Capacity problems and structural paradoxes of the installed wind power plants in Hungary

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Abstract— **Nowadays, there are significant development projects and ideas related to increasing wind power plant efficiency. In Hungary, wind energy capacity increased between 2006 and 2010. The quota was fulfilled at the end of this period, and there weren't any new investments ever since, even though there would be a huge demand for new projects [12, 13].**

A K_F *8760 (hrs/year) variable shows the nominal utilization hours, which is h_n/year (f.e. 8760 x 0,23 = 2018 hrs/year for a P_n performance). According to domestic calculations, the operation of a wind power plant is economically efficient for a nominal performance (P_n) of 2000h_n/year, and the investment returns in 9-10 years with KÁT (feed-in tariff system) subsidy.

The current wind energy capacity is 330MW, which is mainly supplied by modern units, designed for the wind patterns unique to Hungary. Energy production is quite good due to this, namely 740 GWh/year, and the capacity factor of 24.1% is good as well, making our system the 4th best in Europe (based on 2012 data). With this, we save about 220 million m^3 of natural gases every year, and avoid ~400 000 tons of CO_2 emission [15].

It's a fact that wind power plants - after an investment return time of 9-10 years - produce cheap energy. From a financial viewpoint, wind power plant utilization is an investment which has one of the most promising perspectives. Our analysis points out that the ambitious project of Hungary, planned to conclude by 2020 - namely, increasing the utilization of renewable energy - is unlikely to be successful without wind energy utilization.

Keywords— **Wind Power Plant, Wind Energy Capacity, Cost of Wind Energy, Power Plant Lifetime, Rotor Diameter**

I. INTRODUCTION

A) Wind energy in the Word

Wind power plant production is the most dynamically developing industrial branch. Until 2007, Europe was in the lead, overtaken in 2008 by the USA, and in 2009 by China. Now, China installs capacity that equals that of Europe. The estimation of WWEA shows that by the year 2020, the built capacity will amount to the sum of the previous 10 years. This is an investment of 240 million USD/year. Before the end of 2020, 100-800 billion dollars are needed for this investment. This requires a huge producer and developer basis. Hungary can only be a leader in wind energy industry, if we make use of our corporation rate advantage.

In the last few years (until 2013), China made the biggest development [8]. Until 2006, Europe had the leading role in wind power plant production investments. In 2008, the USA, and in 2009, China took over Europe. Since 2011, China has invested more into development of this field than Europe and the US together. The plan of Europe's 27 countries is to triple the capacity until 2020. The trend shows that the plan is feasible [10]. (Illustration 1)

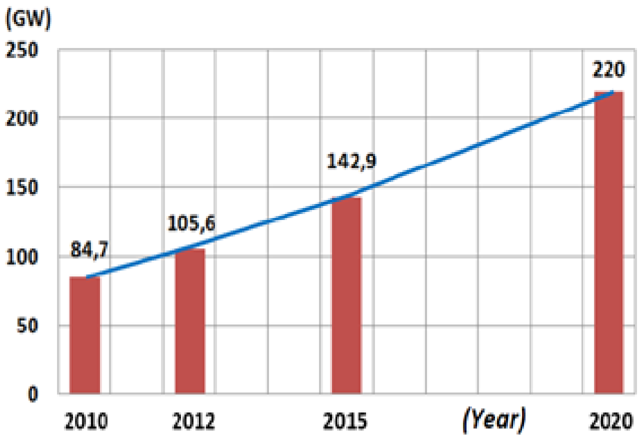

Illustration 1. The plan of Europe's 27 countries [5]

B) Overview of Hungarian development in the field of wind energy

During the period of 1980-1990, wind energy measurements (made on measurement towers) proved that at a height of 100-120m, the circumstances are proper for wind energy utilization in certain areas of Hungary. The first wind measurements made for energetic purposes was done by the experts of Szent István University during 1998-1999, at the Kisalföld area [3,19]. The installation of the first wind power plant was in 2002 at Kulcs (Illustration 2.), in Central Hungary. This wind power plant is an Enercon plant with a performance of 600kW. The height of the tower is 65 m [3, 14, 22]. Its location was chosen according to the measurements of Szent István University (SZIE for short).

