be by sustainable sources of energy. This might be interpreted that Turkey might have some strong parameters to avoid any primary/final energy target in a fixed time period for a long time.

It is identified that, although there are policies implemented in some states and cities in that country, there is no policy at the national level. For instance, the "Net Metering System" application for consumers with small-scale renewable resources-based generation systems is a sub-national application for the US, Italy and Spain. Even though sustainable policies in force are included in the table, these laws are observed to be insufficient in effect and application due to the implementation regulations' lack of development or ineffectiveness. The laws that have been abolished are not included in the table. Some of the policies mentioned can be applied in other areas besides electricity generation, such as solar water heating and biofuels.

The first serious step to increase the use of renewable energy was taken in the use of renewable energy resources for electricity generation in May 2005. This law complements an existing law on the Establishment and Operation of Electric Power Generation Facilities and the Regulation of Energy Sales with the Build-Operate Model (BOT). With this law, private initiations were planned to encourage within the scope of the Electricity Market Law on the Use of Renewable Energy Resources for Electricity Generation. However, revisions were made due to the inadequacy of different pricing according to the source, the technology used and the small-scale producer, and the lack of incentives. Table 4 also shows how Turkish authorities' outdated green energy tariffs for large-scale producers are. As the tariff prices should be designed to encourage the investment and use of renewable energy resources, the prices thereby should have been updated following any change in the dynamics of the green energy market, overall cost trends and their drivers.

On the other hand, most G20 countries have been observed to change their tariffs over the years (generally year by year). The UK has followed a policy of constantly revising the payment rates of electricity generation from green sources without any prior notice [33, 34]. These revisions might enable the sustainable targets to be reached without exceeding the budget, which is spared for sustainable targets [35, 36].

[16] Sub-national administrative divisions overseen by a federal government, e.g., the US state of Virginia, initiated to fund a multi-family shared solar programme in 2020. Therefore, this is highlighted as ⋆* under 'public investment, loans, grants, capital subsidies or rebates' in Table 3.

Table 3. Renewable energy policies and targets by the countries of G20[17]

Member	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory policies							Fiscal incentives and public financing			
			Feed-in tariff/ premium payment	Electric utility quota obligation/rps	Net metering/billing	Biofuel blend, renewable transport obligation/mandate	Renewable heat obligation/mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable rec	Tendering	Reductions in sales, energy, co2, vat or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Argentina	E, p	●	●	●	●	●	-	-	●	●	●	●	●, ☆[a]
Australia	P, p*(n), t*	●	◐	◐	◐	◐	●	●	●, ◐	-	-	-	●, ☆[a], ★*
Brazil	P, t	●	-	-	●	☆	-	-	●	●	●	-	●
Canada	P	●	◐	◐	◐	●, ◐, ☆*	-	☆	◐	●[a], ☆	●[a]	-	●, ★, ☆*, [a, b]
China	E(n), p(n), hc(o), t(o)	●	●	☆	-	☆	●	-	●, ◐[b]	●	●	●, ◍	●, ◍, ★[a, b]
France	E, p(n), hc, t	●	☆	-	-	☆	●	●	●, ◐	● [a]	● [a]	☆	★[a]
Germany	E, p(n), hc(o), t	●	●	-	-	●	● [c]	●	●, ○	●	●	-	●[a] , ★
India	E,p,p*,hc,t	●	◐	●	◐, ☆*	●	-	●	●, ○, ◑	●	●	-	●[a] , ★[b,] *
Indonesia	E, p, t	●	●	●		●	-	-	●	●	●	-	●
Italy	E, p, hc(o), t	●	●	-	●	☆	-	-	●, ○	●	● [a]	-	● [a, b], ★, ★
Japan	E, p	●	☆	-	-	-	-	●	●, ○	●		●	● , ☆ [a]
South Korea	E, p	●	-	●	●	●	●	●		★	●	●	● [a]
Mexico	E(o), p(o), hc, t(o)	X	-	-	●	☆	-	-	●	★	●	-	●, ☆ [a], ★
Russia	E(o), p	●	●	-	-		-	-	●	-	-	-	●
Saudi Arabia	P	●	-	-	-	●, ★	-	-	●	-	-	-	-
South Africa	P	●	-	●	-	●	●	-	●	●	-	-	● [a]
Turkey	P, hc	●	☆	-	●	●	● [c]	-	●, ○	-		☆	● [a]
United Kingdom	E(o), p(n), p*(o), t(n), hc(o)	●	◐	●	-	☆	● [a]	●	●, ◐	●	-	●	● [a], ☆ [b], ★, ★*
United states	T(n), p*(n)	●	◐	☆	☆	◐, ☆	●, ◐ [b]	◐	◐, ◑	●	● [b], ◐ [b], ★, ★	-	● [a], ☆ [b], ★*

