The (r)evolution of wind energy systems in Romania: state-of-the-art, new trends and challenges

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Abstract. After decades of development, one of the most mature renewable energy technologies is recognized to be wind energy. Compared to other renewable energy sources the wind potential that can be used to produce electricity is much higher. Currently, the conversion of wind energy into electricity has several advantages, among which can be mentioned the following: "clean" energy source, renewable energy source, low costs per unit of electricity produced. Thus, the progress of future technological innovations must lead to the achievement of wind turbines that are more efficient, more robust, and less expensive than actual technology. The aim of this work is to provide an overview of the Global, European and, especially, Romanian situation of the wind energy market. Moreover, are presented aspects related to innovative constructive solutions for wind turbines used to capture wind energy in areas where wind potential is low.

1. A brief of history

Nowadays, wind energy has become one of the most widely used renewable energy sources \cite{1}. The main causes that contributed to this can be considered the following: the growing necessity for "green" energy and the sharp reduction of conventional energy resources (e.g.: coal, oil, natural gas etc.) \cite{1,2}.

\textbf{Figure 1.} Sailing boat used by the Egyptians from antiquity until at least the 16th century \cite{3}.

\textbf{Figure 2.} Persian windmill from 500 ÷ 900 BC \cite{7}.

From ancient times, mankind has used and exploited wind power as a source of energy \cite{1}. However, the wind energy technologically development is attributed to the second half of the 20th century \cite{1,2,4}. First, this was due to the lack of knowledge about the aerodynamic aspects of the wind turbine...
blades [4]. A second factor was the default of sustainable materials needed to obtain wind turbines with satisfactory performance in operation [4].

The first use of wind energy dates back over 5000 years [5]. For example, the ancient Egyptians used wind power to propel ships on the Nile River [5÷6]. A sailing boat used by the Egyptians from antiquity until at least the 16th century is shown in Figure 1 [3].

The appearance of the first windmills is documented in Persia, between 500÷900 BC [5÷6]. In Figure 2 is presented the Persian windmill that was used to grind wheat or pump water [7]. Starting with the 1100s, windmills began to appear in various regions of Europe [5÷6]. The first windmills that had a horizontal axis structure appeared on the territory of Netherlands [5÷6]. Figure 3 illustrates the windmills that were used in Netherlands in the 1300s [8]. Although in the 1600s windmills were used extensively in Europe but lost their popularity with the Industrial Revolution [5÷6]. In the 1800s, as settlers headed west, wind turbines were a real success in the United States [6].

![Figure 3. Illustration of windmills used in Netherlands in the 1300s [8].](image)

On the Romanian territory, the appearance of windmills is temporarily placed in the medieval period, mostly in Dobrogea area [9]. Currently, windmills from various regions of the country are exhibited at the largest open-air museum in Romania, Astra Sibiu [9]. Figure 4 presents the last windmill with sails in Romania, exhibited at the Astra Sibiu Museum [9].

![Figure 4. Romanian windmill exhibited at the Astra Sibiu open-air museum [9].](image)

![Figure 5. First windmill for electricity production, James Blyth, 1887, Scotland, Europe [10].](image)

By the end of the 1800s, the engineer Thomas Perry revolutionized the American windmills with the design of "Aermotor" [5÷6]. In 1887, the first windmill capable of producing electricity was designed and built by Professor James Blyth, in Glasgow, Scotland [5÷6]. In Figure 5 is shown the windmill designed by James Blyth [10]. Between 1887÷1888, a wind turbine capable of producing only 12 kW was developed by Professor Charles F. Brush, in Cleveland, Ohio [5÷6]. On the left side of Figure 6 is presented the wind turbine of Charles F. Brush [11].

In 1890, in Denmark, as a part of industrialization, the emphasis was on introducing electricity into small communities [6]. In 1891, the Danish scientist Paul la Cour built the first windmill in Askov,
Danmark [5÷6]. Figure 6 highlights, on the right side, the wind machine of Paul la Cour [12]. In 1931, the first predecessor of modern horizontal-axis wind turbines was put into operation in Yalta, Russia [5÷6]. The "Balclava" generator had the capacity to generate almost 100 kW [6]. In 1956, engineer Johannes Juul built the first modern wind turbine in Denmark [5÷6]. The "Gedsar" wind turbine had a capacity of 200 kW [6].

Figure 6. Charles F. Brush wind turbine, 1887 ÷ 1888, Cleveland, Ohio, United States (left) [11] and Paul la Cour wind machine, 1891, Askov, Denmark, Europe (right) [12].