In 2005, the new law regarding electricity stated that the government subsides in the frames of the KÁT subsidy (KÁ = subsided interval and T = interval after the payback of loan and subsidy). This subsidy supported the investments to produce a return in 9-11 years. After this, a so called "wind tender" was announced for Hungarian companies (approximately 330 MW).

Illustration 2. The first wind power connected to the Hungarian electricity network (Kulcs, 2002) [19]

II. MATERIALS AND METHODS: FEATURES OF TECHNOGICAL DEVELOPMENT AND CAPACITY GROWTH

According to the high wind measurements implemented (based on the European quality demands [1]), proposals were submitted for the favourable areas and main characters of equipment relevant to wind patterns in Hungary. The results of measurements and evaluated basic data are symbolically shown by the above illustrations. For wind turbine engineering, a great variation in wind speed and/or height can be defined, relative to wind measured at a reference height.

Measurements at two different heights (H_{m1} and H_{m2}):

$$v_{m1} = v_{m2}(H_{m1}|H_{m2})^{\alpha}$$

For any height (H_{mx}):

$$v_{mx} = v_{m2}(v_{mx}|v_{m2})^{\alpha}$$

where:

v_{m1} = velocity [m/s] of the wind at a height of H_{m1} [m]

v_{m2} = velocity [m/s] of the wind at a height of H_{m2} [m]

v_{mx} = velocity [m/s] of the wind at a desired height of H_{mx} [m]

α = Hellman exponent

The measured data of Hellmann exponents (Table 1) in Hungary [3, 12, 14, 20]

TABLE I

Region	Hellmann exponent (α)
High grass and bush	0,18
Agricultural crops and alley	0,25
Agricultural vegetation and forest	0,28
Built up areas and suburbs	0,35
Cities	0,4-0,5

$$P_x = c_{px} \cdot \frac{1}{2} \cdot \rho \cdot A \cdot v_x^3 \quad \text{(kW)}$$

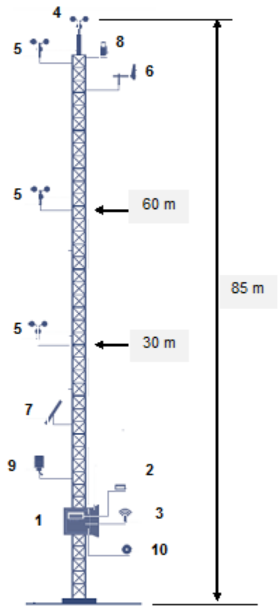

Illustration 3. Hungarian development,

85-100 m tower height

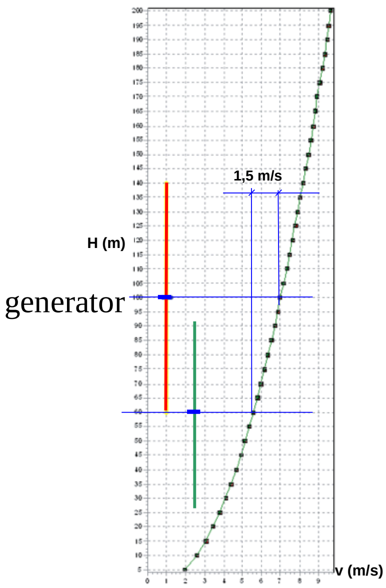

Illustration 4. Data from the measurement system on Figure 1. Wind speed difference 1,5 m/s, 60 and 100 m tower height

1- gauge box, 2- data logger,
3- data transmitter,
4- anemometer (control),
5- anemometer at 30, 60 and 80 m height,
6- wind vane,
7 – energy source (solar cell, PV),
8- light signal,
9- moisture measurement gauge,
10- air pressure measuring gauge.

