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Wind Farm and Installed Wind Power Analyses of Turkey

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Abstract

In this study, the analyses of wind farms and corresponding installed wind power of Turkey are conducted. Wind farms in Turkey have been evaluated by considering five different regions. The map of Turkey is similarly divided into five different regions, and the farms are clearly shown on these maps. The installed power or capacity of each wind farm is clearly shown. So, a total of 251 operating, under-constructional, and licensed wind farms have been extensively analysed in terms of their capacities. On the other hand, the total theoretical wind power potential of the territories has been studied comparatively, and it is concluded that among the total theoretical wind power potential of 115,329 MW, the total installed wind power of Turkey is reported to be 10,599.89 MW. Namely, it is concluded that only 9.19% of an installation ratio has been performed in Turkey, which corresponds an unused wind power potential of 90.81%.

Keywords: Installed power, Theoretical wind power potential, Wind energy, Wind Farm

Türkiye'deki Rüzgâr Santrallerinin ve Kurulu Rüzgâr Gücünün Analizleri

Öz

Bu çalışmada, Türkiye'nin rüzgâr santralleri ve buna karşılık gelen kurulu rüzgâr gücü analizleri yapılmıştır. Türkiye'deki rüzgâr santralleri, Türkiye'nin beş farklı bölgesi dikkate alınarak değerlendirilmiştir. Türkiye haritası da benzer şekilde beş farklı bölgeye ayrılmıştır ve çiftlikler bu haritalarda açıkça gösterilmiştir. Her bir rüzgâr çiftliğinin kurulu gücü veya kapasitesi net olarak gösterilmiştir. Böylece, toplam 251 faal, yapım

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aşamasında ve lisanslı rüzgâr santrali, kapasiteleri açısından, kapsamlı bir şekilde analiz edilmiştir. Öte yandan, bölgelerin toplam teorik rüzgâr gücü potansiyeli karşılaştırmalı olarak incelenmiş ve 115,329 MW olan toplam teorik rüzgâr gücü potansiyelinden, Türkiye'nin toplam kurulu rüzgâr gücünün 10,599,89 MW olduğu sonucuna varılmıştır. Yani Türkiye'de; sadece %9,19'luk bir kurulum oranı gerçekleştirildiği ve bu oranın da, rüzgâr enerjisinin %90,81'lik kullanılmayan bir potansiyeline karşılık geldiği, sonucuna varılmıştır.

Anahtar Kelimeler: Kurulu güç, Rüzgâr çiftliği, Rüzgâr enerjisi, Teorik rüzgâr gücü potansiyeli

1. INTRODUCTION

Fossil fuel sources have declined rapidly in the last decade; besides, the rapidly increasing population and parallel technological developments have increased the demand for energy significantly [1,2]. Utilization of the fossil energy sources and increasing global warming associated due to these fossil fuels as well as the greenhouse gas emissions are the most crucial global problems and these problems have been urgently considered in the last decade by many countries [3-5]. Unless any precautions are not applied, it has been reported by the International Energy Agency (IEA) that the fossil based greenhouse gas emissions are expected to be doubled by 2050 [6]. On the other hand, due to the reason that conventional energy production is not very economical today, as well as when the harmful environmental influences of energy utilization are considered, and because of the continuously increasing energy demand of humanity; some troubles have been associated in obtaining of the sustainable energy demand. Namely, unsustainability occurs in current demand to energy when considered in terms of a worldwide aspect including economic, environmental, human as well as climatic needs [7]. In this context, it is quite indispensable to be shifted from fossil fuel utilization to the renewable energy sources to meet this demand and in parallel to obtain a significant reduction in the global CO_2 emissions to the justifiable levels.

Among the whole renewable energy sources, wind energy can be regarded as one of the most important type [7]. Figure 1 presents the annual and total installed wind power capacities of Turkey in last twenty years, namely between 2000 and 2020. It is observed from this figure that the cumulative installed wind power which was 18.90 MW by 2000, has increased to 8,288 MW by the end of 2020. Besides, the highest annual wind power installation has been actualized in 2016 with an installation of 1,387.75 MW power.

As of the end of 2020, Turkey's total wind power of 8.288 GW is obtained from 194 wind power plants that have been put into operation. But, this value only corresponds to the total number of installed power plants. Besides, the total number of power plants including the installed, under-constructional and licensed ones has reached to 251 in amount by the end of 2020. Turkey has a total installed power of 93.0227 GW, of which 8.91% is obtained from wind energy for electric generation.

However, the aim of Turkey is to increase the share of the wind energy in total generations to a total of 20 GW by the end of 2023. But, unfortunately only 41.44% of the aim has been actualized today. Accordingly, a cumulative of 11.712 GW of new wind power installations is required in the next two years in order to accomplish the projected goal of 2023. So, in order to increase the installed wind power of Turkey, the conscious and effective utilization of wind power potential is very essential. In the current study, the installed wind power and the total power potential of Turkey have been shown as province based. For this aim, Turkey was divided into 5 different regions for the analysis. The total theoretical wind power potential and the installed wind power in each region are analyzed and shown [2].