Notes: –: Not yet disclosed. E: Energy Consumption (final or primary); P: Power; HC: Heating or cooling; T: Transport; (R): Revised; (N): New; (O): Removed or came to term; X: Renewable energy not included in nationally determined contributions; ★: New (one or more policies of this type) ; ★*: New sub-national; ☆:Revised (from previously existing); ☆*: Revised sub-national; ◍: Removed; ●: Existing national policy or tender framework (could include sub-national); ◐: Existing sub-national policy or tender framework (but not national); ○: National tender held in 2020; ◑: Sub-national tender held in 2020. a: Includes renewable heating and/or cooling technologies; b: Aviation, maritime or rail transport; c Fossil fuel heating ban; c:Heat FIT; INDC: An abbreviation of ' Intended Nationally Determined Contributions' representing the commitments of each country (not yet joined the Paris Agreement) to reduce greenhouse gas emissions. NDC: An abbreviation of 'Nationally Determined Contributions' representing the commitments of each country (have already joined the Paris Agreement) to reduce greenhouse gas emissions. RPS: Renewable portfolio standards.

[17] Source: compiled from REN21 annual reports.

Table 4 presents how Turkish policy has been designed to support the development of renewable energy sources by providing a guaranteed, above-market price for green energy producers in the years 2010 and 2020. It can be criticised, however, that the tariff could have followed changes in wholesale electricity prices. The decade from 2010 to 2020 represents a period of significant cost reduction for solar and wind power technologies. With the help of policy and industry support worldwide, renewable electricity from solar and wind power has gone from an expensive niche to a level that can compete head-to-head with fossil fuels for new capacity [37]. For instance, the global weighted average levelised cost of energy (LCOE) of utility-scale solar PV for newly commissioned projects was 0.057 from US$0.381/kWh between 2010 and 2020 as total installation costs fell from US$4,731/kW to US$883/kW and it decreased to USD/kWh by 85% [38]. As the dynamic of the manufacturing sector changes from time to time, stable initiative policies might not often have the potential to attract the interest of green energy investors.

Table 4. Turkish licensed electricity production tariff policies by green energy sources in 2010 and 2020[18]

Type of Production Facility Based on Renewable Energy Source	Applicable prices (¢19 per kWh) in 2010	Applicable Prices (¢ per kWh) in 2020	Domestic manufacturing addition (¢ per kWh)
Hydroelectric generation facility	7.3	7.3	2.3
Wind energy-based production facility	7.3	7.3	3.7
Production facility based on geothermal energy	10.5	10.5	2.7
Nuclear energy-based facility	-	12.35	-
Biomass-based production facility	13.3	13.3	5.6
Solar energy-based production facility	13.3	13.3	6.7/9.2

The average price for electricity production in 2018 was 5.56 cents/kWh in Turkey. Although renewable energy production seems relatively costly, the price of electricity that Turkey will buy from the nuclear plant, which is currently under construction, will be 12.35 cents/kWh on average for 15 years upon the agreement with Russia [3]. Therefore, it is seen that the energy strategy is more towards a new policy set to reduce foreign dependency on energy for the cost of budgetary deficit. As mentioned in Section 2.1.2, the Turkish authority might cut back on renewable energy initiatives and expenses due to long-run agreements underlining the preconcerted high price. Such plans are likely to jeopardise renewable energy production and, thereby, its use in the near future.

