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# SIMULATING THE ELECTRIC YIELD OF WIND FARMS – A SHORT INTRODUCTION INTO HOW TO DEVELOPE WIND PROJECTS SUPPORTED BY AN EXCEL BASED PROGRAM CODE

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**Abstract**

*Amongst the Renewable Energy Sources (RES) contributing to the worldwide electricity production, wind energy became very important. Germany and Turkey own significant wind potentials. 2% of a country's area can be used for wind farms, thus Germany could produce up to 200 TWhel yearly just onshore. However, often legal and especially financial aspects decide about the speed of development. Careful project preparation guaranteed by professional management is obligatory. Beside rights to the property and electric grid connection the suffiency of the wind and peripheral conditions need to be known. A proper wind forecast and yield prognosis are important items. To solve these tasks, professional but often expensive programs are sold on the market. To offer a convenient alternative, authors will present software based on Excel named WindCalc 1.5 which is still under development.*
*Keywords: Wind energy, wind farm planning, yield prognosis, simulation.*
**Keywords:** Wind energy, wind farms, planning, production forecasting, simulation

# RÜZGÂR ÇİFTLİKLERİNİN ELEKTRİK ALAN SIMÜLASYONU – EXCEL TABANLI PROGRAM KODU İLE NASIL DESTEKLENEN RÜZGÂR PROJELERİ GELİŞTİRİLEBİLİR HAKKINDA KISA BİR GİRİŞ

**Özet**

*Dünyada elektrik üretimine katkısı olan yenilenebilir Enerji Kaynakları (YEK)'nın arasında rüzgâr enerjisi çok önemli bir yer tutmaktadır. Almanya ve Türkiye önemli rüzgâr potansiyeline sahip ülkeler arasındadır. Bir ülkenin yüzölçümünün % 2'si rüzgâr çiftlikleri olarak kullanılabilmektedir, böylece Almanya sadece karasal (onshore) olmak üzere yıllık 200 TWhel'e kadar üretim gerçekleştirebilir. Buna karşın, yasal ve özellikle finansal yönler gelişmenin hızını belirlemektedir. Profesyonel bir kurum tarafından garanti altına alınarak hazırlanan ciddi projeler gerek duyulmaktadır. Rüzgâr çiftliğine sahip olma ve elektrik şebekesine bağlantı gibi yasal hakların yanı sıra rüzgârın yeterliliği ve sınır şartlarının bilinmesi gerekmektedir. Uygun bir rüzgâr tahmini ve üretim miktarlarının bilinmesi önemlidir. Piyasada bu sorunları çözmek üzere profesyonel fakat genellikle pahalı programlar bulunmaktadır. Bu çalışmada uygun bir alternatif olarak Excel tabanlı WindCalc 1,5 isimli hala geliştirilme aşamasında olan bir yazılım sunulmaktadır.*
**Anahtar Kelimeler:** Rüzgâr enerjisi, rüzgar çiftliği, planlama, üretim tahmini, simülasyon

## 1 Introduction

Within the last decades, a significant growing of the wind energy branch had been observed. Whereas amongst the Renewable Energy Sources (RES) still the hydropower rules, contributing around 20% of the worldwide electricity production, starting from the early 90s wind energy became the second important RES technology after the hydropower. However, at the end of 2014 Germany operated wind fields with a total capacity of 38.1 GWel onshore and 1.0 GWel offshore [1]. Thus, the potential of yearly electricity production can be estimated to 50-80 TWhel at the end of 2014, which might be enough to cover nearly 10% of the annual electricity net consumption in Germany. In 2012, according to the German Ministry for Environment, onshore/offshore 49.9/0.72 TWhel were produced [2].

Around 2000, Germany reached the point of equivalence at 4 GWel with Denmark, traditionally the wind energy pioneer. Within the following years Spain came up to be one of the first European nations, later than firstly USA and finally China won the leadership in the market. The entire installed capacity amounted to 369.6 GWel worldwide in 2014 [3]. However, since 2010 the Turkey passed the magical 1-GWel-border [4].

For Germany, today serious estimations including (i) expanding the onshore installation, (ii) repowering old onshore wind farms by modern systems, and (iii) further developing the offshore area show that it might be feasible to develop the wind energy in Germany to contribute finally up to 30-40% of the national net electricity demand. For comparison, at the end of 2011 Turkey operated an installed wind capacity of nearly 1.7 GWel aiming at 5 GWel in 2015 and under optimistic assumptions maybe more than 20 GWel in 2025 [4].