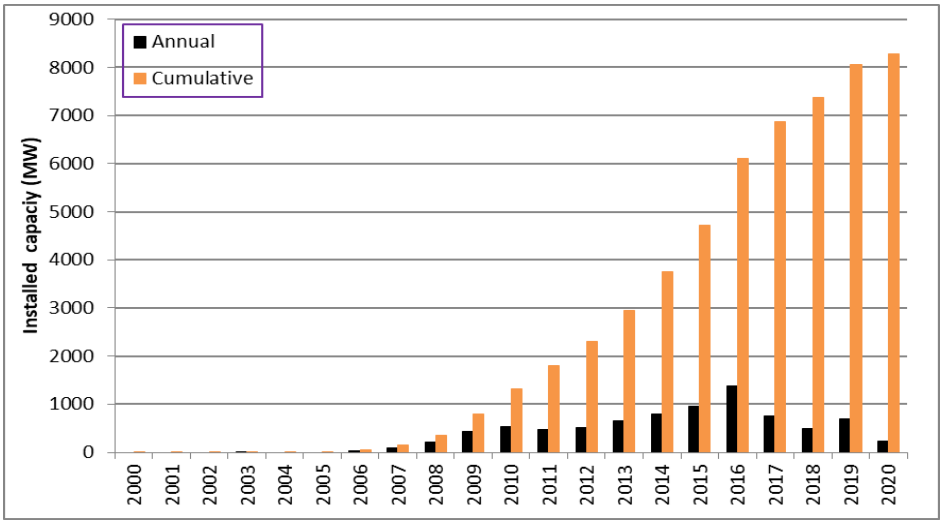

Figure 1. Annual and total installed capacities of Turkey between 2000 and 2020

2. DETAILED WIND POWER EXAMINATION OF TURKEY

2.1. Territorial Analysis of Wind Farm Locations and Corresponding Installed Wind Power Analyses

There are many studies found in the literature dealing with the wind energy potential and status of Turkey [8-11]. Based on the inspection of total wind energy status on Turkey; this study concludes that Turkey has a total of installed wind farms of 251 in which operating, under-constructional and licensed types share this amount by 194, 22, and 35, respectively. On the other hand, the installed wind capacities of each is reported to be 8,177.75 MW, 1,188.59 MW, and 1,233.55 MW, respectively for operating, under-constructional and licensed types of wind farms. These three types of wind power installations constitute a total installed wind power capacity in overall Turkey reaching 10,599.89 MW of installations [12].

In these regards, the maps of Turkey are given considering five discrete regions to present wind farm locations in each province of the state. Initially, the West region of Turkey is demonstrated in Figure 2 showing the wind farm locations of this region. Besides, the wind farm information including the name of the facility as well as the type of the installation, for this region is presented in between Figures 3-6. Namely, Figure 2 shows the wind farm ranking for the analysis and the numbers between 1 and 91 are given in Figure 2, and the same numbers are given for the same wind farms between Figures 3-6 to demonstrate the name and the type. Besides, Figures 3-6 indicate the total power capacity of each discrete wind farms. So, a total of 23 wind farms have been analyzed in each of Figures 3, 4, and 5, and a total of 22 wind farms have been analyzed in Figure 6. The abbreviation “D.M.” has been used in Figure 2a to refer the region shown by rectangular area. It refers to “detailed map” concept and the detailed map of Figure 2a has been shown in Figure 2b. It was convenient to present this region on a detailed map, because due to scale, this region had to be shown on a larger map. The abbreviations shown in Figures 3-6 including “Op.”, “U.C.”, and “L.”, refer respectively to operating wind farms, under-constructional wind farms, and licensed wind farms. The operating, under-constructional, and licensed wind farms have been demonstrated with green, blue, and black colors, respectively in Figure 2 [12,13].

In the West region of Turkey, it is observed that among total of 91 wind farms; while 78 wind farms are in the status of operating; under-

constructional and licensed wind farms correspond to 7 and 6 in amount, respectively. Similarly, in this region of Turkey, among total installed power of 3,720.44 MW; installed power of operating, under-constructional, and licensed wind farms share 87.39%, 10.36%, and 2.25%, respectively, corresponding to 3,251.30 MW, 385.29, and 83.85 MW of installations [12,13].

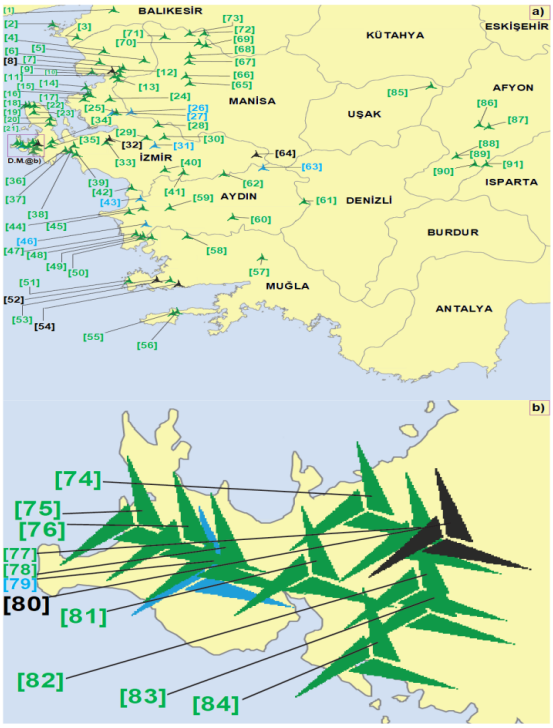

Figure 2. Locations of the installed wind farms in the West region of Turkey, a) whole wind farms in this region, b) D.M. of Alaçatı zone of İzmir province of West region of Turkey

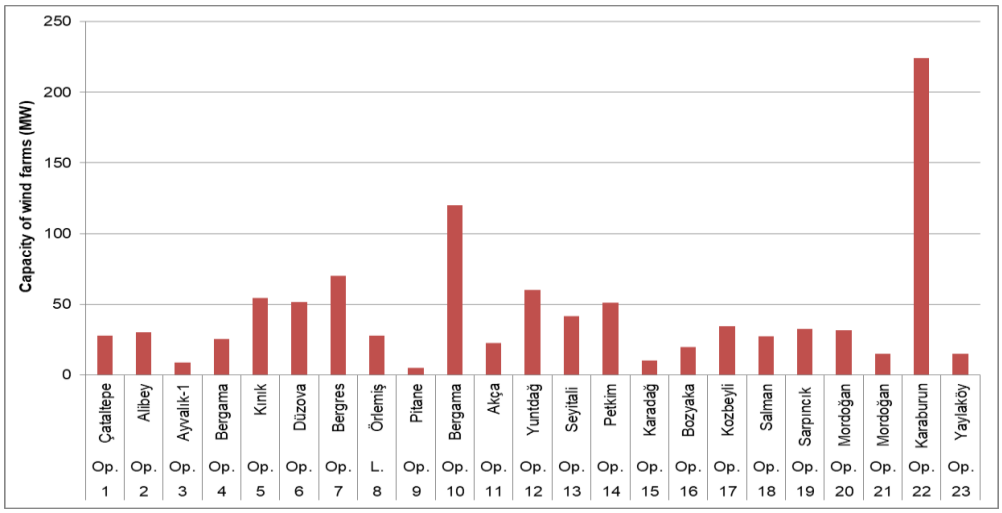

Figure 3. Capacities of wind farms in west of Turkey (wind farms of 1-23 shown in Figure 2)

