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Full Length Article

An assessment of wind energy status, incentive mechanisms and market in Turkey

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ABSTRACT

Turkey attaches great importance to energy diversification to reduce the energy dependence on fossil resources. In this regard, Turkey assigned energy targets by 2023 including 20 GW of installed wind capacity. Yet, despite the good efforts, the current wind installed capacity of 8 GW is far behind the assigned target. This study presents a comprehensive review of wind energy status in Turkey focusing on policies and incentives for improvement of wind energy progress in the country. To that end, the global wind energy market is evaluated and a set of recommendations is presented in the context of the importance of local employment and establishment of local wind energy industry. Then, a feasibility analysis is performed to discuss the current feed-in tariff scheme in Turkey. Lastly, Turkey's competitive position is evaluated over a SWOT analysis to give an overview of all positive and negative determinants, considering internal and external factors.

1. Introduction

Global energy consumption is increasing steadily with the rising population, energy-dependent habits of use, and technological developments. The world population of 6.84 billion in 2009 became 7.59 billion in 2018 with a growth rate of nearly 1.1% [1], and the global primary energy demand of 11,540.3 Mtoe in 2009 reached 13,864.9 Mtoe in 2018 with an average annual increase of 2.01% [2]. Meanwhile, the global electric energy consumption of 17,355 TWh in 2009 reached 22,964 TWh in 2018 with a growth rate of 3.23% [3]. The main reason for the higher growth rate of energy consumption than the global population and primary energy demand has become the rapid rise in the use of electrical devices due to technological advances. This situation prompted countries to look for new ways to meet their ever-increasing energy demands.

As the global energy demand increases, the countries seek new solutions to curtail their demand for fossil resources. The average ratio of electricity production from conventional resources was 66.5% between 2005 and 2015 [4]. The negative impacts on the environment along with the depletion of fossil sources and a large share of energy expenditures in the economy caused interest in renewables and their share gradually increased over the last decade [5]. Among the renewables, the average share of hydroelectric resources in the global electricity production was 16% between 2005 and 2015 [6]. The share of renewables except hydroelectric was increased from 1.96% in 2005 to 6.77% in 2015 and this increase is mostly provided by wind energy [7]. The electricity acquired from the wind energy had a share of 4.55% in the global electricity production in 2017 [8].

Turkey is one of the countries that comply with the global wind energy trend in recent years. The fact that Turkey is an energy importing country (mostly from Russia, Iran, and Iraq), and the electricity is mainly generated by fossil fuels, which has the largest share in energy expenses, made Turkey focus more on reducing its energy dependency by promoting renewable energy resources over the last decade. Wind energy takes the first place in the non-hydro renewable investments due to the country's high wind potential. Yet, despite the relatively good effort in the last decade, the wind energy potential has not been effectively utilized in Turkey.

1.1. Literature review

Currently, all wind power installations in Turkey are onshore, and review studies regarding Turkey have focused on onshore wind energy. Güler [9] presented the wind energy status of Turkey and examined the purchase guarantee for renewables introduced in 2005. Ilkilic [10] investigated the wind energy potential of dif-

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Nomenclature

List of symbols

NCF_t	Net cash flow at time t ($/year)
NCF_0	Initial investment cost ($)
$O\&M_t$	annual operation & maintenance cost of the plant at time t ($/year)
E	Annual wind electricity production (kWh)
P	Installed capacity of power plant (kW)
f	Expected inflation rate
i	Real interest rate
i'	Nominal discount rate
λ	selling price ($/kWh)

List of abbreviations

CF	Capacity factor
DPBP	Discounted payback period
EIE	Electricity Affairs Survey Administration
MoENR	Ministry of Energy and Natural Resources
MoEU	Ministry of Environment and Urbanization
REPA	Wind energy potential atlas
SWOT	Strenghts, weaknesses, opportunities and threats
YEKA	Renewable Energy Resource Areas
YEKDEM	Renewable Energy Resources Support Mechanism

ferent regions in Turkey. Yaniktepe et al. [11] examined the installed wind power capacity in the context of countries and investigated the Renewable Energy Law (2011) which amended the purchase guarantee introduced in 2005. Camadan [12] separately assessed Turkey's priorities of wind energy policies in the short, medium, and long term. In short term priorities, support mechanisms, licensing and coordination, balance, and settlement market were evaluated, while in medium and long term, intermittency of wind energy, demand-side management, and ancillary services were examined. Dursun and Gokcol [13] examined the before and after of wind energy installations following the introduction of the existing Renewable Energy Law of Turkey. Kaplan [14] presented the legal regulations and expectations of the wind energy sector. None of the studies above explicitly examined the wind energy-related industry and local labor force in Turkey.

There is no offshore wind farm in Turkey and the studies in the literature regarding offshore focus on site selection, potential estimation, and feasibility analysis. Argin et al. [15] studied the offshore potential of 20 selected sites on the Black Sea coast of Turkey. Amasra was stated to have the highest potential. Satir et al. [16] conducted a feasibility study for the Aegean coasts of Turkey and made recommendations on the future development of offshore wind energy. Cali et al. [17] determined high-potential sites for offshore wind in Turkey using a multi-criteria site selection method and conducted a detailed techno-economic analysis of the regions. Bozcaada was determined as economically the most viable site. Argin et al. [18] investigated 55 different sites in coastal areas using a multi-criteria site selection method and determined the wind potential of the five most suitable points for offshore as 1,629 MW. Emeksiz and Demirci [19] proposed a novel method to identify suitable sites for offshore wind farms. 9021 MW of offshore capacity was estimated for the selected regions.

1.2. Content and contribution

In this review study, the current status of wind energy in the world and Turkey is evaluated and recommendations are made for Turkey to achieve its wind energy targets taking into account the incentives, wind energy market, wind energy jobs, and local wind turbine industry.

When the literature is examined, it is determined that a study focusing on the local wind turbine industry and the labor force is missing for Turkey. Thus, the study mainly aims to fill this missing part in the literature, comparing Turkey's policies with other countries.

The Turkish feed-in tariff scheme will end by the end of 2020. Its future for licensed generation is still unclear and is a great hesitation factor for the project investors. The second objective of the study is to make recommendations about the future of the Turkish feed-in tariff scheme. Also, a feasibility analysis is included not only to discuss the future of the feed-in tariff scheme of Turkey but also to enrich the comprehensive feature of the study.

Finally, a SWOT (strengths, weaknesses, opportunities, and threats) analysis is made to evaluate Turkey's competitive position considering internal and external factors and to give a clear overview of all positive and negative determinants.

2. Wind energy status in the world

2.1. Global installed capacity

After the oil crises in the 70 s and 80 s, the atmosphere of insecurity about energy resources [20] and the concept of "energy diversification" became one of the indispensable elements of energy policies [21]. As a result, wind energy gained importance especially in Europe and the USA [10]. During the 1980 s and 1990 s, modern wind farm constructions began and the cumulative wind installations in the world reached 6,100 MW in 1996 [22]. By the end of 2000, onshore wind energy capacity in the world was 16,863 MW and nearly 80% of this capacity belonged to Germany, the USA, Denmark, and Spain [23]. Global wind energy investments remarkably increased between 2000 and 2010. The global wind capacity grew 3.5 times in 2005 and 10 times in 2010 compared to 2000. During this period, new countries, such as China and India, joined the wind market. India and China increased their installed capacities by approximately 14 and 85 times, respectively over 10 years [24].