In Hungary, winds with high energy content blow on 80-200 m, so the tower height is very important. Capacity depends on rotor diameter as well, typically D>100m. Based on these data, the possible future energy production and capacity of equipment were calculated.

Expected biggest capacity (can be W_p as well):

$$P_{\max} = \frac{16}{27} \cdot \frac{1}{2} \cdot \rho \cdot A \cdot v_{\infty}^{3} \quad \text{(kW)}$$

where:
ρ - air density [kg/m^3],
A - examined surface ($D^2\pi/4$) [m^2],
v_∞ - wind speed until control [m/s].

Wind speed is important, see v^3. Before wind power plant installation is concluded, these parameters must be defined (Illustration 3.). The change of **v** can be seen on Illustration 4.
Capacity of any given wind power plant *(P_x)*:

$$P_x = c_{px} \cdot \frac{1}{2} \cdot \rho \cdot A \cdot v_x^3 \quad \text{(kW)}$$

where c_{px} is the capacity factor of given areas, defined with v_{nx} (mean wind speed) values. (c_{px} can be measured with experiments. Wind power plant producers give the P-v, c_p-v diagrams.)
On the cp-v diagram at the highest cp value, the Pn nominal performance can be found. Based on the measured annual energy production (kWh/year) and nominal performance, the utilization number (KF) can be calculated as follows:

$$K_F = \cdot \frac{E}{8760 \cdot P_n}$$

A K_F *8760 (hrs/year) variable shows the nominal utilization hours, which is h_n/year (f.e. 8760 x 0,23 = 2018 hrs/year for a P_n performance). According to domestic calculations, the operation of a wind power plant is economically efficient for a nominal performance (P_n) of 2000h_n/year, and the investment returns in 9-10 years with KÁT subsidy.

III. RESULTS: CURRENT HUNGARIAN SITUATION

Based on previous researches and the wind map drawn, the main data of wind power were selected, by which proposals were submitted for geographical locations of usable wind power, ready to be utilized. According to the wind measurement results, it can be stated that Hungary is a proper place for wind energy utilization [4,22,] (Illustration 5).

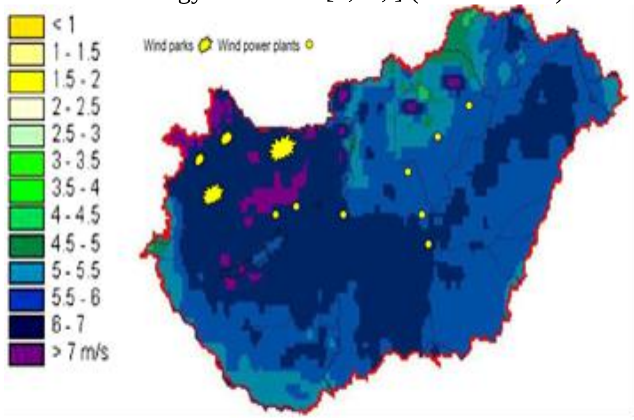

Illustration 5. Hungarian wind map for altitudes of 100-150m, and wind power plants Source: Hungarian Meteorological Service (OMSZ) and Szent István University (SZIE), 2005.

All of the 173 power plants with ~330MW capacity have been built during the period of 2006 – 2010 (see Illustration 6). The owners didn't get any financial support for their investments, but they got support after selling the produced energy (KAT). The Hungarian Electricity System Leader (MAVIR - TSO Hungary) integrated the wind power plants into the Hungarian electricity system. The wind power plants demand an obligatory time table of 15 minute intervals every 24 hours. If the time table is improper, where the difference is +/-60%, they have to pay a fine, but they also have to pay the cost of system control. Regarding these, the entirety of their operation is efficient and economically stable, if they get support.