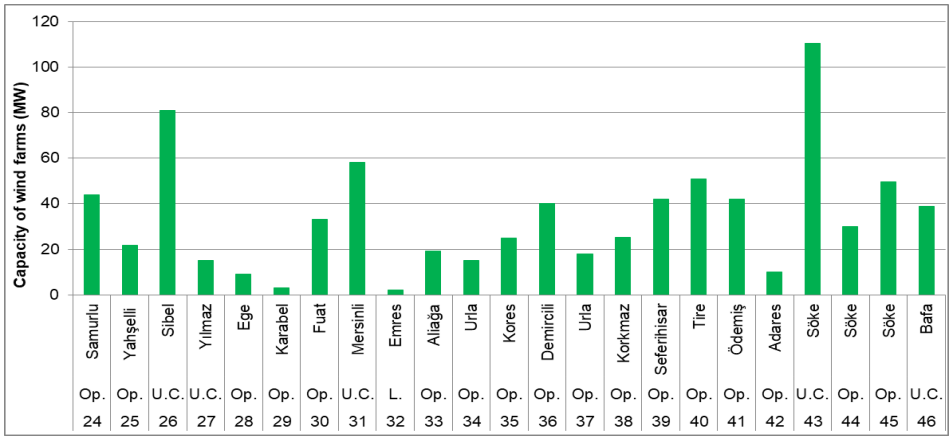

Figure 4. Capacities of wind farms in west of Turkey (wind farms of 24-46 shown in Figure 2)

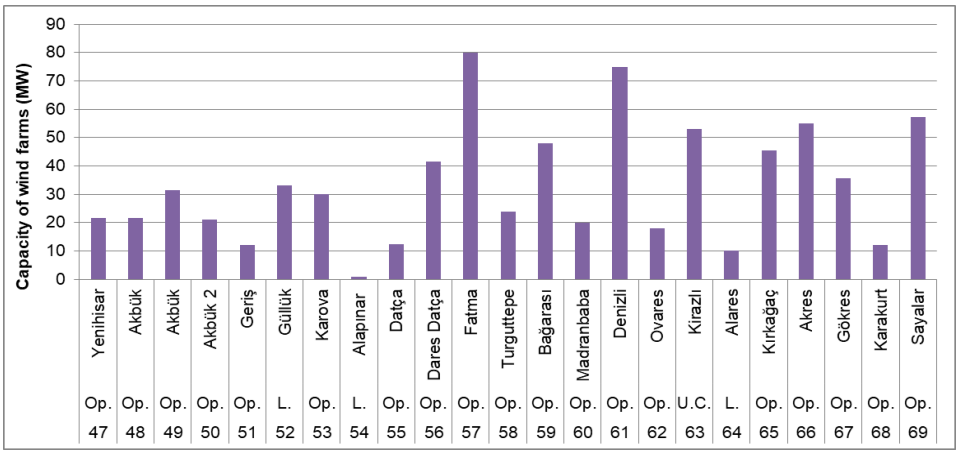

Figure 5. Capacities of wind farms in west of Turkey (wind farms of 47-69 shown in Figure 2)

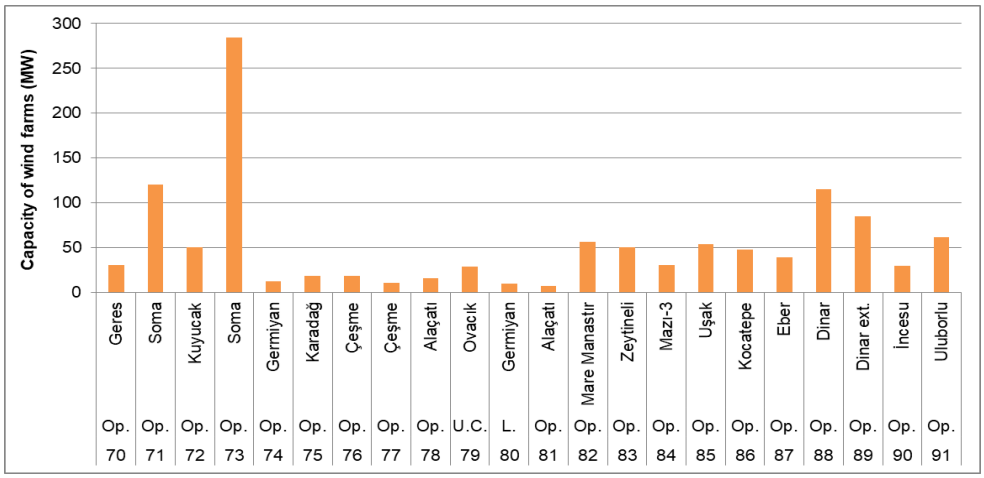

Figure 6. Capacities of wind farms in west of Turkey (wind farms of 70-91 shown in Figure 2)

The Northwest region of Turkey is demonstrated in Figure 7. The figure demonstrates the wind farm locations of Northwest region. Similarly, the wind farm information for this region is indicated in between Figures 8-12. The analysis for wind farm ranking of this region is shown in Figure 7. So, the numbers between 1 and 103 are given in Figure 7 and the same numbers are given for the same wind farms between Figures 8-12 to indicate the name and the type. Besides, Figures 8-12 point out the total power capacity of each discrete wind farms of the region. So, a total of 23 wind farms have been analyzed in each of Figures 8, 9, and 10, and a total of 17 wind farms have been analyzed in each of Figures 11 and 12. The abbreviations and same definitions of "Op.", "U.C.", and "L." are also valid for the wind farm analysis of Northwest region. Furthermore, the same colors of green, blue, and black have been also used for the same purpose of wind farm type identification as shown in Figure 7 [12,13].

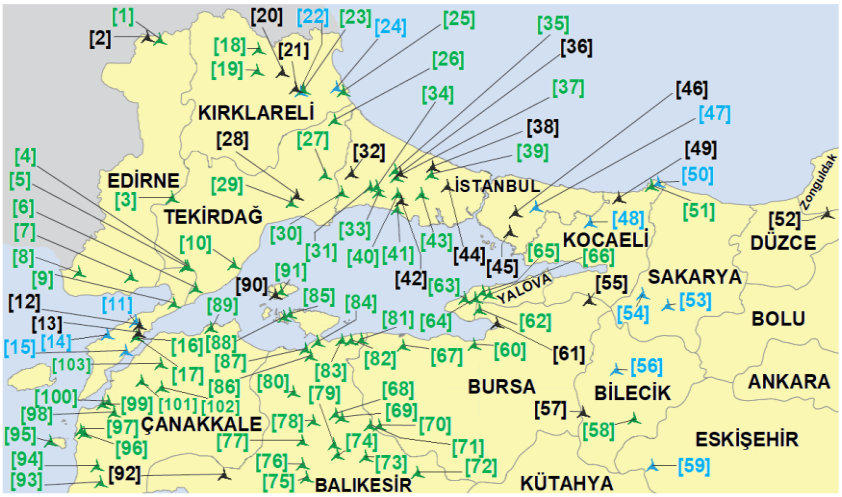

Figure 7. Locations of the installed wind farms in the northwest region of Turkey