The last century innovations brought to the society by the structural materials industry, aerospace industry, and computers industry, have contributed in a significant way on the development of superior performance wind turbines [1÷2]. According to Olabi [1] and Ellabban et al. [2], these performances could be quantified by increasing the area of the wind turbine rotors and, implicitly, the size of the wind turbine blades [1÷2]. Thus, the “wind turbine capacity” has increased, which is quantified by the total potential electricity production [1]. Secondly, the blades of the wind turbines could be positioned higher and higher in the atmosphere, where the wind is more stable [1÷2]. The result was the increase in the "capacity factor" of the wind turbine. This represents the amount of energy produced by the unit, in relation to the installed power of the wind turbine [1÷2]. The definition of the "capacity factor" is explained in equation (1).

\[
\text{Capacity Factor} \% = \frac{\text{Actual ENERGY Generated [MWh]}}{\text{CAPACITY [MW]} \times \text{TIME Period [h]}} \tag{1}
\]

One of the most important stages in the evolution of wind energy history coincided with the drastic rise in oil prices in the 1970s [1÷2]. Thus, the interest of humanity was directed towards the renewable energy production sector [13]. Globally, numerous strategies have been formulated to set and meet renewable energy targets [13]. For example, in Europe, a 20% reduction in greenhouse gas emissions compared to 1990 has been set as a mandatory target for Member States [15÷16]. It has also been established that by 2020 of the total energy consumptions about 20% will be from renewable sources, respectively at least 27% by 2030 [15÷16].

Over time, to have information about the state-of-the-art not only in the field of electricity production, but also for the technological development, numerous studies have been conducted. Reference works for the wind energy sector can be considered those of Wang and Wang [16], Kaldellis and Zafirakis [17], Leung and Yang [18] and Islam et al. [19].

The main purpose of this research work is to provide an overview of both the current situation of the energy sector in the world, European and Romanian, and the current level of technological development of wind turbines industry.

The first part of this paper presents some facts about the Global and European wind energy market. In the second part are described aspects about the actual wind energy sector in Romania. The third part
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shows details about the market penetration of wind turbine concepts. The final part of this paper shows which are the most important conclusions of our research.

2. Global and European wind energy market facts

It is well known that wind energy technology is an advanced one [2]. From the literature [20], the technological development of wind energy capture is attributed to the territory of Denmark. The performances of the current wind turbines are clearly superior compared to those recorded from the beginning of wind energy technology production (25÷30 kW) [20÷21].

Based on the data collected over time, Figure 7 shows the evolution of global cumulative installed wind capacity between 1980 and 2019 [22÷24]. The graph in Figure 7, illustrates the upward growth that the development of technology and the capacity to produce wind energy have had over the about last four decades [22÷24].

![Figure 7. Time evolution of Global cumulative installed wind capacity (1980÷2019) [22÷24].](image)

From the previous studies, it was found that for year 2000 the global wind production capacity was about 17.4 GW, and 198 GW for 2010, respectively [23]. For the beginning of 2020, the value recorded for the world wind generation capacity was 621 GW [24]. By comparing the three previously mentioned distinct values it can be said that world’s wind power generation capacity growth rate was over 30% for the two decades.

![Figure 8. Distribution of Global total installed wind capacity by world region (2019) [22÷24].](image)

According to the 2019 annual report of GWEC [24], the regions in the world with the highest percentage of installed wind capacity are Asia-Pacific (46%), and Europe (29%). In Figure 8 is presented the global distribution of the total installed wind capacity for the 2019 year [24].

The graphical representation in Figure 9 highlights the evolution of the installed wind capacity in Europe in relation to the Global one, between 1998 and 2019 [23÷24]. Also, Figure 9 shows the
contribution that the value of the wind installed power in Europe had from the world’s total one during the 12 years [23÷24].

![Figure 9](image)

Figure 9. Time evolution of European vs Global cumulative installed wind capacity (1998÷2019) [22÷24].

From the analysis of the 2019 data provided by the Global Wind Energy Council [24], it could be found that the country in Europe (see Figure 10) with the largest installed wind power (53913 MW) was Germany (30 %).

![Figure 10](image)

Figure 10. Distribution of European installed wind capacity by countries (2019) [24].

However, in terms of total energy consumed from wind energy, the first placed country in Europe is Denmark [23÷24]. In 2019, Denmark set a record in the process of energy consumption from wind energy, namely about 50% of the total electricity production [24÷25].

3. Actual wind energy sectors in Romania

According to the Global Wind Energy Council report for 2019, in Romania, the value of the total installed wind capacity was equal to 3029 MW [24]. Thus, Romania ranked 24th globally and 16th in Europe [23].

From the data provided by National Energy Regulatory Authority (ANRE), it was highlighted that at the end of 2019, Romania had approximately 11250 MW of installed power only from renewable resources [26]. Thus, Romania has reached its target proposed by the European Union for 2020 in terms of energy production from renewable resources [15÷16]. Figure 11 illustrates the installed capacity in renewable energy sources in Romania, in 2019 [26]. As can be seen in Figure 11, the highest percentage of the four categories of renewable resources has the energy produced by hydropower (60%), followed by the one produced by wind turbines (27%) [26].
In Figure 12 is presented the evolution of the installed wind capacity in Romania, in the period 2006÷2019 [23]. The graph in Figure 12 shows that in 2006 the installed wind capacity had a value of around 2 MW, then had a rapid growth until 2013, reaching 2599 MW [23]. From 2014 (2953 MW) until 2019 (3029 MW) the installed wind capacity, in Romania, had approximately constant values [23].