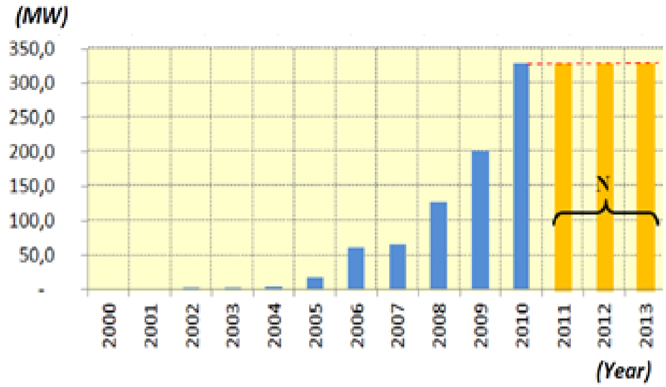

Illustration 6. Trend of Hungarian wind energy capacity [11, 12,13]

(N - Not new installation)

A) The Hungarian wind power park

All the data of built wind power parks are shown in Table-2. All 11 wind power plants are independent, while the other 162 wind power plants were built in parks.

Hungarian Power System and IC (Installed Capacity) of Wind Power Plants [9,18]

TABLE III

WPP data in the Hungarian system	
Maximum generated energy/day	6860,8 MWh
Minimum generated energy/day	5,6 MWh
Pmax gross (based on 15 minute average)	319,5 tMW
Pmin gross (based on 15 minute average)	0 MW
Load factor (annual average)	21,3 %
Smallest wind power unit IC	0,225 MW
Largest wind power unit IC	3 MW
Largest wind power plant farm IC	48 MW
Number of plants	173 Piece
Maximum IC+NTO value of wind power plants	329,3 MW
IC of the Hungarian Power System	**10108MW**
Wind PP generated energy (2012)	**670MWh/a**
P max gross (based on 15 minute average)	**3,26 %**

The Hungarian wind power plants are modern, and they are chosen for the wind patterns unique to Hungary(Illustration 7). Unfortunately, we are not in the lead in wind energy; we are only at the 24th place. 90 % of the Hungarian wind power plants have a tower height of 90-120m, and a performance of 2 MW.

Illustration 7. Wind park built on an agricultural area (2009)

Source: http://www.mszit.hu/uploads/pics/Colombus_windpark_09.JPG

The energy production is 610-700 GWh/year. The utilization factor is 21-24 % (Illustration 8.). At some parks, a value of 23-25 % can be measured. With these data, we can prove the estimations were correct (the nominal utilization hours >2018 h/year - for a P_n performance).

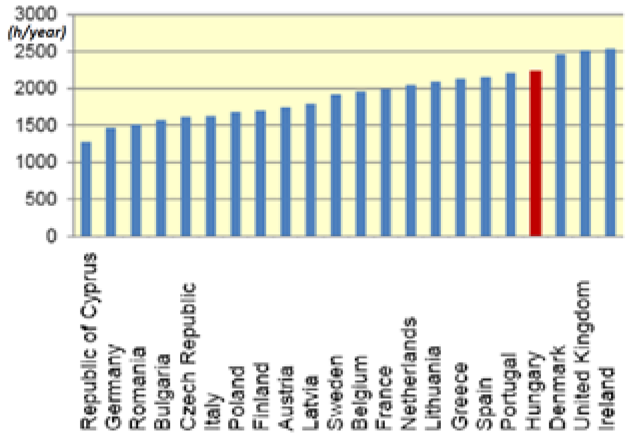

Illustration 8.Utilization of wind power plants (hn/year) of the EU's 27 countries [6]

The Hungarian TSO (MAVIR) demands time tables for both wind power plants built independently, and wind parks respectively. The estimated output should be given the following day for every 15 minutes. If the difference is +/- 60%, the energy producer should pay a fine equal to 15% of the income. The energy producers have studied for the last 4-6 years, to be able to give almost the exact time table, therefore fines were mostly unneeded. The total sum of fines didn't exceed 1,5% of the total income. Illustration 9 shows that the time table does not include considerable differences, the planned and achieved results and data correspond well. Over the above mentioned data, the energy producers should pay system controlling fees, the average level of which is 1,5 – 2,0% of the income.