## 2 General Assumptions to Set-Up A Wind Farm

The following paragraphs are using internal information from planners and the common German literature [5-7]. Usually, 2% of a country's area can be used to install wind farms, if respecting technical, environmental and other limitations. Thus, according to typical technical rules,

- under an anisotrop wind regime, the distance between two wind turbines ranges between 2 and 10 times the rotor diameter,
- in isotrop wind regimes around 5 to 6 times.

Taking 5 times the rotor diameter as distance between two single turbines in an hexagon-shaped field into account,

- in a wind farm consisting of Enercon E-82 (typ 2000) wind turbines,
  - o each wind turbine occupies in its hexagon nearly 150,000 m2 of land and has 5,182 m2 of rotor surface area.

At 14 m/s wind speed, the E-82 (2000) wind turbine reaches its rated power of 2,050 kWel. Talking German onshore wind regimes at 138 m hub elevation into account,

- with around 2,000 full-load hours such a system may produce
  - o 4,100,000 kWhel gros as a single system.

As a compartiment of a wind farm, due to negative interference effects depending on the circumstances, the total yield may reach

- 85 to 95% of it.

With respect to periods of operation (technical availability) and periods out of operation, under German conditions, such wind turbines usually are

- 85+/-5% of the annual 8,760 hours in operation,
  - o with a technical availability of up to 99/100,
- only 1-2/100 they are not available because being out of order due to
  - o real technical defects or
  - o immaginary (= measured, but unreal) malfunction messages.

The restal times of non-operation of the machines are related to

- cut-off due to
  - o low-wind or
  - o storm plus
  - o maintenance services.

> As a joke, in former times some were heard being saying: “The observations that wind energy technology is insufficient because the systems always are out of order and standing still are (i) surely not related to technical problems between rotor and electrical grid, that is clear, but (ii) maybe related to medical troubles allocated between the observers’ eyes and their ears.”

Taking all these assumptions into account, applying the 2 MWel class systems in Germany, the annual yield may reach

- Around 790 kWhel per m2 of rotor area

And, which is much more interesting,

- 27 kWhel per m2 of land occupied by the wind farm (however, occupied means agriculture still is feasible).

As a conclusion, under this conditions in Germany with total area of 357,000 km2, under this optimized conditions maybe up to 200 TWhel per year could be produced using wind energy just onshore in Germany. For comparison, Turkey has a total area of 815,000 km2 but in average lower wind speed thus estimated ¼ to ½ of the specific yield estimated for Germany. Nevertheless, this results in specific yields of 7-14 kWhel per m2 of used landscape or totally in 110-230 TWhel on 2% of the country’s area. According to Ata (2013), after estimations of the OECD Turkey theoretically has 166 TWhel a year of wind potential [4].

## 3 Project Management – Financial and Legal Aspects

The technical side to develop a RES electricity technology such as wind power is one thing, but finally legal and last but not least financial aspects usually are the most important factors. However, whereas this work is mainly related to technical set-up and simulation of yields, nevertheless the project management aspect should be discussed here briefly, as well.

To implement and further develop innovative technologies such as electricity from RES techniques, (i) sufficient funding systems and (ii) a proper legal background are needed.

### 3.1 Financial Aspects and the Project Management

Firstly, in order to stimulate price-learn effects and to shrink the energy production costs, the way of funding is an important presupposition:

Thus, e.g. Germany invented finally after finallizing inefficient legal tools from the 90ies in 2000 the “Renewable Energy Sources Act” (EEG: Gesetz zum Vorrang der Erneuerbaren Energien) in the field of the electricity market, which became very successful [8]. The model is based on an allocation means cost-sharing model but not on subsidy: all consumers share the additive costs for RES electricity while the RES operators get payed for their services on a additive-cost neutral level. Neither taxes nor the government are envolved. There are guaranteed fees by the EEG changing in time. The fees consist of a base tariff plus specific additives (boni). For instance, according to this initiation and the stimulated progress, one kWhel of electricity from modern onshore wind-farms is paid by means of the EEG today with approximately 7-9 Euro Cent, the net production costs without interest but payback, maintenance and other operation costs may reach 4-6 Euro Cent per kWhel. Thus, until last years it was a good deal to implement wind farms, money was collected from investors to be returned with up to 8% interest yearly. However, since new policy came up in Germany, situation become more difficult for investors and operators due to changes of the EEG.