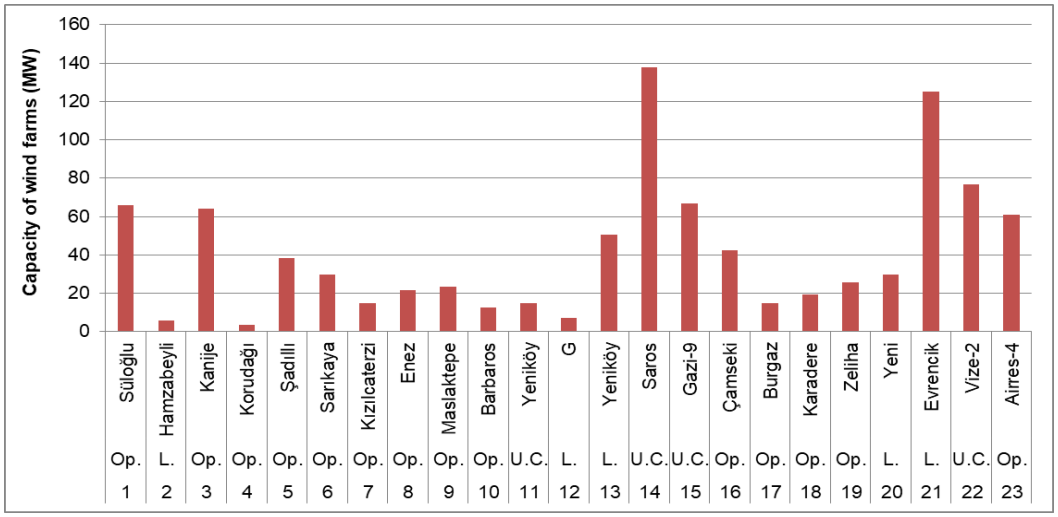

Figure 8. Capacities of wind farms in northwest of Turkey (wind farms of 1-23 shown in Figure 7)

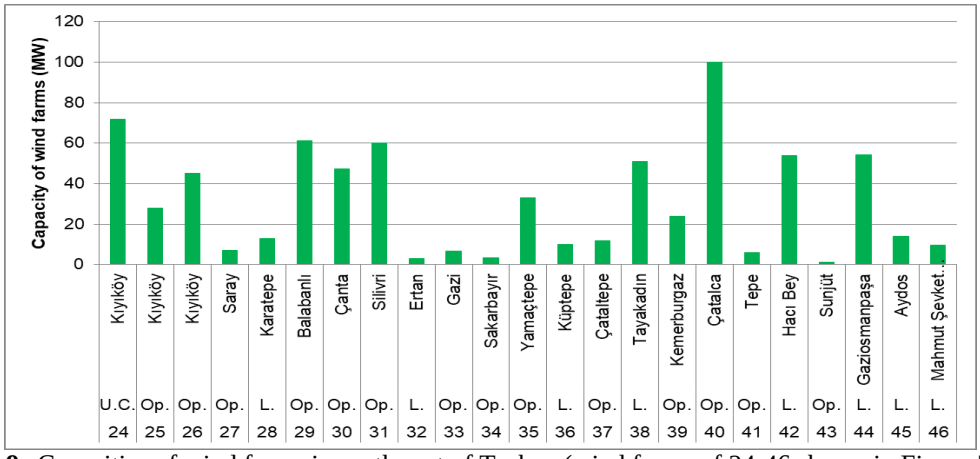

Figure 9. Capacities of wind farms in northwest of Turkey (wind farms of 24-46 shown in Figure 7)

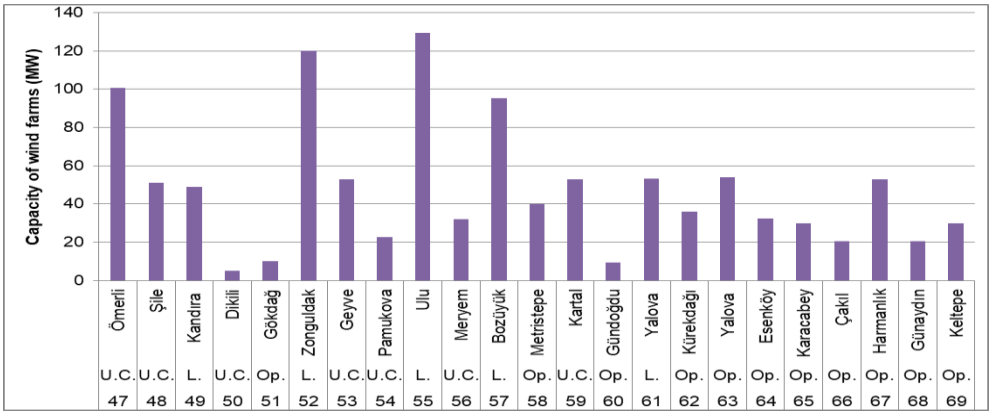

Figure 10. Capacities of wind farms in northwest of Turkey (wind farms of 47-69 shown in Figure 7)

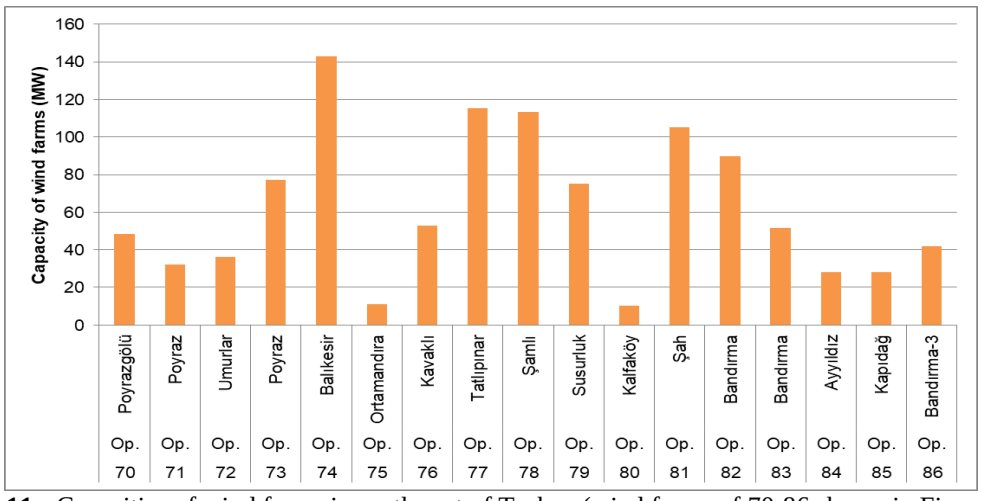

Figure 11. Capacities of wind farms in northwest of Turkey (wind farms of 70-86 shown in Figure 7)