The total global installed wind capacity of 180,850 MW in 2010 (177,794 MW onshore) increased to 622,704 MW in 2019 (594,396 MW onshore) [23]. Fig. 1 shows the total onshore and offshore wind capacities in the world from 2010 to 2019. The cumu-

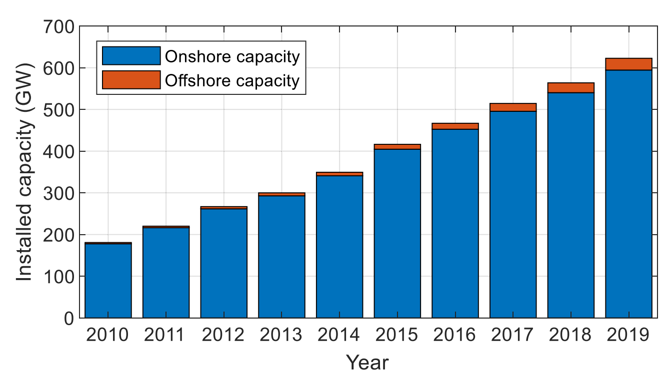

Fig. 1. The global installed onshore and offshore wind capacity [24].

lative installed capacities of the top 15 countries are listed in Table 1. The top 15 countries constitute 88.5% and 89.5% of global wind capacity for onshore and offshore, respectively. China is the leading country in onshore with installed wind capacity of 204,548 MW and the United Kingdom has the highest offshore wind capacity with 9,945 MW in the world [23].

2.2. Global electricity production

The share of renewables (especially wind) in total electricity production increased considerably in the last decade. The change in global electricity generation from wind energy between 2010 (342,092 GWh) and 2017 (1,134,451 GWh) is given in Fig. 2. It is seen that the wide majority of the generation belongs to onshore. According to the latest data for wind electricity production, the ratio of the electricity generation from the onshore wind energy to the total wind generation was 98% and 94.9% in 2010 and 2017 respectively [8]. The development of the offshore electricity generation is slower than the onshore mainly due to their high expenses, constructional difficulties, and unavailability of individual use [25,26].

The share of wind energy in the total electricity production for the top 15 countries is given in Fig. 3. It is seen that the countries invested in wind energy in the early 2000 s such as Denmark, Spain, and Germany have higher wind share today. At the beginning of the 2000 s, the global share of wind in the total electricity production was 0.2%, which reached to 4.55% in 2017. The top three countries in wind electricity generation were Denmark (12.72%), Spain (2.11%), and Germany (1.62%) in 2000. The other countries had lower shares of less than 1%.

The share of wind electricity production has increased for countries over the years due to technological advances and reduced costs. In 2017, the top three countries in wind electricity production were Denmark (40.67%), Portugal (20.76%), and Spain (17.86%). By 2017, six countries have wind share more than 10% and five countries have wind share between 5 and 10% in their total electricity production.

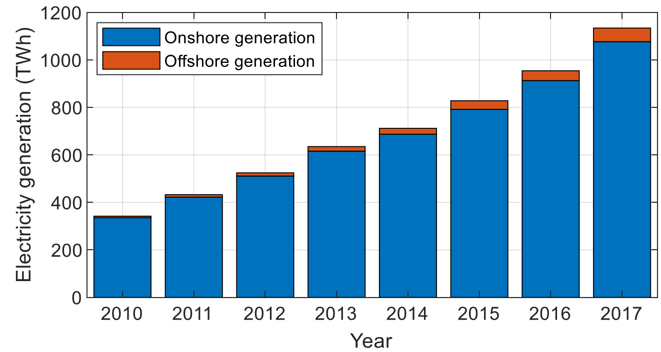

Fig. 2. Global electricity generation from the wind [24].

China's wind share (4.63%) is below 5% however above the world average. France, Canada, and India have a wind share below 5% and also below the world average among the top 15 countries.

2.3. Capacity factors by countries

Capacity factor (CF) is calculated as follows:

$$CF = \frac{E}{P \times 8760} \quad (1)$$

where E represents the annual wind electricity production (kWh) and P is the rated installed capacity (kW). Here, the average capacity factor values are calculated by the ratio of the annual energy production of the country to the installed power capacity output over a period of a whole year for the top 15 countries

Table 1
Onshore and offshore installed wind capacities of the top 15 countries and the world [23].

	[MW]	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
China	Onshore	29,534	46,145	61,306	76,314	96,379	130,489	147,037	161,587	180,077	204,548
	Offshore	100	210	291	417	440	559	1,480	2,788	4,588	5,930
USA	Onshore	39,135	45,676	59,075	59,973	64,232	72,573	81,257	87,568	94,388	103,555
	Offshore	–	–	–	–	–	–	29	29	29	29
Germany	Onshore	26,823	28,524	30,711	32,969	37,620	41,297	45,303	50,174	52,447	53,315
	Offshore	80	188	268	508	994	3,283	4,132	5,406	6,396	7,507
India	Onshore	13,184	16,179	17,300	18,420	22,465	25,088	28,700	32,849	35,288	37,505
	Offshore	–	–	–	–	–	–	–	–	–	
Spain	Onshore	20,693	21,529	22,789	22,953	22,920	22,938	22,985	23,120	23,400	25,548
	Offshore	–	–	–	5	5	5	5	5	5	5
UK	Onshore	4,080	4,758	6,035	7,586	8,573	9,212	10,832	12,597	13,554	14,183
	Offshore	1,342	1,838	2,996	3,696	4,501	5,093	5,293	6,988	8,217	9,945
France	Onshore	5,912	6,723	7,562	8,250	9,110	10,258	11,567	13,497	14,898	16,258
	Offshore	–	–	–	–	–	–	–	–	–	–
Canada	Onshore	3,967	5,265	6,201	7,801	9,694	11,214	11,973	12,403	12,816	13,413
	Offshore	–	–	–	–	–	–	–	–	–	–
Brazil	Onshore	927	1,426	1,894	2,202	4,888	7,633	10,124	12,294	14,833	15,364
	Offshore	–	–	–	–	–	–	–	–	–	–
Italy	Onshore	5,794	6,918	8,102	8,542	8,683	9,137	9,384	9,737	10,230	10,758
	Offshore	–	–	–	–	–	–	–	–	–	–
Sweden	Onshore	1,854	2,601	3,443	3,982	4,875	5,606	6,232	6,408	7,097	8,685
	Offshore	163	163	163	212	213	213	203	203	203	203
Turkey	Onshore	1,320	1,729	2,261	2,759	3,630	4,503	5,751	6,516	7,005	7,591
	Offshore	–	–	–	–	–	–	–	–	–	–
Poland	Onshore	1,108	1,800	2,564	3,429	3,836	4,886	5,747	5,759	5,766	5,917
	Offshore	–	–	–	–	–	–	–	–	–	–
Denmark	Onshore	2,934	3,081	3,241	3,548	3,616	3,806	3,975	4,226	4,420	4,416
	Offshore	868	871	922	1,271	1,271	1,271	1,271	1,297	1,701	1,701
Portugal	Onshore	3,796	4,254	4,410	4,608	4,854	4,935	5,124	5,124	5,172	5,225
	Offshore	–	2	2	2	2	2	0	0	0	8
World	Onshore	177,794	216,244	261,575	292,749	340,808	404,559	452,485	495,565	540,191	594,396
	Offshore	3,056	3,776	5,334	7,171	8,492	11,718	14,342	18,837	23,629	28,308

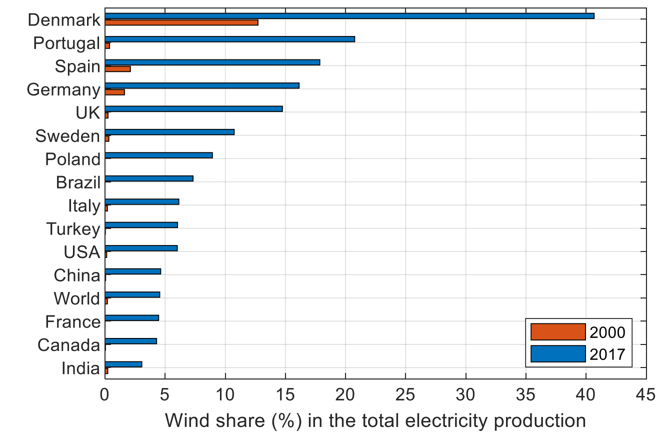

Fig. 3. Wind share (%) in the total electricity production for the top countries and the world.

between 2013 and 2017 (Fig. 4 and Fig. 5) for onshore and offshore wind energy, respectively [8,27]. From Fig. 4, it is seen that Brazil has the highest capacity factor for onshore followed by the USA and Turkey. The average capacity factor of Turkey is above its European neighbors for onshore wind energy. For the offshore, Denmark has the highest capacity factor, followed by the UK and Sweden.