### 3.2 Legal Aspects and the Project Management

The second item is the legal part (the legal background for funding was explained above) including all the project-management stuff [9]:

Whereas the engineers often think, if a system runs with high reliability, everything is fine, often the truth is, if the financial background or the project management are insufficient, a wind farm may fail whereas from the technical view everything seemed to be OK.

Usually such projects consist of e.g. seven phases, (i) initiation of the project idea, (ii) pre-investigations to select and verify the field, (iii) establishing all rights and grid connectivity, simultaneously in foreign countries (iii-a) getting in touch with local firms and/or authorities, (iv) getting permissions, starting intensified data acquisition plus optially measurement and public relation work, (v) construction of streets for transport, earthworks and fundament construction, (vi) set-up and execution of the construction work plus finalizing and (vii) taking the system into operation.

Taken from the view of the planner, according to the German HOAI (Honorarordnung für Architekten und Ingenieure) the planning process consists of 7 phases, thus (i) basic evaluation, (ii) preliminary planning, (iii) blueprint planning, (iv) approval planning, (v) execution planning, (vi) preparation of public tender, (vii) assisting the public tender, (viii) assisting the execution work, and (ix) assisting the acceptance of work and final documentation [10]. During all phases, the financial controlling is obligated to the planner.

However, anywhere in the meantime investors must be found simultaneously. After set-up operating the field, there is a period of operation including technical maintenance plus financial and other management until the time of utilization ends, followed by the end of the life-cycle maybe by recycling the devices and landscape.

The priority list of the “what to be done first, what to be done next” in fact can be explained as a triangle R—E—W, with the baseline of R—E topped by the W:

- R: Rights to the poperty, such as:
- ➢ Owning the land by
    - ▪ Acquisition,
    - ▪ rent or
    - ▪ leasehold of the ground
- ➢ Land servitude for
    - ▪ right of ways and laying of cables
- E: Electric grid connection
- ➢ Allocation of the grid connection gate and
- ➢ capacity limits
- W: Wind and periphery
- ➢ Wind speed and other climatic properties
- ➢ Public relations to
    - ▪ community and municipality
- ➢ Permissions

In terms of executing the project management, beside the (i) getting the rights due to the property, (ii) getting the needed permissions is an important item. From the legal view, under German legislation (big) wind energy turbines cannot be constructed within settlements but are exclusively permitted in rural land if some competiting rights stay untouched. Relevant regulations related to wind systems are (i) federal and local building laws and ordinances, (ii) immision laws and ordinances, (iii) environmental laws and regulations and (iv) others. Furthermore, there are technical requirement to protect energy supply infrastructure, energy availability and public health and security. However, in terms of permission planning often the threat to the environment and/or public health and security is in the focus of interest. Sometimes in some countries (i) an ecological audit and/or (ii) a grid-compatibility study is required.

## 4 First Planning Steps To Start A Wind Project

While working on the topics of R—E baseline often discretion better has to be recommended, also in the beginning of the work phase on the topping W – as long nobody goes to fieldwork, it is often seen as being better not to dissiminate news to early (i) to prevent negative publicity, neither (ii) to loose the public acceptance nor (ii) to disbalance the local prices. However, project leaders for RES are maybe sometimes but often not followers of the Mammon. Simply, to act unclever also maybe diminish the chances and development of all the Renewable Energy Sources in the region for long time.

### 4.1 Analyzing the Land Utilization and the Wind Properties

The aim of this work period is to collect data and information from various personal, analog or digital sources plus by investigating the field in order to collect (i) maps or GIS underlayersand information about the field, (ii) to extract informations about restricted areas finally to evaluate areas of permission, (iii) to evaluate existing rights on the properties finally to evaluate opportunities finalized by signing contracts, and (iv) to evaluate the local wind potential in order to generate attractively for investors without provoking the public and getting priliminary information up to first yield prognosis (final electric yield forecast).

As mentioned before, works have to be executed in an adequate way with respect to the needs of discretion in order to protect e,g. the public sensibility.