Turkey is among the world's countries with tremendous geothermal energy potential. Considering the installed power of geothermal power plants by country, the USA maintains its leadership by a wide margin, followed by the Philippines, Indonesia and Turkey, where many new GPPs[20] have been launched recently [39]. These four countries exceed the 1 GW installed power threshold in geothermal energy. In addition, the share of geothermal in Japan's electricity consumption is currently 0.3%, but the Japanese government has decided to increase the contribution of geothermal to electricity consumption to 10% to become the 4th G-20 member exceeding the 1 GW installed power [40]. The success of Turkey is the result of a strong policy

[18] Source: Self-prepared using official annual reports by Energy Market Regulatory Authority in Turkey.
[19] (¢) symbol used to represent hundredths of a dollar.
[20] Geothermal power plant.

about heat FIT, as revealed in Table 3. Turkish policies have considered geothermal electricity both for electricity and side uses such as integrated heating, greenhouse, cooling, spa, thermal tourism, and chemicals.

4. Discussion

The major constraints encountered by renewable energy in Turkey have varied, such as uncertainties in the Turkish lira, insufficient purchase guarantees, foreign technology dependency, inadequate research and development funds, weaknesses in R&D studies, and inconsistencies in incentives.

4.1 Uncertainties in the Turkish economy

From the perspective of green energy, inflation affects all aspects of the economy, from the consumer purchasing power to buy energy and business investment and employment rates to government programmes, tax and initiative policies of the renewables, and loan rates [41]. The annual core inflation rate in Turkey rose to a nearly all-time high of 80% in 2022. Higher inflation can impact exports by having a direct impact on input costs such as renewable energy materials. On the other hand, labour power for building and operating the plants is weakened and will be a further burden on investors.

Developed countries are usually able to offer more financial support than developing countries due to low inflation and high borrowing opportunities [42]. In contrast to the common point of view, the current policy follows that higher interest rates do not result from higher inflation, but, rather, that higher interest rates cause higher inflation. As a result, Turkey's central bank has gradually voted to cut the country's key interest rate, leading to the lira sinking to new record lows against foreign currencies [43]. It is also worth noting that the credit rates lean towards increasing despite the decrease in the country's interest rate. Therefore, a major challenge for the development of Turkish renewable energy projects is expressed to be limited funding available from the local finance sector.

Any large-scale renewable energy project requires a substantial upfront investment for equipment, which is generally financed through multilateral banks, public and private international and national banks, and export credit agencies [44]. That is, the costs of credit continue to staggeringly increase, which makes it difficult for project developers to access these necessary funds in Turkey’s current macro-economic situation. As the private sector has to make debt repayments in foreign currency, local finance sector players (mostly state-owned banks) might be struggling to provide credit for expenses invested in renewable energy properties in the upcoming years.

4.2 Insufficient purchase guarantees

Solar and wind power are the forms of renewable energy that have been planned to dominate Turkey’s energy mix. To do so, a large number of legal regulations and policy supports have been enacted, as shown in Section 2.1. Due to the higher inflation rate and weak lira discussed in Section 4.1, external and internal finance for credit supply to the procurement of solar and wind power plants in Turkey becomes harder to get. Moreover, loan repayment for existing investors might become severely problematic.

The capital costs of wind energy projects are dominated by the cost of the wind turbine itself.

In Turkey, the tariff guarantee is valid for the first ten years of operation of renewable power plants (See Section 2.1). However, this period might be insufficient to pay off the financial investment, especially in renewable energy sources such as wind and solar. FITs of many G-20 countries commonly involve long-term contracts, from 15 to 20 years. For example, in Germany, this period is usually 20 years. Extending the operating period of purchase guarantees will encourage renewable energy projects. In regard to large-scale electricity generation, the lifetime assumption of solar or wind plants is roughly 20 years, although this could be extended to 25 years or longer depending on the kind of technology that is used and various environmental factors.