3. Electricity production and targets of Turkey

Turkey is a developing country with a fast-growing population, industry, and economy. The population of Turkey which was 73.7 million in 2010 reached 83.2 million in 2019 with an average annual increase of %1.3 [28]. In the last decade, the Turkish economy had an average growth rate of 4.86% [29], and accordingly, the average increase rate of the gross electricity generation in Turkey became 4.5% [30]. The majority of electricity is supplied from conventional resources and Turkey imports almost all fossil resources except lignite from the other countries.

The electricity generation and installed capacities by sources for Turkey are given in Table 2 by the end of 2019 [30–32]. Coal has the highest share in electricity production (37.18%), followed by hydro (29.21%). The rest of the electricity demand is met by natural gas (18.64%), and non-hydro renewables (14.73%) as wind, solar, geothermal and biomass. The share of wind energy (7.07%) is ranked as the highest among the non-hydro renewables.

The on-going energy strategies of Turkey aim to reduce the dependency of the country on imported fossil fuels and to decrease

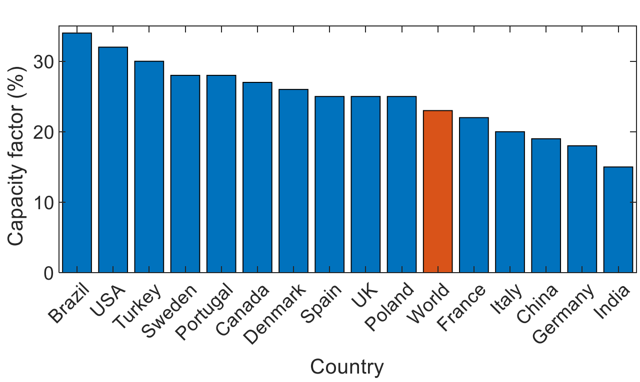

Fig. 4. Average capacity factor of the selected countries for onshore wind energy between 2013 and 2017.

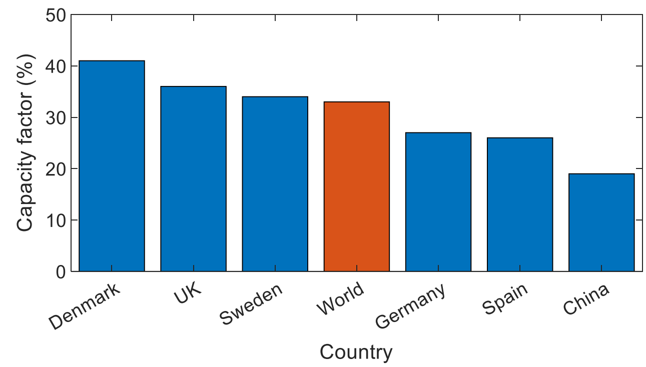

Fig. 5. Average capacity factor of the selected countries for offshore wind energy between 2013 and 2017.

the environmental impacts through measures to maximize the efficient use of renewable energy resources. For the 100th anniversary (2023) of the foundation of the Republic of Turkey, the Turkish government assigned a set of targets in many fields including energy. In 2009, the "Strategy Paper on Electricity Market Reform and Security of Supply" was issued to achieve an increased share of electricity generated from renewable resources by 30% with a specific target of 20 GW installed power capacity for wind energy, by 2023 [33].

The target of 30% renewable energy production by 2023 was not changed in Strategic Plan 2010–2014 published by the Ministry of Energy and Natural Resources (MoENR) and the Turkey Climate Change Strategy 2010–2020, published by the Ministry of Environment and Urbanization (MoEU) [34,35]. The development of renewable energy technologies was supported by the "Strategic Plan" of MoENR, and one of the long-term objectives of the "Climate Change Strategy" was determined as generating more electricity from wind energy.

Owing to its high installed hydropower capacity, as of 2018, Turkey is capable of meeting 30% of its electricity generation from the renewables. However, by the end of 2019, the total installed wind capacity is 7.59 GW and the average rate of new capacity installations of 627 MW per year in the last decade makes it impossible to reach the target of 20 GW in wind energy. Therefore, Turkey should introduce more effective policy measures to reach its 2023 targets in wind energy.

The other renewable targets of Turkey in terms of installed capacities of renewable sources are 1 GW for geothermal, 1 GW for biomass and 5 GW for solar photovoltaic (PV) [36]. The targets for geothermal and solar PV have already been achieved by the end of 2018 [30].

4. Wind energy status of Turkey

4.1. Wind energy potential of Turkey

Turkey is located between 36°-42° northern latitudes and 26°-45° eastern longitudes with a total surface area of 783,562 km^2. The Wind Energy Potential Atlas (REPA) is introduced in 2002 by the Electricity Affairs Survey Administration (EIE) to explore the wind energy potential in Turkey (Fig. 6) [37]. The REPA is a geographic information system (GIS) based map and has been compiled by using the collected data of EIE and General Directorate of State Meteorology Affairs (DMI) in 200 m × 200 m resolution [38].

According to the REPA, the wind speed at 50 m height is 6 – 7 m/s in the coasts and 5.5 – 6.5 m/s in northwestern and southeastern parts of Turkey. The western part of the country has the

Table 2
The distribution of electricity generation by sources in 2019 [30–32].

Source		Installed Capacity (MW)	Electricity Production (TWh)	Share in electricity production (%)
Non-renewables	Coal	20,283.7	113.12	37.18
	Natural gas	25,904.3	56.70	18.64
	Liquid fossils	311.6	0.73	0.24
Renewables	Hydro resources	28,503.0	88.89	29.21
	Wind	7,591.2	21.51	7.07
	Solar	5,995.2	10.07	3.31
	Geothermal	1,514.7	8.71	2.86
	Biomass	1,163.4	4.52	1.49
	Total	91,267.1	304.25	100.0

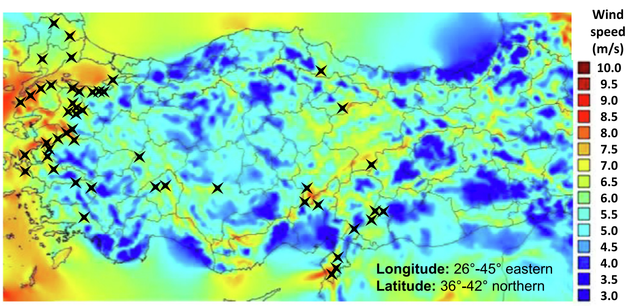

Fig. 6. The wind energy potential of Turkey at 50 m height and location of top 50 wind power plants above 50 MW (modified from [37]).

highest potential with a wind speed of 7 – 8.5 m/s in the coasts and 6.5 – 7 m/s in internal territories between western and northeastern parts [9]. According to EIE, onshore wind potential at 50 m height is 131,756 MW in Turkey [38].