Analyzing areas, usually the following items, facts or materials can be checked and materials can be resulted:

1. Analog or digital maps or GIS ground-layers.
2. Overlayers for maps etc. mentioned under (1) with areas restricted by:
    a. Environmental protection
    b. Residential areas, settlements, mixed areas
    c. Zones of protected infrastructure, such as:
        i. Streets
        ii. Airports
        iii. Railways
        iv. High-voltage lines
        v. Others
3. Property rights
4. Wind potential in form of wind speed distribution or mean datas, wind direction etc.
    a. Weather forecast service authorities (long-term statistics)
    b. Regional and European wind atlas
    c. Wind simulation programs
        i. WindPRO 2.9 (EMD) [11]
        ii. WindCalc 1.5 (authors)
        iii. Others
    d. On-site-measurement surveys
    e. Expertise without measurement

## 5 Wind Basics and Wind-Turbine Yield Simulation

This chapter is foreseen firstly to give basic information on how wind regimes work and especially how electric yields generated from them can be predicted, and secondly, how to manage computional simulation, comparing (briefly) professional but often too expensive software tools with a simple but forceful new EXCEL based program code named as WindCalc 1.5.

### 5.1 Basics on Wind Performance – Input to the Simulation Models

In order simulate electric yield from wind energy systems, due the compatibility of the input some transformations are needed. As well, some background theory is needed [12], [13]:

Wind often is measured close to surface, standardized 10 m above the ground. If measurements had been taken at higher levels, it will be remarked in wins speed maps or data will be reduced on a reference level. Long-term observations result in statistical averages. This data are fundament of the calculation.

First point of interest is the long-term average of the wind speed at reference level in order to obtain a statistical distribution in hub elevation. There are three steps to obtain this:

1. Evaluation of data and calculation of long-term ground wind-speed average
   a. Data can be collected or measured
2. Height correction and evaluation of long-term hub wind-speed average which must be expected
   a. The height formula is one opportunity to simulate the wind speed profile, thus minimum the roughness z0 as function of the landscape type is required
3. Calculation of the wind-speed distribution by Weibull or Rayleigh theory
   a. In terms of Weibull theory the so-called shape factor is needed, a property of the landscape type and altitude

To complete the technical calculation, machine parameters and mechanical calculations finally are needed. In order to prepare a wind field, also further information due to air temperature, air pressure and humidity functions during the season will be collected and evaluated. To solve the question how to adjust the wind-farm shape, further investigations and evaluation on the direction distribution will be done (wind-rose). However, this can be respected later to estimate the farm factor.

Formula (1) shows the height formula to calculate wind-speed average in hub elevation according to a logarithmic model, formula (2) is the Hellmann formula.

Height formula

$$v_2 = v_1 \frac{\ln\left(\frac{h_2 - d}{z_0}\right)}{\ln\left(\frac{h_1 - d}{z_0}\right)} \qquad (1)$$

with

$v_2$: Wind speed on the upper level h2 (e.g. hub) (in m/s)

$v_1$: Wind speed on the lower level h1 (e.g. measurement) (in m/s)

$z_0$: Roughness (in m)

d: Shift

Hellmann formula

$$v_2 = v_1 \left(\frac{h_2}{h_1}\right) \qquad (2)$$

with

$v_2$: Wind speed on the upper level h2 (e.g. hub) (in m/s)

$v_1$: Wind speed on the lower level h1 (e.g. measurement) (in m/s)

α: Hellmann exponent (---); starting α = 0.14

In table 1 the landscape types, roughness factors z0 and other properties can be found. Figure 1 compares results of mast-based long-term anemometer measurements in different levels with the calculation according to formula (1) and (2).