Compared to European and other G-20 countries, the tariff guarantee for domestic production in Turkey appears to be quite low and varies between 9.47 and 14.22 Eurocents per kilowatt-hour (kWh) for solar energy and 5.19-7.82 Eurocents for wind. This is an important obstacle to the realisation of large-scale solar and wind energy projects, especially with high investment costs. However, Germany provided a very rapid development of the photovoltaic sector in the country by offering a tariff guarantee of 26.7-33.01 Eurocents per kilowatt-hour, even though the rate of its solar exposure is considerably lower than Turkey's. Similarly, Denmark provides a fixed premium of roughly 17.32 Eurocent per kWh for 20 years on top of the Danish spot market price, which fluctuates in the range of EUR 30 to 40/MWh.

4.3 Foreign technology dependency

Composed of the limited availability of local fossil resources, Turkey's high potential for new energy resources has created the opportunity to enter renewable energy technologies, which can be evaluated as an advantage that reduces energy dependence. It has been stated that Turkey's energy exports will exceed 100 billion U.S. dollars by the year 2023 [45]. Promoting the production of domestic energy equipment and R&D centres is also optimistic at reducing energy export and creating added value for the country's economy, reducing the current account deficit and creating employment opportunities.

Turkey's first ambitious strategy embarked on nuclear energy to limit the use of imported fuels for electricity generation. Turkey has two nuclear power plant projects, one at the construction stage and the other at the project stage. The first unit of the NPP[21] under construction is scheduled to enter into operation at the end of 2023. Agreements were made with Russia for technology transfer, which includes students sent to study in Russia to work in the NPP. However, to what extent the other subjects of the technology transfer, such as fuel management, use and disposal, were agreed on is not clearly declared. By the agreed procurement method's nature (Built-Operate-Transfer[22]), the public entity should be able to have sufficient ability and knowledge to run the facility at the end of the agreed-upon period. Therefore, it might be expected that Turkey will have advanced and specialised nuclear engineering and science knowledge.

Unlike most G-20 countries, a general arrangement was made regarding the support of the domestic parts used to produce electrical energy from renewable energy sources in 2016. When contractors use domestically manufactured mechanical and/or electro-mechanical components in electricity generation facilities, the prices are added for five years from the generation facility's initial operation date (see Table.4 in Section 3).

[21] Nuclear power plant.

[22] A government grants a concession to a private entity to finance, design, construct, own, and operate a facility for a set period of time. The project is returned to the public entity after that period.

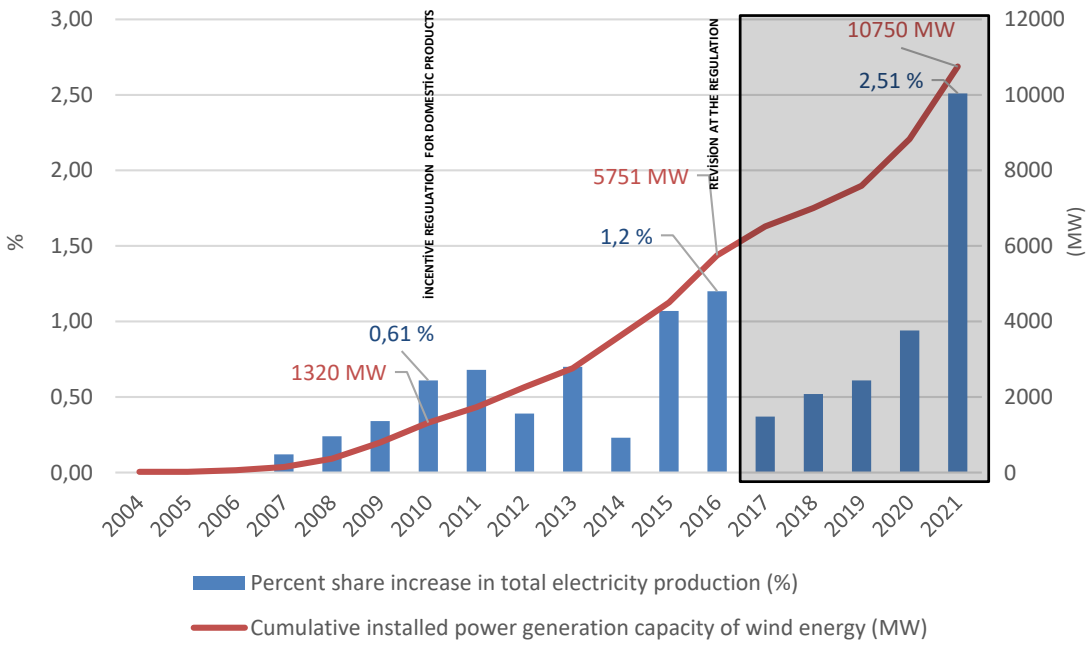

Figure 3. Changes in wind power production in Turkey[23]