The location of the top 50 wind plants above 50 MW installed capacity in Turkey are highlighted in Fig. 6. The distribution of the operational wind power plants by geographical regions of Turkey in 2019 is shown in Fig. 7 [31]. From Fig. 6, it can be seen that the high wind energy potential of the western parts of the country is already being exploited, whereas wind turbine installation rate stays low in the central and eastern parts of the country. In addition to high wind energy potential, the northern and western parts of Turkey have higher energy consumption. At the same time, the qualified labor force and industry are located in the same part of the country.

4.2. Wind energy installed capacity and generation in Turkey

The share of wind energy in the gross electricity production of Turkey has been rapidly growing. In 2010, the installed capacity of wind energy was 1,329 MW and the share of wind energy in the gross electricity production was 1.39%, whereas the total capacity reached 7,591 MW by the end of 2019, and the share of wind energy in the gross electricity production [39] became 7.07% (Fig. 8 and Fig. 9). In the last decade, the annual average capacity increase became 627 MW.

4.3. Feed-in tariff scheme for wind energy in Turkey-YEKDEM

Turkey put in place the country's first feed-in tariff scheme in 2005 under the Renewable Energy Resources Support Mechanism (YEKDEM) with the enactment of amendments to Law No. 5346 to promote renewable energy systems [40]. The rate was Turkish Lira-denominated which corresponded to 5.0 – 5.5 Euro cent/kWh [12]. This scheme, which was valid between 2005 and 2011 was not successful to promote renewable energy investments as expected. There were two main reasons for this. Firstly, the Turkish Lira-denominated feed-in tariff pushed the market participants into uncertainty due to exchange rate fluctuations. The profitability of renewable energy investments was not predictable in advance. Secondly, the feed-in tariff rates were not very attractive and most of the time the market players preferred to sell the electricity in the balancing market where the prices were slightly higher.

In 2011, the promotion law was amended. The replaced YEKDEM feed-in tariff is eligible for the first 10 years of operation [41]. To benefit from YEKDEM, the projects should be implemented before the end of 2020. In the new law, the feed-in tariff rate is US Dollar-denominated instead of Turkish Lira, also, the rate is

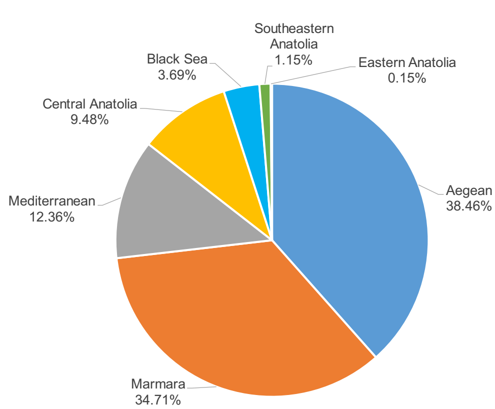

Fig. 7. The distribution of the operational wind power plants by regions of Turkey [31].

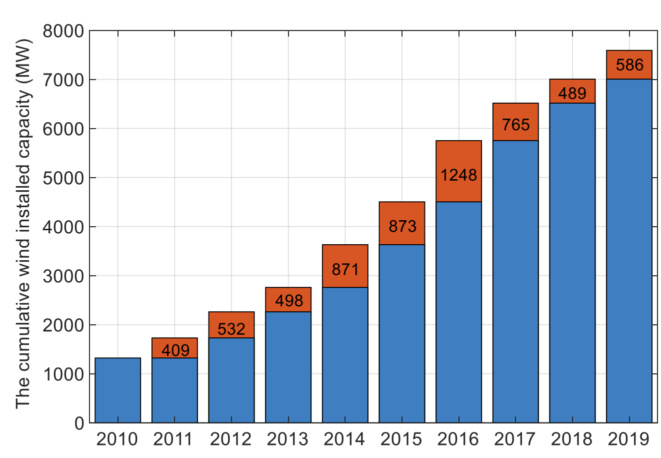

Fig. 8. The cumulative wind installed capacity in Turkey [31].

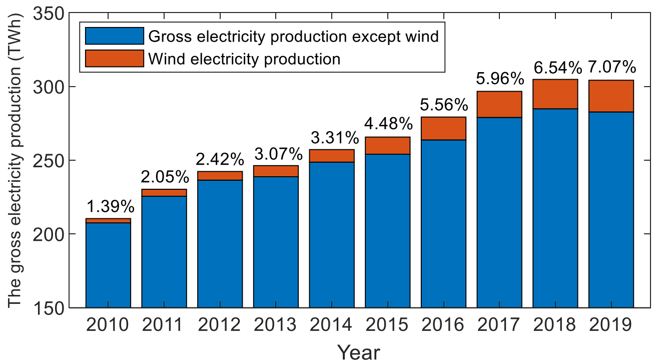

Fig. 9. The share of wind electricity in the gross electricity production of Turkey.

increased and differentiated for particular renewable technologies as:

- 7.3 $ cent/kWh for wind and hydropower
- 10.5 $ cent/kWh for geothermal
- 13.3 $ cent/kWh for biomass and solar PV

In addition to the base feed-in tariff amount, a local content bonus is introduced for locally produced mechanical and electromechanical equipment to promote the local manufacturing in Turkey. For wind energy, local content bonus varies between 0.6 and 3.7 $ cent/kWh as detailed in Table 3 [42]. The local content incentive is valid for the first 5 years of the operation.

The future of the feed-in tariff after 2020 is still unclear for the licensed production. Yet, it is clarified for the unlicensed production with the new Regulation of Unlicensed Electricity Production in Electricity Market and the Presidential Decree No. 1044 dated 10 May 2019 [43]. According to the new unlicensed law:

- The incentive rates have been Turkish Lira-denominated as it was before 2011.
- The new amount of rate is determined as the retail energy price (without distribution fee, and VAT) which is on average 45 kurus/kWh as of 2020, and corresponds to 7 $ cent/kWh depending on the currency rate.
- Unlike the previous law, the amount of rate varies according to the retail price of user groups (residential, commercial, industrial, agricultural, and lighting) [44].
- The differentiation of the incentives applying to the different renewable technologies has been ended, and the determined price applies to all technologies.
- The upper limit of 1 MW unlicensed capacity has been increased to 5 MW. Since wind technology is not a modular technology as PV, the increase in the upper limit causes a severe reduction in the unit cost of installations. It will be possible to use more cost-effective and higher capacity wind turbines.

Table 3
The list of local equipment bonus for wind energy power plants [42].

Local content	Bonus ($ cent/kWh)
Blades	0.8
Generator and power electronics	1.0
Tower	0.6
Other mechanical parts inside rotor and nacelle	1.3
Maximum local content bonus	3.7
Feed-in tariff (base)	7.3
Feed-in tariff (maximum)	11.0

- The new projects will be able to benefit from these incentives for 10 years once they are in operation.

The feed-in tariffs in YEKDEM may not always be the exact revenue of the projects. The project investors enter auctions for the allocation of connection capacity. As a result of the auctions, the owners pay a connection price to the state in terms of $ cent/kWh. The amount to be paid for the connection capacity is usually proportional to the capacity factor of a location.

In these auctions, some project investors may offer negative prices. This means these investors choose to sell the produced electricity in the free market and have a higher trust for the market prices than feed-in tariffs. In this case, the selling price becomes below the market-clearing price depending on the offered negative price [45]. Here, the market-clearing price can both become above and below the feed-in tariff rate. The risk belongs to project owners.