Table 1. Landscape types, roughness and other properties [12] [13]

| Class of Roughness | Roughness z0 (m) | Energy Index | Typ of Landscape |
|---|---|---|---|
| 0 | 0.0002 | 100 | Ocean |
| 0.5 | 0.0024 | 73 | Flat land, Greenland, coastal land |
| 1 | 0.03 | 52 | Open agricultural land |
| 1.5 | 0.055 | 45 | Wide agricultural land |
| 2 | 0.1 | 39 | Medium agricultural land |
| 2.5 | 0.2 | 31 | Narrow agricultural land |
| 3 | 0.4 | 24 | Settlements, forest etc. |
| 3.5 | 0.6 | 18 | Cities with high buildings |
| 4 | 1.6 | 13 | Big cities |

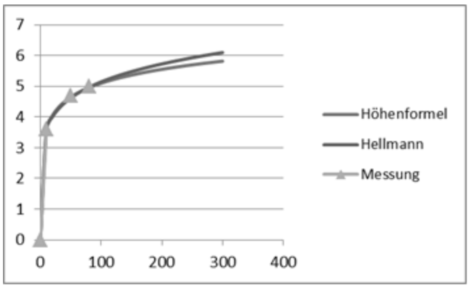



Figure 1. Comparing measurement data and calculation (height and Hellmann formula)

Formula (3) shows the from the statistics the Rayleigh distribution, formula (4) shows the mother fubnction, the Weibull distribution. If the shape factor of Weibull is set =2, it results in the simplified so-called Rayleigh distribution.

Rayleigh distribution

$$f(v_i) = \frac{\pi}{2}\frac{v_i}{v_m^2} e^{-\frac{\pi}{4}(\frac{v_i}{v_m})^2} \qquad (3)$$

Weibull distribution

$$f(v_i) = \frac{C}{A}\left(\frac{v_i}{A}\right)^{C-1} e^{-(\frac{v_i}{A})^C} \qquad (4)$$

with

C: Shape factor = form factor (---)

A: Scale factor (m/s)

$$A = (2/\sqrt{\pi}) * V_m$$

Figure 2 (a) shows an example of a Rayleigh distribution of the wind-speed at 100 m a.s.l. in the nearshore in Germany (Northern Sea), calculated with EXCEL

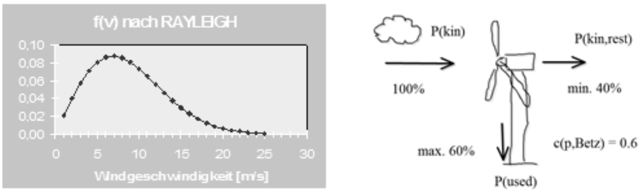



Figure 2. (a) Example of Rayleigh distribution of wind-speed, (b) Scheme of the ideal energy flow at the hub

Figure 2 (b) shows idealized energy flow scheme at the hub of a wind energy turbine. In the early 20th century Albert Betz postulated the so-called Betz-theorem which defines the maximum efficiency of an aerodynamic updraft system (Albert Betz in 1923) not to exceed 0.5926.

The formulas (5) and (6) explain the flow of kinetic energy in the wind, the extractable electric power respecting technical efficiencies and finally the total yield (refer to Figure 2 (b).

Physics of the wind and the machinery

$$P_{el}(v_i) = 0.5 c_{p,anl}(v_i) A \rho v_i^3 \tag{5}$$

$$W_{el,a} = \sum_{i=1}^{n} (P_{el}[v_i] t[v_i]) = \sum_{i=1}^{n} \left(0.5 c_{p,anl}[v_i] A \rho v_i^3 t[v_i]\right) \tag{6}$$

with

$E_{kin} = 0.5 * m * v^2 \mid d/dt$

$dE_{kin}/dt = P_{kin} = 0.5 * dm/dt * v^2$

$V = A * x \mid d/dt$

$dV/dt = A * v$

$m = V * \rho \mid d/dt$

$dm/dt = dV/dt * \rho = A * \rho * v$

$P_{kin} = 0.5 * dm/dt * v^2$

$P_{kin} = 0.5 * A * \rho * v^3$

$P_{el} = 0.5 [c_{p,Betz} * \Pi_j \eta_j] * A * \rho * v^3$

$c_{p,anl} = c_{p,Betz} * \Pi_j \eta_j = c_{p,Betz} * \eta_{rotor} * \eta_{bearing} * \eta_{gearbox} * \eta_{generator}$

### 5.2 Numerical Simulation with WindCalc 1.5 – Forecasting the Yearly Electrical Yield

The Excel based program code WindCalc had been established as an alternative calculation tool to professional simulation programs such as WindPRO. Their advantage is to cover several of the needs of professional work in the field of developing wind farm project often on high level, so noise immission and shading analysis, computational flow simulation and so on. On the other, in the field of science and education often such tools simply are too expensive to be applied.