Figure 3 illustrates the feedback from the Turkish wind power industry after two regulation changes regarding the use of domestic technology in green power plants. Aside from total capacity, the percentage changes in wind power-based renewable facilities are presented. There seem to be two years since the overall pace of wind power installation was shifted. To reduce foreign dependency on green technology parts, a regulation was enacted to underline that investors can benefit from initiatives only provided that a domestic contribution rate of product[24] is at least 51%. Although the wind power capacity appeared to increase, acceleration in ascension was not to the extent it used to be. This might be interpreted that some companies did not have any ability to respond well.

This was a continuation of the private sector's desire for "long-term incentives and a predictable market". However, no value-added parts, such as bolts, concrete towers, or aluminium lath, were observed to have been produced in Turkey, and the production of non-value-added parts was increasing. The Turkish policymakers later decided to revise the existing policy in 2016. Under the Amendment Regulation, domestic components are defined as components in which the sum of the ratios of the relevant integrative parts produced in the country belonging to the component used in the electricity generation facility is at least 55%. It has been recently claimed that the Turkish wind energy industry is currently one of the leading sectors in the localisation of energy technologies, with a domestic production rate of 65% [46].

It becomes clear that Turkey saw the development of renewable technologies, that it could not be a buyer and that it should be in the field as a technology producer, not just a manufacturer. This could be counted as a successful step as the Turkish renewable energy industry has attuned to the aim of consecutive policies. The next step to be taken might be how to compete with world giants in foreign markets.

[23] Source: Self-prepared using the Ministry of Turkish Energy and Natural Resources' database.
[24] Initiative is not issued for products imported as parts from abroad and created by simple assembly at home.

4.4 Insufficient research and development funds

In R&D activities, the process should generally work as follows; after the R&D studies are carried out by the researchers (mostly university employees), an idea emerges, and this idea is then developed. Then this idea becomes a product and is later produced by companies. Finally, a marketing plan is prepared for this new product, and the demand for the product is created and increased. This whole chain often takes a long time to complete. In contrast to this common belief, Turkish R&D activities on renewable energy appear to not be run in the ideal way described above but, instead, enforced by regulations (See Sec 2.1). This might cause shortening the essential time that is necessary to reach economic value products.

To reveal whether technological innovation occurs in a country, patents are valuable tools [47, 48]. Additionally, innovation activity is found to be quite responsive overall to policy instruments for the renewable energy [49]. Table 5 shows the distribution of renewable energy patents by year and kind. It appears that there is no upward trend. Supporting findings that a pandemic causes a drop in the number of patent applications [50], a sharp drop was recorded a year before WHO was informed of cases of COVID-19 pneumonia. Thus, the findings could explain the delay in recovering such a drop. The sharp drop could be associated with the revised regulation in 2016 (see Section 4.3).

Table 5. Renewable energy patent applications between 2010 and 2020[25]

Years	Bioenergy	ET	Geothermal	Hydropower	Ocean	Solar	Wind	Total
2010	8	18	1	3	9	38	15	92
2011	11	29	-	11	1	37	13	102
2012	9	17	-	6	1	24	18	75
2013	7	25	-	2	1	9	18	62
2014	3	41	1	3	1	21	26	96
2015	8	52	-	7	4	24	6	101
2016	7	45	1	9	3	28	15	108
2017	6	46	-	6	3	59	12	132
2018	-	9	-	4	2	21	12	48
2019	1	27	-	11	2	11	7	59
2020	2	3	-	8	-	15	14	42

Notes: ET: Enabling technologies include utility-scale batteries, artificial intelligence and big data, blockchain, grid stability and reliability, etc.