On the other hand, a total of 103 wind farms are available in the Northwest region of Turkey, in which, operating, under-constructional, and licensed wind farms in this region compose 71, 12, and 20, respectively in amount, as shown in Figures 7, 8, 9, 10, 11, and 12. Namely, the total installed power of 103 wind farms in this region reaches 4,457.00 MW of installations. In this location of Turkey, the shares of operating, under-constructional, and licensed wind farms of 4,457.00 MW of total installations are reported to be 2,825.70 MW, 686.20 MW, and 945.10 MW of power values, respectively [12,13].

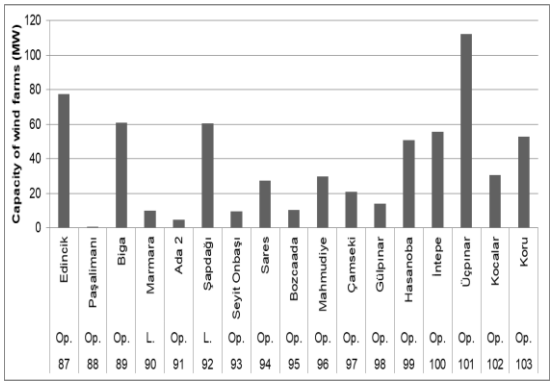

Figure 12. Capacities of wind farms in northwest of Turkey (wind farms of 87-103 shown in Figure 7)

Figure 13 presents the North region of Turkey in the analysis of wind farms, namely whole wind farm locations of the region is demonstrated in this figure. The wind farm information regarding the North region is exhibited in Figure 14. The wind farm ranking of the region is presented in Figure 13. So, in Figure 13, the numbers between 1 and 11 are shown for the wind farms of this location and the same numbers are demonstrated for the same wind farms in Figure 14 to indicate the name and the type of the wind farm. Besides, Figure 14 denotes the total power capacity of each discrete wind farms of the region. The abbreviations and the color utilizations that were used in the previous regions have been also applied in the wind farm and the capacity analyses of North region of Turkey [12,13].

Figure 13. Locations of the installed wind farms in the North region of Turkey

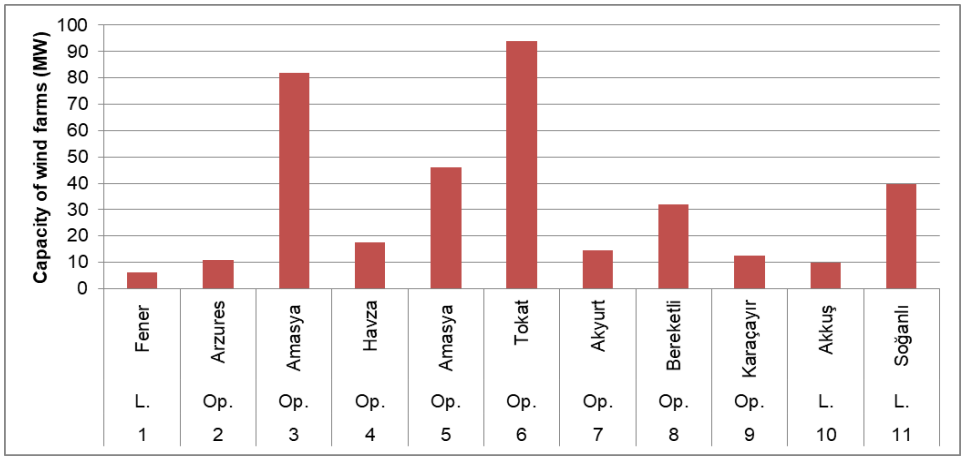

Figure 14. Capacities of wind farms in north of Turkey shown in Figure 13

Similarly, in the North region of Turkey, a total of 11 wind farms are found as demonstrated in Figures 13 and 14. While, 8 wind farms stand for operating type and 3 wind farms stand for licensed

type, it is observed that no under-constructional type of wind farm is existed in this location. The total installed power value of 11 wind farms constitutes a power value of 365.40 MW. And, 309.80 MW of installations and 55.60 MW of installations are reported to be existed in operating type of installations and licensed type of installations, respectively [12,13].

The wind farm analysis of the South and Middle regions of Turkey has been shown in Figure 15. On the other hand, the information regarding the wind farms of the region is demonstrated in Figures 16 and 17. The wind farm ranking of the region is presented in Figure 15, in a similar way. So, the numbers between 1 and 37 are demonstrated for the wind farms of the region in this figure and the same numbers are shown for the corresponding wind farms in Figures 16 and 17 to indicate the name and the type of the wind farm. Besides, both figures exhibit the total power capacity of each discrete wind farms of the region. While 23 wind farms have been analyzed in Figure 16, 14 wind farms have been taken into account in Figure 17. Same abbreviations and color utilizations are also valid for the South and Middle regions of Turkey [12,13].

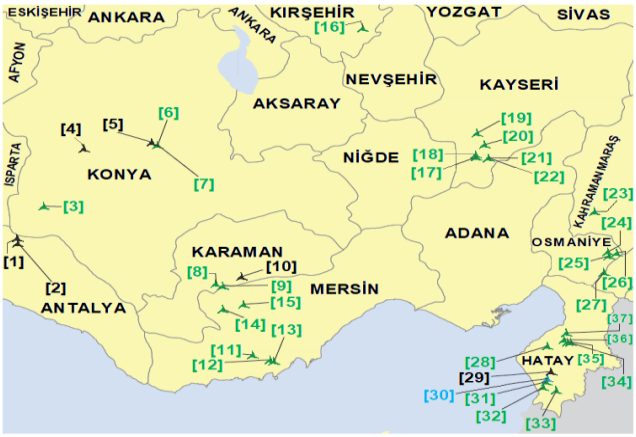

Figure 15. Locations of the installed wind farms in the south and Middle regions of Turkey