4.4. Wind energy auctions in Turkey - YEKA

In addition to YEKDEM feed-in tariff mechanism, Turkey has begun to apply a widely used auction mechanism to expand the capacity of renewable energy power plants since 2012 (2017 for wind energy power plants). Turkish auction model, Renewable Energy Resource Areas (YEKA) aims:

- Promotion of local manufacturing of high-technology wind and solar power equipment in Turkey
- Technology transfer
- Establishment of a competitive domestic market for low-cost renewable energy
- Efficient use of renewable energy resources with rapid investments
- Utilization of local labor force in wind energy

Turkey has established two YEKA auctions so far for onshore wind, with capacities of 1,000 MW and 4x250 MW, 2,000 MW in total. Also, an offshore wind auction with a capacity of 1,200 MW was planned to take place in October in 2018, however, postponed to a near unknown future [46]. With the realization of all the three YEKA auctions for wind energy, Turkey will add 3,200 MW wind capacity by the end of the projects.

4.4.1. The first YEKA auction

The first YEKA auction was held in 2017 both for onshore wind (1,000 MW) and solar PV (1,000 MW). Eight consortiums, all with foreign partners participated in the wind auction and Siemens-Turkerler-Kalyon consortium awarded the right to develop the announced 1,000 MW capacity for onshore wind. The auction started from the ceiling price of 7 $ cent/kWh and closed with 3.48 $ cent/kWh which was considered as a record-low price, below the 2017 global average of 6 $ cent/kWh [46,47]. The energy production license is given for 30 years with 15 years of guarantee of purchase for the first YEKA auction.

- The consortium is responsible for conducting R&D activities for 10 years in at least three of five areas, namely, Blade, Generator design, Material technologies, and manufacturing techniques, Software, and Innovative gearboxes.
- A budget of $ 5 million will be allocated for R&D activities every year.
- 50 technical personnel, 80 percent of whom are local engineers, will carry out R&D activities.
- A wind turbine factory with an investment cost of over $ 100 million will be established.

- The installation period of the factory will be 21 months from the date of signing the contract and the license period of the project will be 30 years.
- 300 – 450 wind turbines with a minimum capacity of 2.3 MW will be manufactured at the factory.
- The local content requirement in the turbines is determined to be 65% including tower and blades.

The winner consortium will invest more than $ 1 billion in wind plants. With this project, a minimum of 3 billion kWh of electricity will be generated each year with the commissioning of the power plants to be established, and the annual electricity demand of approximately 1.1 million households will be supplied from the wind energy. At the same time, an average annual reduction of 1.5 million tons of carbon emissions will be achieved [46,48].

Since the high wind energy potential of Turkey in the regions of Marmara and Aegean is already being exploited, the government plans to exploit the unused high wind energy potential especially in the region of Central Anatolia (Fig. 6). The domestic wind plants will be located in 5 provinces:

- Kayseri – Nigde (Central Anatolia)
- Sivas (Central Anatolia)
- Edirne – Kirklareli – Tekirdag (Marmara)
- Ankara – Cankiri – Kirikkale (Central Anatolia)
- Bilecik – Kutahya – Eskisehir (intersection of regions of Marmara, Central Anatolia, and Aegean)

4.4.2. The second YEKA auction

The second YEKA auction was made in 2019 for four areas for wind energy, each of 250 MW and 1,000 MW in total. The auction has started from 5.5 $ cent/kWh and closed with:

- 4.56 $ cent/kWh for the province of Aydin (Aegean)
- 4.00 $ cent/kWh for the province of Mugla (Aegean)
- 3.53 $ cent/kWh for the province of Balikesir (Marmara)
- 3.67 $ cent/kWh for the province of Canakkale (Marmara)

The lowest bids were given by Enerjisa Power Plants with Sabanci Holding and German E.ON in Aydin, Enercon in Mugla and Balikesir, and Enerjisa in Canakkale. As it was in the first YEKA auctions, the requirement of local content in the second YEKA auction is also determined as a minimum of 55% for wind turbines with at least 65% for turbine tower, 60% for blade and 51% for other parts. In the second YEKA, the produced turbines will have a minimum power of 3.0 MW [46,48]. In the second YEKA auction, the energy production license is given for 49 years with 15 years of guarantee of purchase.

4.4.3. Offshore YEKA

Turkey also aims to invest in the offshore wind through YEKA auctions. An offshore wind auction with a capacity of 1.2 GW was planned to take place in October in 2018, however, postponed to a near unknown future. Wind offshore auction ceiling prices were determined to be 8 $ cent/kWh and in the region of Marmara in locations of Saros, Gelibolu, and Kiyikoy. The local content requirement is set to be 60% with at least 80% of the employees are local [46].

5. Estimation of feasibility of wind energy projects in Turkey

In this part of the study, the discounted payback period (DPBP) of wind energy projects in Turkey is investigated. Wind power generation is calculated based on capacity factor, and the feasibility of the projects is evaluated through YEKDEM feed-in tariffs. Net cash flow NCF_t (\$/year) is calculated as follows [49]:

$$NCF_t = P \times CF \times 8760 \times \lambda - O\&M_t \quad (2)$$

where t is time, P is the installed capacity of energy plant (kW), CF is the capacity factor, λ is the selling price (\$/kWh) and $O\&M_t$ is annual operation & maintenance cost of the plant at time t (\$/year). The real interest rate i is calculated as [50]:

$$i = \frac{i' - f}{1 + f} \quad (3)$$

where, i' is the nominal discount rate and f is the expected inflation rate. The payback period is the time where the initial investment reaches the break-even point. DPBP is calculated as follows [51]:

$$DPBP \rightarrow \sum_{t=1}^{DPBP} \frac{NCF_t}{(1+i)^t} \equiv NCF_0 \quad (4)$$

where NCF_0 is the initial investment cost (\$), i is the real interest rate, and NCF_t is the net cash flow in year t (\$/year).

The feasibility of the projects for YEKDEM feed-in tariff is investigated through three cases:

- Base case (7.3 $ cent/kWh)
- Possible case - Tower and blade are locally manufactured and benefit from local content bonus (8.7 $ cent/kWh for the first 5 years and 7.3 $ cent/kWh for the second 5 years)
- The best case - All the components are locally manufactured and benefit from local content bonus (11 $ cent/kWh for the first 5 years and 7.3 $ cent/kWh for the second 5 years)

In the analysis, the wind turbine cost is taken as 945 USD/kW according to the average wind turbine cost data of Vestas and BloombergNEF [52]. The other costs such as grid connection, land rent, road construction, electrical installation, etc. constitute approximately 25% of total installation costs [53]. Therefore, the total installation cost is set as 1205 USD/kW. Operation and maintenance (O&M) cost is 2% of total investment [54]. The installed capacity is assumed as 5 MW which is also the upper limit for unlicensed installations. Thus, consistency is provided for unlicensed case analysis. The real interest rate is calculated as 0.03 by using the average of the nominal discount rate and the inflation rate of the last 10 years. The system lifetime is 25 years and the capacity factor is 0.3 as the average of Turkey.

The limitations of the study are as follows: Connection capacity cost is not included in the calculations considering the capacity factor is not high and there is no or low competition. Not to add another parameter to the sensitivity analysis and to keep the results more comprehensible, it is assumed that the land and construction costs will be the same throughout the country. Due to the currency rate fluctuations occurred in the last years in Turkey, the sell-back price in Section 5.2 can vary.

The net cash flows of the investment for three cases are shown in Fig. 10. According to the results of the feasibility analysis, the payback periods of large-scale wind energy projects in Turkey under the YEKDEM feed-in tariff are 4.96 years (best case), 6.94 years (possible case) and 8.21 years (base case). In Turkey there exist qualified manufacturers for tower and blade components as mentioned in Section 5 and project owners are very likely to benefit from the local content bonus provided for these two components. Therefore, the "possible case" can be considered as the most realistic case for Turkey.