The WindCalc is still under development and does not yet include modules such as (i) economic analysis, (ii) ecological footprint or (iii) noise analysis. However, external modules are under development in the moment to be included in upcoming versions. The program is still not distributed, neither commercially nor as free-ware. WindCalc 1.5 is executing technical calculation routines in order to forecast annual average yields from wind farms. Several test calculations for running systems proved that WindCalc 1.5 works quite well and reliable to provide data input for the economic calculations. It consists of (i) free programmable data base with selection mode, (ii) input data overview, (iii) machine parameters overview, (iv) power calculation, (v) wind farm parameters, (vi) location parameters, (vii) hight correction, (viii) statistic calculation, (ix) yield calculation, and (x) summary of results.

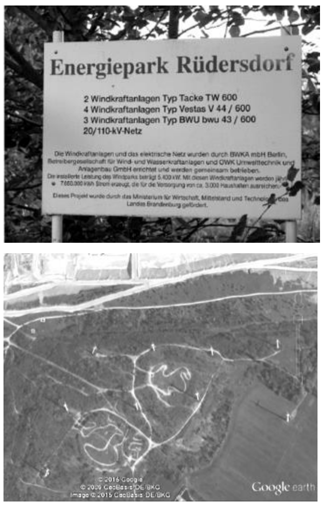
### 5.3 Case Study with WindCalc 1.5 – Repowering a Wind Farm Closed to Berlin

This paragraph is to show how to apply WindCalc 1.5 on a real case: Rüdersdorf is a small town in Germany, approximately 40 km east of the city center of Berlin. Traditionally, this a pit mining area for limestones and marls in order to produce cement. On a former mining dump area beside the pit mining, in the middle of the 90ies – five years after the German re-unification – nine wind turbines of the 600 kWel scale had been installed as a pioneer project. Nowadays, the machinery is 20 years old. Old, inefficient and noisy technology – it could be replaced nowadays by new, efficient, big scale and less hectic/ noisy systems. According to the recently needed investment, the maintenance costs and guaranteed fees from EEG – this could be a feasible deal, making it better for everyone. However, from the view of the local authorities, instead of the nine small systems just one new would be permitted – what a challange.

However, the questions of the project managers will be:

1. Will it be possible to produce the same amount of electricity just with one plant instead of nine before?
2. Will it be economicly feasible and attractive for investors to execute this project?
3. We do not know, who will do (either politicians, investors, or somebody else) but one may ask: Will it be ecologically senseful to do this? – (we cannot answer this question now using these tools, unfortunately).

Figure 3 (a) shows the Google earth view on the Rüdersdorf wind farm. Figure 3 (b) explains technical details of the field: the number of wind turbines and their producers and types, the installed capacity, annual yields to be expected and further details.




(a)

(b)

Figure 3. (a) Rüdersdorf wind farm near Berlin, (b) Information plate close to the wind farm (from 90s; Photo M. Sohn)

As far the task is clear now, simulation should show how to answer question 1:

One plus x scenarios are to be simulated, first is the data feedback from the existing situation – to be compared with the external results (compare Figure 3(b)). The simulations x are different technical solutions reflecting the task from question 1.

The existing situation (scenario "reference") had been calculated using the Tacke TW600 as reference of all nine machines. Different alternative scenarios had been tested using data from the German wind turbine producer Enercon and its products and services (however, the authors do not prefer any producer, this is just an example):

- Download page: http://www.enercon.de/en-en/88.htm
- Product catalogue: http://www.enercon.de/p/downloads/ENERCON_Produkt_en_06_2015.pdf

Three new, alternative scenarios may be presented here, (a) two turbines type Enercon E-82 E2, (b) one turbine type Enercon E-101, and (c) one turbine type Enercon E-126 EP4.

Table 2 shows the input data sets for the reference and the three alternative scenarios. The cut-in and cut-out wind speed had been fixed for the calculation.