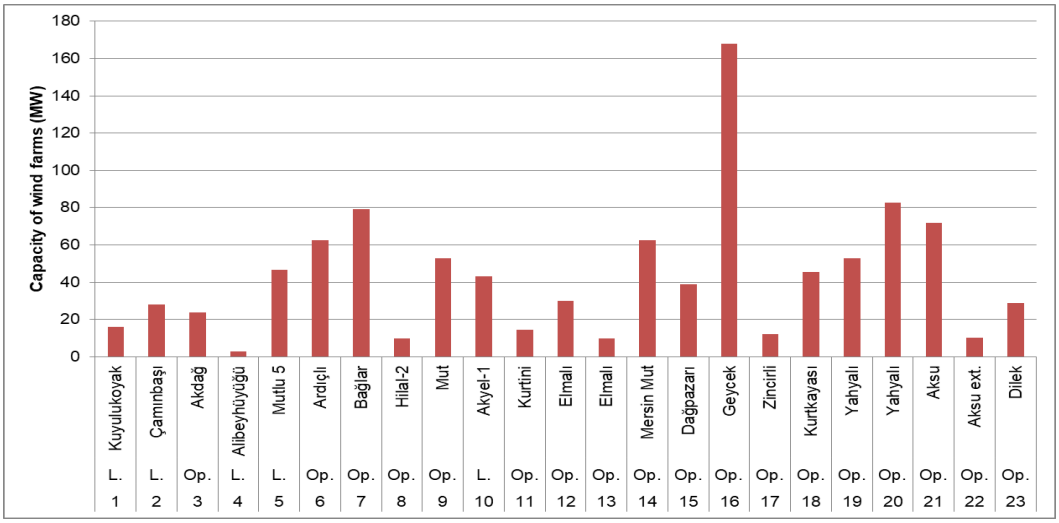

Figure 16. Capacities of wind farms in South and middle of Turkey (wind farms of 1-23 shown in Figure 15)

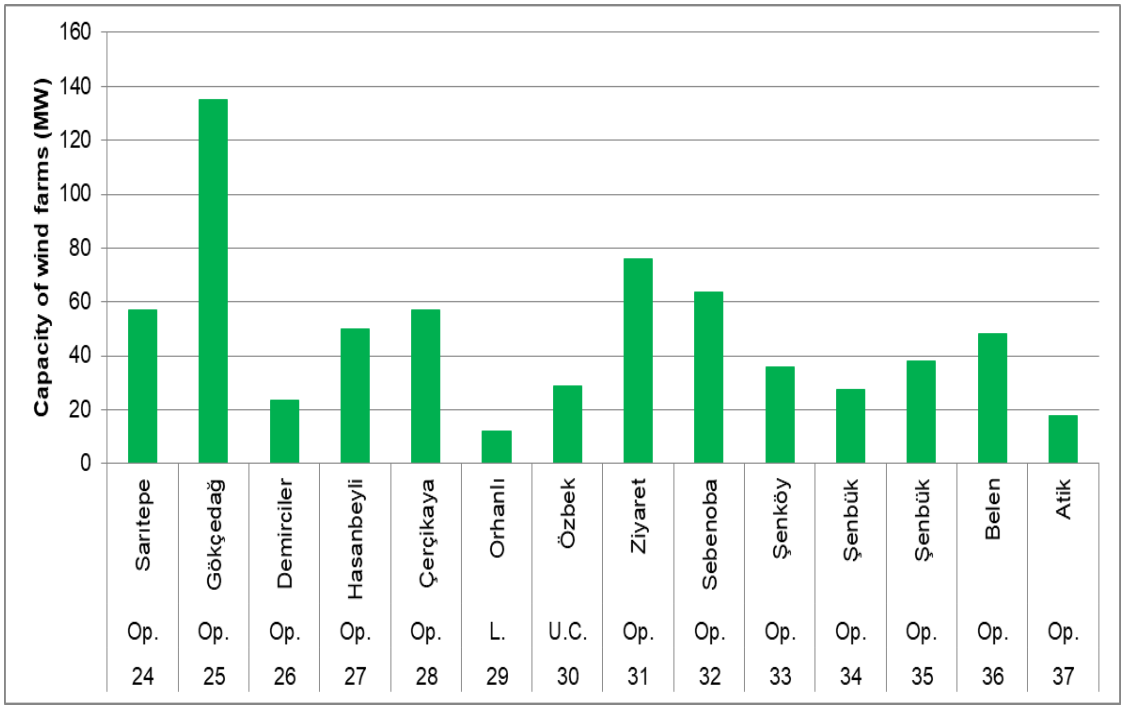

Figure 17. Capacities of wind farms in south and middle of Turkey (wind farms of 24-37 shown in Figure 15)

Furthermore, a sum of 37 wind farms is situated in the South and Middle regions of Turkey. Among these cited wind farms presented in Figures 15, 16, and 17; 30 operating, 1 under-constructional, and 6 licensed wind farms are available. Besides, total installed power of these wind farms reach to 1,485.90 MW for operating ones, 28.80 MW for under-constructional ones, and 149.00 MW for licensed ones are reported. Total of these three types of installations compose a cumulative installed wind power of 1,663.70 MW in these locations of the country [12, 13].

Finally, the wind farm analysis of the South and Southeast regions of Turkey has been considered in Figure 18. In parallel, the wind farm information of the region is shown in Figure 19. In a similar approach, the wind farm ranking of the region is given in Figure 18. So, the numbers between 1 and 9 have been demonstrated for the wind farms of these locations in this figure. Besides, the same numbers show the corresponding wind farms in Figure 19 in order to exhibit both name and the type of the same wind farm. The figure demonstrates the total power capacity of each separate wind farms of the region. Same abbreviations and color utilizations have been also utilized for the South and Southeast regions of Turkey [12,13].