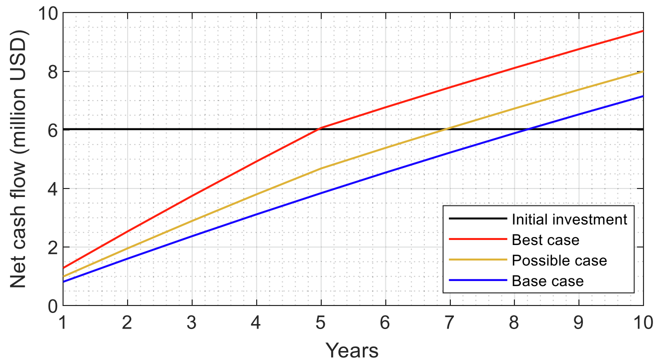

Fig. 10. Net cash flow for the feed-in tariff duration.

5.1. Sensitivity analysis

The capacity factor of a region directly affects the DPBP. Also, the initial investment cost of wind plants is still gradually decreasing and the real interest rate can change according to the economic situation of the country. Therefore, these three parameters are taken into consideration in the sensitivity analysis. The selling price used in the sensitivity analysis belongs to the "possible case".

The capacity factor in Turkey is investigated and found to be varying between 19.7% and 56.8% [55], thus, the capacity factor is set in the range of 20–50% in the analysis. The initial investment cost is assumed to decrease by at most 20% in the short-term. The results are evaluated under different real interest rates of 0.01, 0.03 (current average of last 10 years), and 0.05.

The results are presented in Fig. 11. The range of DPBP changes between 8.72 and 17.14 years for low capacity factor regions (20%) and 2.87 and 4.02 years for high capacity factor regions (50%). It can be seen that the regions which have low capacity factor are more vulnerable to the changes in real interest rate and initial investment cost, whereas, the high capacity factor regions have more stable DBPB.

5.2. Results for new unlicensed prices

The future of YEKDEM is unclear for licensed production. Yet, it has been clarified for unlicensed production [43]. Thus, here, the feasibility of unlicensed projects with new prices is analyzed. The new price is approximately 45 kurus/kWh as of 2020 which corresponds to 7 $ cent/kWh for the time being. This price is very close to the previous "base price" provided by YEKDEM.

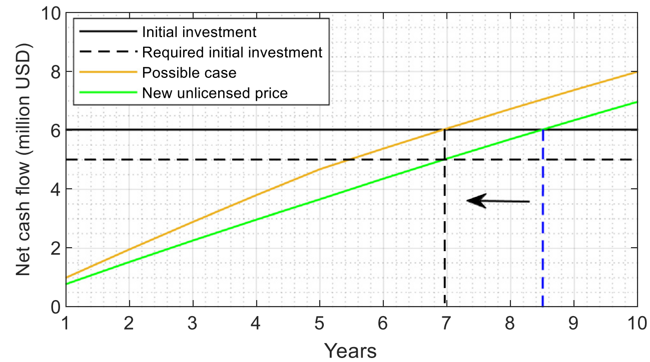

Fig. 12. Comparison of payback period under old YEKDEM (possible case) and new unlicensed production prices.

The results are presented in Fig. 12. The payback period is found as 8.50 years for the "new unlicensed price" which is close to 8.21 years of the old "base price" (Fig. 10).

It is seen that in order to reach the previous payback period of the "possible case" of the YEKDEM scheme (6.94 years), the initial investment cost of the projects should decrease by 17% from 1.205 to 1.00 million USD or the state should maintain the local content bonus as in the previous YEKDEM. Presence of a local content bonus also overlaps with the country's willingness to establish a local wind energy industry. When there is a local content bonus, investors will want to invest in equipment that will be produced in Turkey.

6. Status of wind energy market

In the late 1970 s and early 1980 s, the wind turbines were on a small-scale around 20–30 kW. The first wind farm was established in 1980 in the USA with 30 kW-turbines [56]. At present, the turbine dimensions and power-scales are much higher than before and the turbines have reached a power rating of 9.5 MW [57]. The manufacturing processes today require high-technology, advanced production facilities, experience, and know-how. Notable countries working in this field are Germany, Denmark, Spain, the USA, and China. The turbine manufacturing companies of these countries comprise almost the entire global wind market. The leading manufacturers and their countries are given in Table 4 according to market shares based on sales in 2019 [58]. Although China

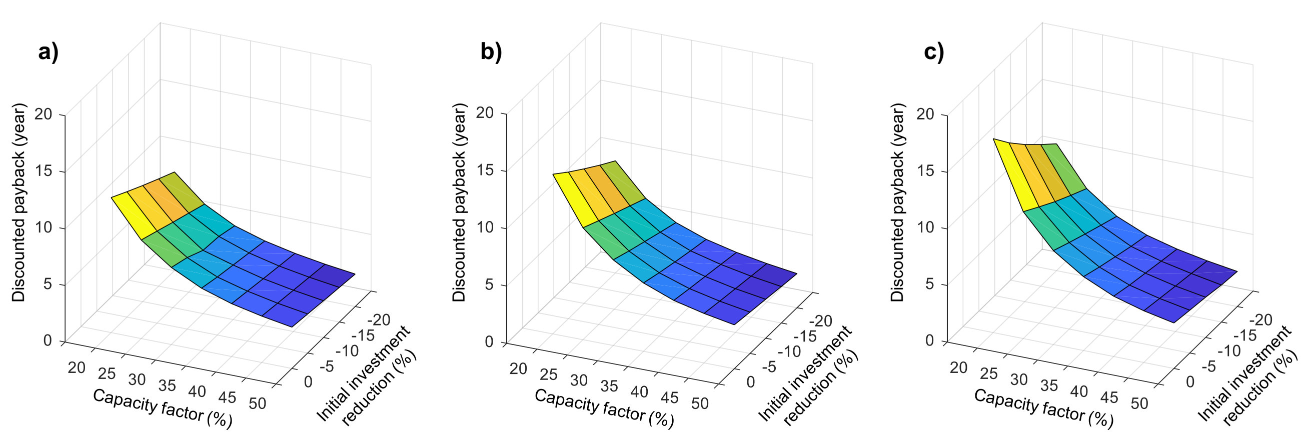

Fig. 11. The impact of capacity factor, initial investment cost, and real interest rate on DPBP of the wind farm investments in Turkey (a- Real interest rate: 1%, b- Real interest rate: 3% (current), c- Real interest rate: 5%).

Table 4
The shares of the leading wind turbine manufacturers in the market in 2019 [58].

Manufacturer	Country	Market share (%)
Vestas	Denmark	15.7
Siemens Gamesa	Spain	14.4
Goldwind	China	13.5
GE Renewable	USA	12.1
Envision	China	9.5
Mingyang	China	7.4
Windey	China	3.4
Nordex	Germany	3.2
Shanghai Electric	China	2.8
CSIC	China	2.4

has entered the wind turbine market later than the others, today it has become one of the leading countries in the market.

These companies are not only dominant in the global market but also their domestic markets. For instance, Siemens Gamesa has a 55% market share in Spain [59] and Suzlon (India) comprises 35% of the Indian market [60]. Nordex and Enercon (Germany) have a total market share of over 60% in Germany by 2018 [61]. China is the most remarkable country in this respect that the market share of Chinese manufacturers has reached almost 90% in their domestic markets [62].