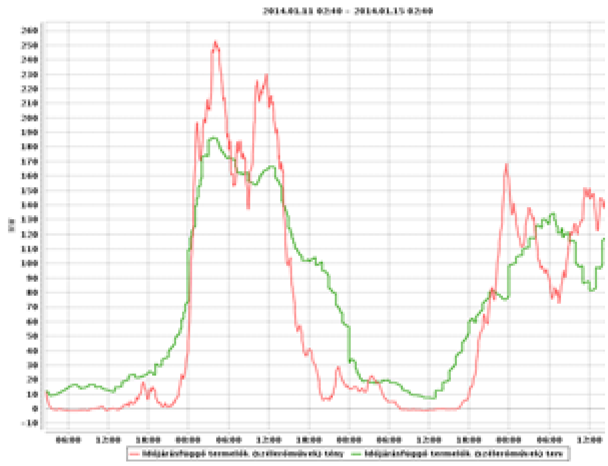

Illustration 9: The given time table for a day (24 hours, green line) and the real production (red line), which shows suitable correspondence in case of 0-80% change in production.

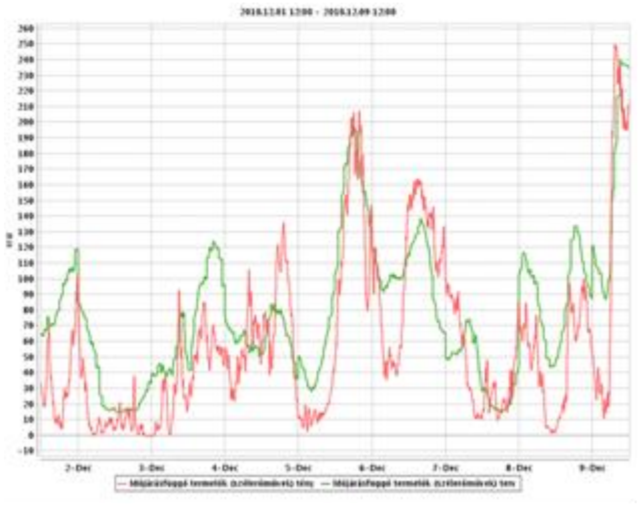

Illustration 10: The time table (green line) and the real production (red line) which shows suitable correspondence in case of 0-85% change in production for an interval of seven days.

In general, the wind parks in themselves result in considerable equalization [2], as seen on Illustration 10. This means that in case of one wind park with a wind power production of 14 MW, the difference during a timeframe of 4 hours can be about 70% of production, but (Σ) all differences of the wind park can only be 35-40% at best (Illustration 11).

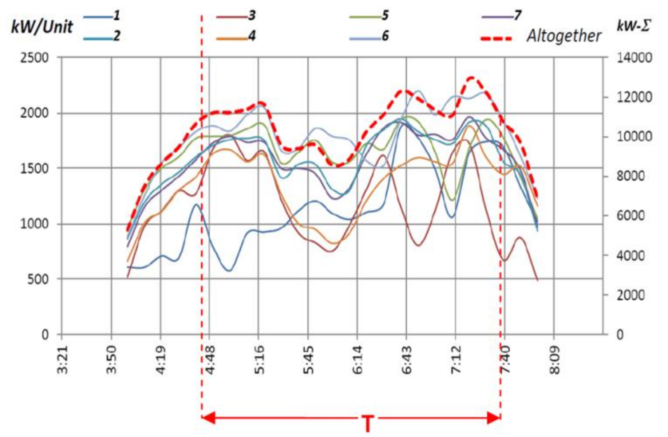

Illustration 11: output changes of machines both summarized and respectively, in case of 14 2MW capacity wind power plants of the wind park for a "T" period of 4 hours.

B) Costs of utilization of the wind power plants

The production costs of the wind power plants have to be defined by their utilization level ever since 2000. The terrestrial types have higher towers and bigger rotor diameters, but the blade angle change (pitch control) is happening faster.