Figure 18. Locations of the installed wind farms in the South and southeast regions of Turkey

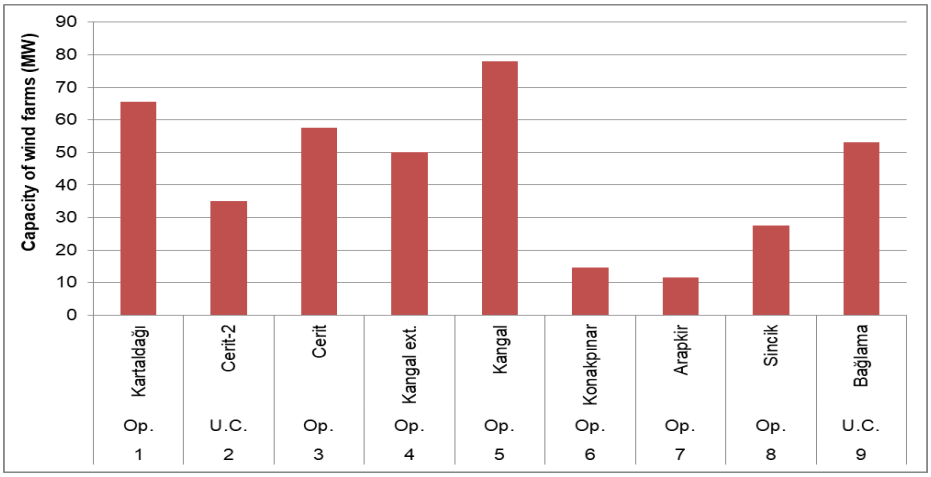

Figure 19. Capacities of wind farms in South and Southeast of Turkey shown in Figure 18

In the last part of the analyses, the South and Southeast regions of Turkey have been considered. In these locations, currently 9 wind farms are available, as indicated in Figures 18 and 19. Among them, while 7 wind farms are operating, 2 wind farms are in the state of under-construction. However, no wind farms of licensed type are available in these locations. On the other hand, the total wind power in these zones is observed to be 393.35 MW of installations. In this regards, the cumulative installations for operating, under-constructional and licensed types are conducted to be 305.05 MW, 88.30 MW, and 0.00 MW, respectively, in South and Southeast regions of the country [12, 13].

In determining the proper location of a wind farm, first of all, the wind capacity of the region where the wind farm will be installed, needs to be measured. Propeller length, blade system, and turbine model should be adjusted completely according to the wind pressure. Namely, there should be proper matching of the machinery components and the wind pressure of the region. If proper optimization is not obtained between both, the propellers may deteriorate and the efficiency of the wind turbine may decrease. On the other hand, it is also important to position the wind turbine in such a way that it does not affect the ecosystem. This is very important for the continuation of natural life without any damage. For this reason, high care should be taken when deciding on the place of the wind farm. For instance, establishing a location that will affect the migration routes of birds can cause serious damage to the ecosystem. Shortly, the area to be established should be studied first, and then the design and material needs should be met according to the requirements of the region.

In order to reach a solution in a short way, wind energy potential atlases can be used. By using these maps, the location of the wind power plant can be decided correctly. For example, if the wind speed is measured and found to be more than 7 kilometers and have continuity; it can be determined that the region is suitable for establishing a wind farm. After this stage, it will be necessary to obtain a license by applying to authorized institutions. Besides, wind farms cannot be established in protected areas, national parks, nature protection areas and wildlife protection areas. Therefore, the fact that the surveyed region receives enough wind and that is suitable for wind energy production cannot be considered as the only criterion. Moreover, countries often publish maps of locations where wind farms cannot be installed. Finally, after obtaining the necessary permits and completing the other necessary tasks, wind turbines can be installed in the interested area.

Considering the analysis in the present article, it has been understood that the installed wind power has increased significantly in the western regions of Turkey. This is directly due to the fact that high wind speeds can be achieved in the western regions of the country. In these locations, the mountains lie perpendicular to the sea coast and the wind energy blowing from the open sea to the land is easily transported to the regions at a certain distance from the coast. Namely, less losses of the wind power in the western region of Turkey occurs, that result high wind farm installations in these regions.

2.2. Territorial Comparison of the Theoretical Wind Power Potential and the Installed Wind Power

Wind farms are the locations that are open to the free wind flow, and the devices which are used to capture wind energy are the wind turbines, namely wind turbines are utilized to generate electricity.

The approaching free-stream wind speed to the turbine rotor disc is the most important parameter influencing the generated output power obtained from a wind turbine. Accordingly, the change of the wind power potential is proportional with the cube of the free-stream wind speed. The available or the theoretical power that can be captured from an air stream is physically expressed with Equation 1, shown below:

$$P_{av}=0.5\rho A_d V_i^3 \quad (1)$$

In this equation, the designations demonstrated by P_{av}, ρ, A_d, and V_i respectively indicate the available wind power, the air density, the cross-sectional area of the wind turbine rotor disc, and the free-stream wind speed approaching the wind turbine rotor disc. In this equation, the free-stream wind speed approaching the wind turbine rotor disc has the potential of available wind power. However, the coefficient of the Betz-limit is multiplied by the theoretical power to obtain the maximum accessible turbine power. The maximum power limited by Betz is given by Equation 2, demonstrated below [14]:

$$P_{Betz}=0.5\rho A_d V_i^3 x0.59 \quad (2)$$

Namely, it is not so possible to convert whole available wind power in an air stream of certain velocity, to electrical energy. In determining the theoretical wind power potential of a certain location, or whole Turkey, Eq. (1) is valid, and it is utilized considering the wind speed maps. On the other hand, the real installed wind power at a certain location or in whole Turkey remains always less than the theoretical wind power potential due to the losses or due to the existence of the locations where wind turbine installation has not been actualized. In short, the ratio of the installed wind power to theoretical wind power potential is an important parameter to make a comparison of the actualized installations on the land to the total available wind power. Thus, studies can be carried out considering this ratio, on the extent to which the installations can be increased.

There are also ways to circumvent the Betz limit. The Betz limit is an efficiency barrier in conventional wind turbines. However, this barrier can be overcome by converting local pressure energy into kinetic energy using shrouding systems. In this way, more portion of the theoretical wind power can be converted to real installed wind power.

The comparison of the theoretical wind power potential expressed according to the installed wind power in five different territories of Turkey is presented in Figure 20. In this figure, y-axis is presented as logarithmic in order to demonstrate the comparison better. The values shown on top of each column demonstrate the real values of theoretical wind power potential and the corresponding installed wind power. The analyzed territorial regions in terms of wind power of Turkey include West, Northwest, North, South and middle, and South and southeast regions. The theoretical wind power potential column shown with the designation "*Others*" include 9 cities which do not have any corresponding installed wind farm. On the other hand, the ratio of installed

wind power to the theoretical wind power potential for five territorial regions is shown in Figure 21. These 9 cities of Turkey which do not have any wind farm or installed wind power include Çankırı, Karabük, Bartın, Kars, Kırıkkale, Hakkari, Artvin, Ardahan, and Iğdır provinces. These provinces have theoretical wind power potential of 315 MW, 73 MW, 62 MW, 40 MW, 40 MW, 29 MW, 10 MW, 9 MW, and 2 MW, respectively, constituting a total of 580 MW. Namely, these provinces of Turkey having a total of 580 MW of theoretical wind power can considered as locations for the investors in terms of wind farm installations.