They do not only manufacture wind turbines for their domestic and foreign markets but also contribute to employment in the countries they serve. The approximate number of employees of the wind turbine manufacturers [63–68] are given in Table 5. Vestas, Siemens Gamesa, and Enercon are the leading companies in terms of employment. It should be noted that the number of employees is not limited to these numbers. These complex devices feed many sub-sectors and further expand their businesses [69].

The wind energy sector creates remarkable employment. According to the International Renewable Energy Agency (IRENA) job report [70], the wind power sector provides 1.16 million jobs worldwide. Table 6 shows the number of jobs in the wind sector by the top 10 countries. The top 10 countries constitute 85.4% of the total employment. China alone comprises 44% of the total labor force, followed by Germany, the United States, India, and others. Turkey's labor force is 6,700 in the wind industry.

It should be noted that all the leading countries in terms of employment have their domestic wind turbine brands except one. Brazil distinguishes from others by holding a high labor force without having a notable wind turbine brand. Therefore, the unique aspect of Brazil and the policies in the country are examined in detail in the discussion part and compared to Turkey.

6.1. Status of the wind energy market in Turkey

In Turkey, almost all the active turbines used in wind power plants are imported products. The country does not have any notable domestic manufacturer in a megawatt-scale. Fig. 13 shows the distribution of the total installed wind capacity in Turkey by turbine manufacturers [31]. Nordex is the leading company (26.16%) in terms of installed wind capacity, followed by Vestas, Enercon,

Table 5
The approximate number of employees by the manufacturers.

Manufacturers	The approximate number of employees
Vestas	25,000
Siemens Gamesa	23,000
Enercon	18,000
Goldwind	8,000
Nordex	7,500
Suzlon	6,000

Table 6
The number of jobs in wind energy sector by countries [70].

Country	Number of jobs
China	510,000
Germany	140,800
United States	114,000
India	58,000
United Kingdom	44,140
Denmark	34,200
Brazil	34,000
Spain	20,500
France	18,500
Philippines	16,874

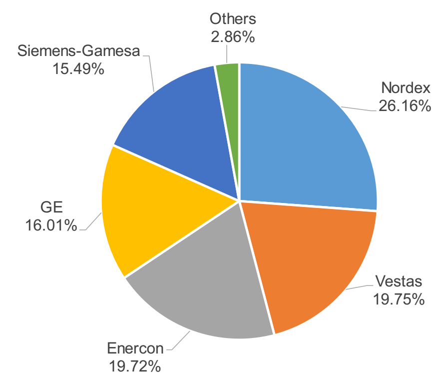

Fig. 13. The distribution of the installed wind capacities in Turkey by turbine manufacturers.

Siemens-Gamesa, and General Electric (GE) respectively. The other manufacturers are Suzlon, Sinovel, Goldwind and Senvion which have a 2.86% market share in Turkey.

There exist 25 wind power plants under construction which constitute 1309.79 MW in Turkey and majority of them are installed in Marmara (729.4 MW) and Aegean (410.49 MW) regions [31]. Among the new installations, Nordex and GE have large installation capacities with 732.79 MW and 350.20 MW respectively and the majority of these constructions are located in regions of Marmara and Aegean which have steady and high-speed wind potential, also contain the required industry and labor force.

As mentioned above, the wind energy sector in Turkey provides 6,700 jobs [70]. These jobs are mostly related to the construction processes of wind power plants, manufacturing of some of the wind turbine components such as blade, tower, and other sub-components. Also, blade manufacturers operating in Turkey are sub-companies established by global wind companies. For instance; Aero Wind and LM Wind are the sub-companies of Enercon and GE respectively. Turkey has advanced construction companies such as Alke, Çimtaş, Gesbey, and Temsan, and the country is capable of tower production in this regard.

7. Discussion

The discussion part is examined in four sub-sections for better understandability and concluded with a SWOT analysis to present a clear overview of all positive and negative factors.

7.1. Turkish Lira-denominated feed-in tariff

The future of YEKDEM is unclear for licensed production. Yet, it has been clarified for the unlicensed production. In the new law, the selling price is denominated in Turkish Lira for unlicensed production. Turkish Lira-denominated feed-in tariff had been in use between 2005 and 2011 before. Back then, the use of domestic currency became a matter of debate. Both financial corporations and sector stakeholders demanded US Dollar or Euro-denominated fixed-prices which are not subject to change due to exchange rate fluctuations. Especially banks demanded them to predict cash flows and offer debt ratio to investors. Such that, after 2011, with the amendment of the law, the amount has been denominated in US Dollar and the rate of new installations has increased significantly.

When the electricity selling price is Turkish Lira-denominated, it becomes a hesitation factor for the investors since the investments and loans are denominated in US Dollars or Euro. If the selling price is considered to be Turkish Lira-denominated, then, Turkey should wait until its domestic wind energy industry develops and becomes mature, that is:

- As the equipment to be used in projects will be locally produced and trade of these products will be Turkish Lira-denominated, the investment of a wind energy project will be Turkish Lira-denominated. Then, the incentives provided in Turkish Lira will be meaningful. Investors will have a lower risk factor and will not be affected by the exchange rate volatility.
- If Turkey decides to continue with Turkish-lira denominated feed-in tariffs, then Turkish banks should provide better loan options for these investments. Because the investors obtain loans from foreign banks denominated in US Dollar or Euro. In case the incentives (which means the cash flows of the project) are in another currency, and fragile to exchange rate volatility, these banks may want to avoid taking risks.
- In order to prevent the money loss that can be caused by currency fluctuations, Turkish Lira denominated feed-in tariff rates can be updated in short periods based on US Dollar/Euro or inflation rate.

7.2. Local wind energy industry and labor force in Turkey

The domestic wind energy industry highly contributes to the local labor force and technological know-how. Turkey which holds relatively cheap labor force and qualified staff can combine these features and get close to its target of 20 GW installed capacity in wind energy by reducing the risk factors mentioned in Section 7.1 for investors and establishing its local wind energy industry. The top countries holding the highest installed capacity in wind energy are the developed countries that started their wind energy investments earlier than others, except China and Brazil.

Although the installed wind power in China is very high and the Chinese market dominates a large part of the market share in the world (Table 4), China entered the wind market later than the others and turbine production is mainly directed to the domestic Chinese market [62]. To reduce carbon emissions and supply the energy demand, the Chinese government provided incentives and subsidiaries for wind energy such as tax reduction, feed-in-tariffs valid for 20 years, supports for local manufacturing of wind turbines such as availability of better funds from state-owned banks, funds given for research & development (R&D) projects, and grants given for wind turbine manufacturers for production of 1.5 MW or higher capacity wind turbine parts [71,72].

In Brazil, despite the country's high installed capacity, there are no domestic wind turbine manufacturers. Brazil has achieved its success in wind energy with its local content requirements set in wind auctions. Brazil's wind auctions strongly promote localization in wind turbine manufacturing. Although not obligatory, to benefit from the favorable credit options of the Brazilian Development Bank BNDES (a governmental funding agency responsible for most of the energy financing in Brazil), the companies should fulfill local content requirements. These requirements impose investors to manufacture or assemble at least three of the four main wind turbine components: towers, blades, nacelles, and hubs, in Brazil [73]. The local content requirements policy has become successful to promote low and medium technology manufacturing in Brazil. Wind turbine components that are difficult to transport such as parts of the nacelle, hubs, and blades are currently being produced in the country. Yet, expensive high technology and high-quality content, which requires a more qualified labor force, is still being imported [74].

In this respect, instead of creating a local wind turbine brand in the first stage, Turkey should consider establishing partnerships with large brands that maintain their production since the 80 s. Turkey has achieved such success in the automotive industry and become one of the top manufacturer countries [48]. Also, the Brazilian example shows the success of this method. Although Brazil does not have any domestic wind turbine brands, it has become one of the leading countries in wind energy and contains one of the highest labor force. This model was so successful that, especially after 2013, the country has increased its installed wind capacity significantly (Table 1).