Based on the estimation of IRENA in 2012, apart from the cost of machines' investments, the price of energy is basically determined by the construction characters of machines, and usage conditions of wind speed (see Illustration 12). Naturally, return burdens dependent on the system leader also has an influence on the energy production, which appears in capacity condition. In Hungary, the system leader (TSO Hungary) does not use the return burdens of wind power.

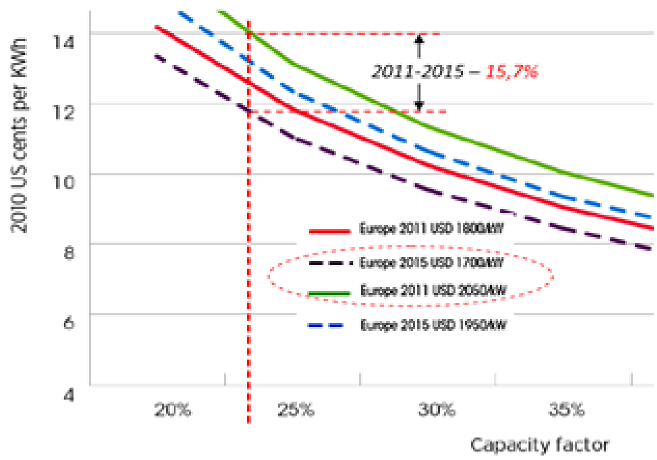

Illustration 12: The energy cost of wind power plants, and the utilization of the estimated price of investment (development for years 2011-2015) [10]

C) Production cost during life cycle

The price of electricity is changing, because of cheap surplus energy, and this may cause differences in stock prices. The power plants where the investments returned, have only low external costs. *For an example, let's check the costs long-term.* Such an example can be seen on Illustration 13. After the installation of the plant, the costs are typed (KÁT interval). The maintenance, repair and other costs don't amount to 25-30 % of overall costs, but they are 15-20% bigger than the market price of electricity (PA). At the interval of return, the wind power plant gains subsidy, in case of an interval with a minimum of 8-10 years.

The energy production costs are 25-30% smaller at ŐK1 and ŐK2. It rises because of f.e. higher maintenance costs. At T, the difference between average wind energy price and costs is bigger than the subsidies. *In case of governmental investments, the profit is also governmental*. In Germany, the price of wind energy will be lower than the estimated price of market electricity in 2015-2016. The power plants which were built before 2006 returned the investments.

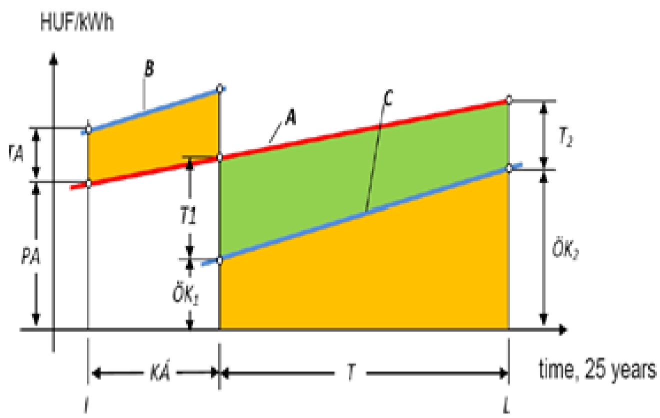

Illustration 13. Costs of electricity during wind power plant lifetime [12,13]

Abbreviations:

PA = market price of electricity
TA = governmental subsidy (KÁT, or METÁR)
A = trend of electricity price
B = trend of subsidies
I-L = lifetime of equipment = KÁ + T
KÁ = subsided interval
T =interval after the return of loan and subsidy
ÖK1 =costs of wind energy production (utilization, repair, control costs) after KÁT
T1 = the difference of electricity price and wind energy production costs after KÁT
C = trend of electricity production (increasing utilization, repair and maintenance cost)
ÖK2 = costs of wind energy production (at dismantlement of the plant).
T2 = costs of wind energy production (utilization, repair, control costs) at dismantlement of the plant
T1 , T2 , A and C area= society's gains (min.3-4KÁT investment)

After the return of investments and capital costs of wind energies, the cost of the electric energy production will be equal to production costs of other power stations, or the market price of networks (see Illustration 14.)