As it is shown in Figure 20, the total theoretical wind power potential of Turkey and the total installed wind power are 115,329 MW and 10,599.89 MW, respectively. As seen in Figure 21, these power values correspond to a ratio of 9.19%. From another point of view, Turkey's total wind power potential of 90.81% has not unfortunately been evaluated yet. Besides, the analyses have presented that the highest wind power installations have been executed in the Northwest region of Turkey. In this location, while the value of the installed wind power is 4,457.00 MW, the corresponding theoretical potential is equal to 33,841 MW. Namely, the highest ratio of 13.17% of installations has occurred in Northwest region. Considering West region, it is observed that the installations of wind power in this region are also comparatively higher. In this region, installations of 3,720.44 MW of wind power have been actualized among the total of 42,764 MW of theoretical wind power. These outcomes demonstrate that in the West region, a ratio of 8.70% of installations has occurred. Finally, as also mentioned above, although 580 MW of theoretical wind power is available in 9 cities of Turkey as shown in Figure 20, there is no installed wind farm in these cities which results an installation ratio of 0%, as shown in Figure 21. An important point that is required to be mentioned here is the y-axis of Figure 20, i.e., the logarithmic power. The y-axis of Figure 20 has been shown as logarithmic axis, because the discrepancies between the theoretical wind power potential and the real installed wind power are so large in terms of the arithmetic axis. Namely, for the analyzed five regions of Turkey, and also for the cumulative values of wind power, the ratio of the real installed wind power to the theoretical wind power potential is in between 2.12% - 13.17%. This ratio interval for whole regions and for the cumulative values of wind power would cause that the distance between the values of the both functions on the arithmetic axis would be so high; so, it was decided the analyses to be shown on the logarithmic axis.

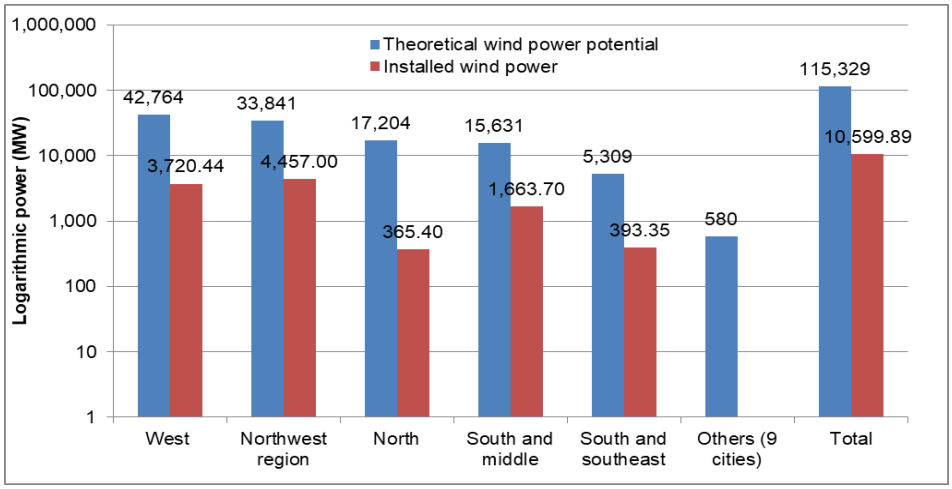

Figure 20. The comparison of the theoretical wind power potential and installed wind power

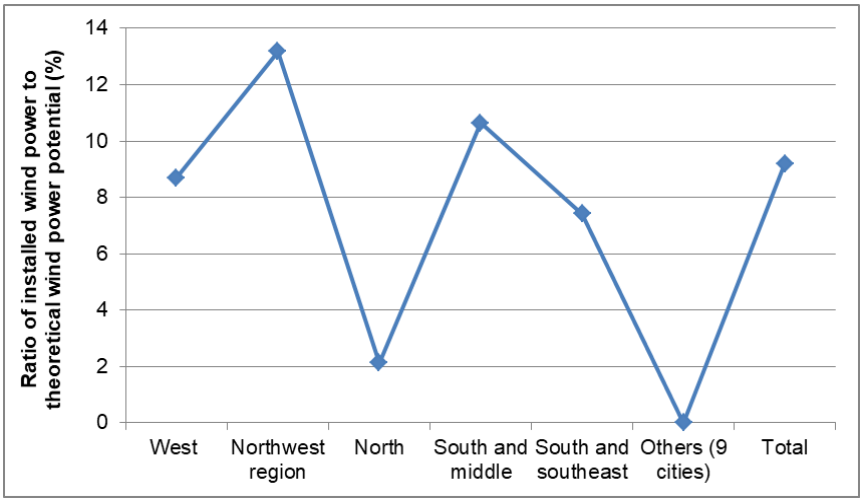

Figure 21. Ratio of installed wind power to the theoretical wind power potential

3. CONCLUSIONS

This study has provided a good focus on the current status of installed wind power and theoretical wind power potential of Turkey. Besides, when the analyses performed on the current study are considered, it can also be reported that the total installed wind power of Turkey considering the worldwide situation has increased in terms of the percentage. Namely, the global installed wind power capacity has increased from 18,039 MW to 743,000 MW, respectively from 2000 to 2020. So, it has been concluded in this study that the ratio of wind power installations of Turkey to whole World was initially 0.10% by 2000, which has increased to 1.12% by 2020. As a result of these analyses, it has been also reported that Turkey has a better installation speed in wind energy compared to the rest of the World and gives more importance to wind investments.

Besides, in this study, operating, under-constructional and licensed wind farms were analyzed in five different territories of Turkey. Namely, a total of 251 wind farms have been taken into account in West, Northwest, North, South and middle, and South and southeast regions of the country. Besides, in these locations, theoretical wind power potential values have been presented. The comparison of the installed wind power with respect to the theoretical wind power potential has been executed for the five regions. It has been concluded that highest installations have occurred in Turkey in Northwest and West regions. However, it has been observed that although sufficient wind power potential is available in 9 cities of Turkey corresponding to 580 MW, it is reported that no wind farm installations have been unfortunately actualized in those cities. Total installed wind power of Turkey is 10,599.89 MW among the total theoretical wind power of 115,329 MW, which correspond an installation ratio of 9.19%. In other words, the unused wind power potential of Turkey is 90.81%. Finally, it is concluded that there is a need of installations of additional wind farm facilities in five regions considered separately as well as in 9 cities which do not have any installed wind farm yet.

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