One of the successes of Brazil's auction model is undoubtedly the country's highest capacity factor in the world. This is one of the main factors that attract firms to invest in Brazil. Likewise, Turkey is a country ranked with the third-highest capacity factor in the world, and with this feature, Turkey has a similar potential to attract investors, if necessary incentives and supports are supplied. If Turkey continues its YEKA auctions and insists on domestic labor and domestic industry stand out in these auctions, it is likely to be successful as can be seen from the example of Brazil.

The incentives and support mechanisms in wind energy provided by Brazil and China had a positive impact on the wind installations in their countries as well as on the labor force. As given in Table 6, these countries are among the top ten countries in the world concerning the number of wind-related jobs. China and Brazil have 510,000 and 34,000 wind-related jobs in their countries, respectively. This is also one of the factors that enhance the country's technological know-how and qualified manpower.

7.3. Wind energy auctions

Turkey has applied two YEKA auctions so far. Both auctions aimed to promote locally produced wind turbine equipment, conduct R&D in wind turbine technology, and use local labor force in wind energy projects. These two auctions were achieved with very low prices in the range of 3.48–4.56 cent/kWh while the global average of onshore wind auctions was 6 cent/kWh (2017) [46]. The low prices were caused by the high capacity factor of the project areas and the large capacity of the projects (1,000 MW of each).

The achieved low prices show that the YEKA auction model can be further expanded in Turkey. The authorities and decision-makers can develop YEKA-like auction models with lower capacity projects and in the regions with lower capacity factors while auction prices still stay below the global average. This might further expand the use of wind power, improve the wind industry, and increase local employment in Turkey.

Moreover, small-scale YEKAs can overcome another threat: a possible project failure. In big projects a failure may cause a valuable time loss in the process of Turkey's local wind industry establishment. Dividing the risk can be another option to be considered.

7.4. SWOT analysis

Lastly, a SWOT (strengths, weaknesses, opportunities, and threats) analysis is made to summarize the discussion part and evaluate Turkey's competitive position considering internal and external factors (Table 7). Turkey's industrial development and

Table 7
SWOT analysis of wind energy in Turkey.

(S)trenghts	(W)eaknesses	(O)pportunities	(T)hreats
• High capacity factor in the country. • Qualified and cheap labor force. • Governmental willingness to develop local wind energy industry. • Strong domestic demand of wind turbine equipment. • State policy of energy diversification and energy independency. • Increased know-how in Turkey over years	• Lower feed-in tariffs compared to developed countries. • The highest-potential wind sites are already occupied. • Some of the high-speed wind areas exist on bird migration routes. • Bureaucracy and institutional incoordination can be challenging from time to time. • Short duration of feed-in tariff (10 years).	• Untouched, high offshore wind potential. • Wind turbine raw materials are already being produced and in use in other sectors in Turkey. • Closeness to new markets. • Upper limit increase for unlicensed plants (1 MW to 5 MW). • Unexploited high-medium, medium wind speed sites. • Increase of infrastructural investments.	• Unclear future of feed-in tariffs after 2020. • Unwillingness of businesses to use Turkish Lira denominated feed-in tariff. • High exchange rate and interest rate volatility. • Country's vulnerability to economic crises. • High competition in the market due to lower production costs and higher technological develpoment of India and China. • Removal of bonus price for use of domestic equipment in new unlicensed feed-in tariff.

low-cost, skilled workforce stand out as the country's "strengths". The industrial force, combined with the governmental willingness can help the country to achieve its goal of establishing a local wind energy industry. The bureaucracy and institutional incoordination in Turkey can be seen as a "weakness" in general but that can be eliminated with facilitating arrangements. Here, Turkey's main "opportunity" is the country's closeness to the new markets such as Mediterranean, Middle Eastern, North African and Central Asian. Turkey also already produces wind turbine raw materials and use them in various sectors, which can accelerate the country's achievement of its goal. Yet, the main "threat" is India and China, which have already established their industrial facilities with low production costs and high technological development. Taking a share from a market that is targeted by Indian and Chinese manufacturers will be one of the main challenges.

8. Conclusions

By the end of 2019, the total installed wind capacity reached 7.59 GW in Turkey which is far away from the country's target of 20 GW by 2023. The average rate of 627 MW capacity installations per year makes it impossible to reach the assigned target. Thus, to get close to "2023 targets" in wind energy, Turkey should increase the efficiency of the current policy measures. In this respect, the below recommendations are made and economic feasibility results are presented to give a broader view about the country's potential:

- Turkish Lira-denominated feed-in tariff is a hesitation factor for project owners due to the exchange rate and interest rate volatility. If Turkey wants to continue with the Turkish Lira-denominated feed-in tariff, then the Turkish banks should offer better credit options to attract investors.
- Turkish Lira-denominated feed-in tariff will be justified when Turkey establishes its local wind energy industry. Yet, until then, measures should be taken to prevent investors from a possible money loss. In this regard, Turkish Lira-denominated feed-in tariff rates can be updated in short periods.
- In the first stage, instead of creating a local wind turbine brand, Turkey should consider going into partnerships with well-established firms. Brazil's own success story in wind energy and Turkey's success in the automotive sector show that this model can work for Turkey and the country can develop a remarkable wind energy industry and employment with its qualified and relatively cheap labor force.
- The future of the YEKDEM feed-in tariff mechanism which ends by the end of 2020 should be clarified. The uncertainty causes hesitation for the investors.
- Turkey should maintain the local content requirements in its successful YEKA auctions and feed-in tariff scheme. Local content requirements can be provided for unlicensed projects as well. Especially taking into account that the definition of unlicensed projects is expanded from 1 to 5 MW, this may be required to boost the promotion of unlicensed projects.
- The duration of Turkey's feed-in tariff (10 years) is lower compared to many countries (15–20 years). A longer feed-in tariff (even with a lower feed-in tariff rate) can provide better predictability for both banks and project investors.
- While large capacity YEKA auctions were achieved with record low prices, the risk gets bigger as the capacity increases. A possible project failure may cause a valuable time loss in the process of Turkey's local wind industry development. Thus, mini-YEKAs with lower capacities should also be considered.
- Wind energy investments in Turkey are concentrated in certain regions (Fig. 6). This brings necessary infrastructure investments with an economic burden. Within a strategic plan, investments can be homogeneously shifted to other high-capacity regions that require less infrastructure investment.
- Although wind energy projects have not faced with strong opposition in Turkey so far, offshore projects can suffer from "Not in my backyard" (NIMBY) syndrome due to the touristic aspect of Turkish coasts. Suitable offshore locations having low public opposition can be mapped considering social effects.
- In the economic analysis, the DPBP of large-scale wind power plants are determined to be between 4.96 and 8.21 years depending on taking advantage of the local content bonus provided by YEKDEM feed-in tariff scheme. The DPBP of 4.96 years belongs to the best case where all the used equipment are locally produced. Yet, in the possible case DPBP is 6.94 years due to the limited availability of locally produced equipment in Turkey.
- It is seen that, the new unlicensed scheme to be used after 2020 provides a DPBP of 8.5 years which is close to the previous DPBP of 8.21 years under YEKDEM without any local content bonus. If the government decides to apply the same rates to the licensed projects after YEKDEM (as applied previously), then the local content bonus must be maintained in the new scheme to reach the old payback periods. This also overlaps with the country's willingness to establish a local wind energy industry. When there is a local content bonus, investors will want to invest in equipment that will be produced in Turkey.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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