**Figure 11.** The installed capacity in renewable energy sources, in Romania, in 2019 [26].

**Figure 12.** Time evolution of Romanian installed wind capacity (2006÷2019) [23].

**Figure 13.** The map from 2006 for annual average wind speed at 50 m above the ground [27].
Considering the status of the technology, an economic use of the wind potential is possible only on restricted areas in Romania. The studies by Dragomir et al. [27] and Degeratu et al. [28] showed that in Romania, the Black Sea coast area has good aeolian potential. Several works [29÷30] placed this area (Dobrogea Region, Constanța County and Tulcea County) as the 2nd place in Europe characterized by large wind potential. In Figure 12 is presented a map from 2006 for the annual average wind speed at 50 m above the ground [27].

Not only the annual distribution of the average wind speed on the Romanian territory [27], but also the fact that the current wind turbines operate efficiently at average wind speeds of at least 7 m/s [31] were decisive factors in finding solutions for the exploitation of areas with low aeolian potential.

Another important factor was the low use of current wind turbines due to the fluctuating nature of the wind [32]. Figure 14 ÷ Figure 17 shows the wind energy production, the average wind energy production, and the total installed capacity in Romania between 2016 and 2019 [33].

In Table 1 are summarized the values of aeolian production, average aeolian production, total installed capacity, and capacity factor in Romania, between 2016 and 2019 [30], [33].
From Table 1, it can be said that taking into account the amount of energy produced each year (production) and the amount of energy used (average production) from the total installed power, values within the normal limits were achieved for the “capacity factor” [29]. These values are a result of the fact that even wind is an inexhaustible source of energy and involves no cost [30], it is not a constant source of energy because it depends on weather conditions [27],[32].

Table 1. The values of aeolian production, average aeolian production, total installed capacity, and capacity factor in Romania, during the period 2016÷2019 [30],[34].

| Year       | 2016     | 2017     | 2018     | 2019     |
|------------|----------|----------|----------|----------|
| Production [TWh] | 6.385    | 7.301    | 6.226    | 6.157    |
| Average Production [MW] | 728      | 833      | 711      | 764      |
| Total installed capacity [MW] | 3028     | 3029     | 3029     | 3029     |
| Capacity factor [%] | 24.04    | 27.50    | 23.47    | 25.22    |

4. Market penetration of wind turbine concepts
To reduce the size of wind turbines and the investment costs to achieve the same amount of wind energy from areas with low potential (v_{wind} = 2÷5 m/s), various solutions have been tested [35]. These solutions were both for horizontal-axis and vertical-axis wind turbines [35÷36]. An optimal solution in solving the above-mentioned considerations was the use of a casing [36]. Thus, a device with the effect of wind energy concentrator was designed [36÷37].

The idea of casing the wind turbines rotors is not a new concept on the market [35÷37]. The effectiveness of these wind turbines, compared to conventional systems, was firstly recognized in 1979 at the United States Conference on Innovative Wind Systems [37].

In the works of Agha et al. [36] and Kosasih et al. [37] are presented the most common types of casings. Also, in these studies are discussed the main factors that contributed to the improvement of the “wind turbine capacity” (e.g.: the shape and geometry of the casing, the geometry of the rotor blades, the aeolian potential from the site) [36÷37].

Coșoiu et al [38] developed and tested a casing equipped with passive flow control devices. The experimental and numerical tests took place within the Hydraulics and Environmental Protection Department of the Technical University of Civil Engineering Bucharest. The obtained results will have a significant contribution to the development of a new technology for capturing wind energy. This consists in the use of small, ducted wind turbines equipped with passive flow control devices, in areas characterized by low aeolian potential.

5. Conclusions
In this paper is presented not only the current situation of the Globally, European, and Romanian energy sector, but also the actual technological development of wind turbines industry. The main purpose of this study was to have an overview on the (r)evolution of wind energy systems, especially in Romania.

An extensive bibliographic study was carried out to present the most important historical stages in the exploitation of wind energy. Also, the most important factors that contributed to directing the attention on the use of renewable energy resources were highlighted.

Data regarding the time evolution of Global and European cumulative installed wind capacity were collected, processed, and presented. The distribution of Global total installed wind capacity by world region and the one of European installed wind capacity by countries for the 2019 year was presented in this work.

Regarding the current wind energy sector in Romania, aspects related to the installed capacity in renewable energy sources and the evolution over time of the installed wind capacity were detailed. Moreover, the factors that contributed to the need to develop constructive solutions capable of efficiently exploiting wind energy in areas with low potential were briefly presented.

In conclusion, it can be said that the focus of our research was to emphasize the fact that an upward increase in the evolution of energy capture and production technology using wind turbines was recorded in the last decades. Given the proposed target for 2030 for European Member States [15÷16], innovative
solutions are still being researched to increase the performance of wind turbines and exploit the wind potential in the most efficient way.

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