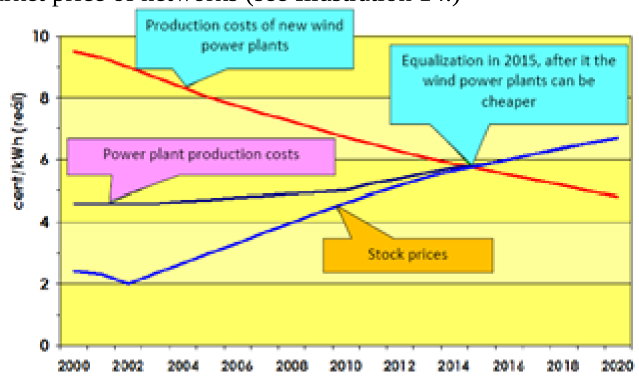

Illustration 14. Estimated price of electricity produced by wind power plants.

Source: [13], et al.

In Hungary, the control price in 2011-2012 was 0.8-1.5 HUF/kWh. These costs do not influence the production costs. It is important to state that the control of the electricity network can be done with capacities bigger than the current as well. The utilization level of the **COGAS** plant in Gönyű (460 MW) was 6 % since it is in operation a single time. The plant capacity of Hungary is approx. 9000 MW, the maximum consumption is approx. 6000-6500 MW. Annually, we use 1000-1500 MW import energy. It is not true that the existing 330 MW wind energy capacity, or 3-4 times bigger than that would cause unsolvable problems in control [17,].

In Hungary the government does not invest direct stock in the wind energy installation, only the KÁT subsidy. The KÁT subsidy returns short term. With the usage of wind energy, the fossil fuel dependency of the country is decreasing, and income rises from selling CO_2. The lifetime of the modern wind power plants is 20 years, but it can reach 25 years with care. In the future, the energy produced by wind power plants will be cheaper than the energy produced by carbon plants or gas plants. The technological advancement, and the increasing value of fuel prices cannot be neglected. Basically, if the investment returns in approximately 10 years with subsidies, the price of electricity decreases to 8-10 HUF/kWh. The KAT price in 2013 was 33 HUF/kWh. There is no cheaper energy source, and the plants produce it for an additional 10 years, maybe 20 years [9].

D) Fundamental numbers of National Action Plan (Nemzeti Cselekvési Terv, 2020)

According to NAP (NCST), 740 MW wind energy capacity should be reached until 2020. This means that an additional 410 MW capacity worth of plants must be built. (See Illustration 8.) In 2009, a tender was announced, and companies competed for 1100 MW. The tender was not announced properly, so the quotas were not distributed. New capacities can be built as soon as 2015. Reaching the 740 MW (750 MW??) can only succeed if new plants are built progressively.

The wind power investments did not get subsidies. Investment rate and opportunity is sufficient; three years ago, 1000-1200 MW additional capacity could've been established. If we would like to reach the capacity defined in the NAP (NCST), than we need to build an additional 900-1000 MW capacity worth of plants. With this, by the end of 2020, 1300 MW capacity worth of plants would operate. Of course, the investors will only invest, if they see their investment as a good one, which offers return [12, 13, 15]. Wind energy - much like other alternative energy sources - need network equalization. All wind parks have a big network equalization effect.

IV. CONCLUSIONS

The current wind energy capacity is 330MW, built of modern units, which are designed for the Hungarian wind patterns. Because of this, energy production is sufficient, namely 740 GWh/year, and the capacity factor of 24.1% is good as well, which was the 4th best of Europe in 2012. With this, we save about 220 million m3/year's worth of natural gas, and we avoid ~400 000 tons of CO2 emission.

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