As seen in Table 5, patenting activity has been highly concentrated on ET, solar and wind, which is more than 70% of all. It has been observed that geothermal energy-related innovations lag behind what is desired through strategies and policies (see Section 1.1). Compared to all geothermal-oriented patents worldwide over the years between 2010 and 2020 (9801 patents in total)[26], it might be said that Turkey's academia and developers have not allowed potential domestic investors to add value to their business so that they can increase profits. Furthermore, about 4% of Turkey's geothermal potential (38,000 MW)[27] appears to be currently utilised in thermal use and electricity generation in Turkey. With globalisation and a rapidly changing renewable energy market, more competing businesses exist than ever [51]. Findings show that Turkey fails to foster competitive advantages over the global geothermal market, fulfilling a 'domestic and national vision' in this regard. However, 312 innovations in enabling technologies

[25] Source: Self-prepared using IEA database.
[26] Source: Self-prepared using IEA database.
[27] Source: retrieved from Balat (2006).

that play a crucial role in facilitating the integration of renewable energy (4% of all ET-based patents) indicate a relatively booming trend on a limited budget.

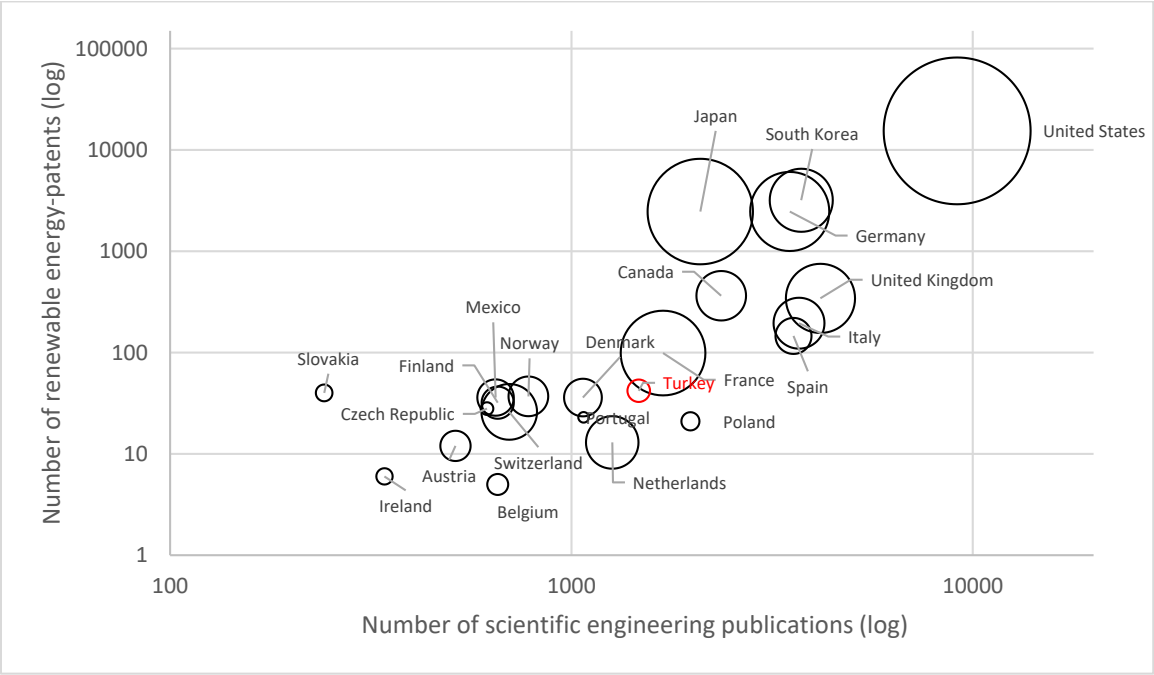

Figure 4. Publication and patent productivity by IEA member countries in 2020 [28]

More importantly, it might be argued whether or not Turkish academia can meet the R&D demands of the industry. Figure 4 illustrates the relative productivity of the Turkish researchers against those of the other developed countries in 2020. The horizontal axis and the vertical axis represent logarithmically the number of renewable energy-based patents and the logarithm of the number of scientific renewable energy-based studies, respectively. The graph determines circle sizes by R&D budgets, reflecting the size of total money spared for renewable energy in 2020.

It is not a coincidence that the countries with the highest spared R&D budget are revealed predominantly to be the leading countries in both scientific studies and patents. Spain, Italy and Canada appear to be competitive even if their R&D budgets are relatively low compared to many countries such as the UK, and France. On the other hand, Turkey, with limited R&D, seems to perform remarkably in the green energy-based scientific publication.

The USA and Northern European countries with the highest GDP are also the leading countries in scientific studies and patents per capita. The number of patents in Japan, the USA, South Korea and Germany seems to be slightly less than the number of their scientific studies. However, the ratio of the parents and the studies in Turkey is around one in fifty, reflecting that Turkish regulations aiming to increase the number of green patents failed. As stated in Section. 2.1, Turkey's currently developing economic and currency crisis not only makes renewable investments difficult but also affects targeted research and development associated with any of the green technologies. However, Turkey seems to publish articles considering its limited R&D budget substantially. Therefore, it might be concluded that budget policies might be

[28] Source: Self-prepared using IEA, Scimagojr and OECD databases.

reconsidered to increase the productiveness of innovation. Unless the country invests more in basic research in renewable energy, it would be hard to count it as one of the leading countries in renewable energy.

5. Conclusion

Turkey appears to have achieved the EU energy target that underlines a 20% share of renewable energy in the final energy consumption [52]. Additionally, Turkey continues in a net zero-carbon emission trend with a highly decarbonised power system already in place, mainly onshore. However, there are many essential steps that Turkey needs to take to adapt to its vision of 100% renewable energy production and to move towards a future where its energy needs are met only by renewable sources. These steps can be recommended as follows:

Increasing the use of each renewable source at the same scale: compared to fossil fuel-fired power generation, albeit the cheapness of lignite in Turkey [53], onshore wind and hydropower can provide electricity competitively. It has been identified that harnessing heat from geothermal resources has been stable for a long while. Turkey already has plenty of geothermal energy, but due care has not yet been taken [54]. Insufficient renewable energy promotion and innovation appear to have been responsible. The untapped natural energy resources have been identified as a priority area to tackle for a carbon-free aim. The fact might be that power generation using mature renewable technologies, i.e., onshore wind-solar, is currently competing head-to-head with fossil fuels without financial support [55]. Thus, Turkey should seek to increase the share of renewable energy use by biomass and geothermal and pave the way for upgrading and re-engineering current policies and strategies to obtain maximum benefit from those.

Increasing financial competitiveness: Incentives for renewable energy are relatively low compared to most G-20 countries. Most of the electricity produced in Turkey relies on natural gas, which is responsible for about one-third of all. Considering the substantial increase in natural gas prices, initiatives associated with renewable energy projects should be updated. Strengthening and encouraging legal regulations should also be implemented to use renewable energy effectively. The Turkish green energy sector seems to take an immediate response against regulatory changes. Therefore, with various policies supporting the financial competitiveness of green resources, it appears that the industry might help minimise foreign energy dependency.

Improving the productivity in green research and development: Strong knowledge and insights ameliorate the existing process where costs decrease and efficiency increases. Moreover, R&D spurs innovation, invention, and progress, enabling Turkey's current prevailing strategy: economic growth and reducing foreign dependency. One of the significant issues appears to be that the public funding of R&D expenditure considerably lags behind the other IEA member countries. Notwithstanding the current practice of R&D funding, Turkey has been observed to make as many innovations as most IEA members, providing more funding. To promote the development of green innovation quality and quantity, Turkey should draw a roadmap that clarifies the most-to-least significant renewable energy sources in light of the potential that the country has. The innovation gap between leading countries, e.g., Canada and South Korea, and Turkey should also be narrowed. The policymakers must further encourage stable R&D and breakthroughs, promoting all stages of the life cycle of technology, from the early stages of the research to the commercialisation of the product with the collaboration of academia.

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