Table 2. Input data of reference (R) and three tested scenarious (A, B and C)

| | Unit | Scenario R | Scenario A | Scenario B | Scenario C |
|---|---|---|---|---|---|
| Producer | ---- | Tacke | Enercon | Enercon | Enercon |
| Type | ---- | TW 600 | E-82 E2 | E-101 | E-126 EP4 |
| Rated Power (at NWS) | kWel | 600 | 2,050 | 3,050 | 4,200 |
| Nominal Wind Speed (NWS) | m/s | 14 | 13 | 13 | 14 |
| Power Coefficient (at NWS) | ---- | 0.212 | 0.290 | 0.283 | 0.200 |
| Cut-in Wind Speed | m/s | 3 | 3 | 3 | 3 |
| Cut-out Wind Speed | m/s | 20 | 25 | 25 | 25 |
| Rotor Diameter | m | 46 | 82 | 101 | 127 |
| Rotor Area | m2 | 1,661 | 5,281 | 8,012 | 12,668 |
| Hub Height | m | 52 | 138 | 135 | 135 |
| List of Power Coefficients | ---- | Catalog Copy | Internet Catalog | Internet Catalog | Internet Catalog |
| Air Density (Reference Air) | kg/m3 | 1.225 | 1.225 | 1.225 | 1.225 |
| Air Pressure (Reference Air) | Pa | 1.013*105 | 1.013*105 | 1.013*105 | 1.013*105 |
| Number of Turbines | ---- | 9 | 2 | 1 | 1 |
| Technical Availability | ---- | 0.96 | 0.99 | 0.99 | 0.99 |
| Wind Farm Factor | ---- | 0.95 | 0.98 | 1.00 | 1.00 |
| Roughness of the Ground | m | 0.25 | 0.25 | 0.25 | 0.25 |
| Shift | m | 0.0 | 0.0 | 0.0 | 0.0 |
| Hellmann Exponent | ---- | 0.22 | 0.21 | 0.21 | |
| Weibull Shape Factor | ---- | 2.0 | 2.0 | 2.0 | 2.0 |

Table 3 shows the results for the reference and the three alternative scenarios.

Table 3. Output data from simulation with WindCalc 1.5 of reference and three scenarious

| | Symbol | Unit | Scenario R | Scenario A | Scenario B | Scenario C |
|---|---|---|---|---|---|---|
| Producer | ---- | ---- | Tacke | Enercon | Enercon | Enercon |
| Type | ---- | ---- | TW 600 | E-82 E2 | E-101 | E-126 EP4 |
| Rated Power (at NWS) | Pel | kWel | 600 | 2,050 | 3,050 | 4,200 |
| Rotor Diameter | dR | m | 46 | 82 | 101 | 127 |
| Hub Height | hh | m | 52 | 138 | 135 | 135 |
| Number of Turbines | N | ---- | 9 | 2 | 1 | 1 |
| Technical Availability | ζTA | ---- | 0.96 | 0.99 | 0.99 | 0.99 |
| Wind Farm Factor | ζWF | ---- | 0.95 | 0.98 | 1.00 | 1.00 |
| Annual Electrical Yield (1 WET) | Wel,a | kWhel/a | 929,653 | 5,206,435 | 7,736,444 | 10,827,538 |
| Annual Full-load Hours (max.) | tb,a | h/a | 8,720 | 8,731 | 8,731 | 8,731 |
| Annual Full-load Hours (1 WET) | bv,a | h/a | 1,549 | 2,540 | 2,537 | 2,578 |
| Annual Electrical Yield (WF) | Wel,a | kWhel/a | 7,630,588 | 10,102,567 | 7,659,079 | 10,719,263 |
| Annual Full-load Hours (WF) | bv,a | h/a | 1,413 | 2,464 | 2,511 | 2,552 |

## 6 Conclusions

This paper had been targeted (i) to report about development and state of the art of the wind energy to contribute clean electricity for the future, (ii) to show the importance to support and develop the application while there are significant potentials in several countries, (iii) to demonstrate that wind energy is an environmentally friendly and clean technology (iv) to provide a certain portion of the domestic electricity for a feasible price.

On one hand, in countries such as Germany during the last decades wind energy grew fast and properly to contribute nowadays around 10% of the net electricity consumption. On the other hand, still mainly the coal power contributes nearly 45% of the national CO2 emission in Germany, around 360 Mill. tons per year from power plants in 2012 [14].

Germany and Turkey own significant wind potentials. 2% of a country's area can be used for wind farms, thus Germany could produce up to 200 TWhel yearly just onshore. However, often legal and especially financial aspects decide about the speed of development. Careful project preparation guaranteed by professional management is obligatory. Beside (i) rights to the property and (ii) electric grid connection, (iii) the suffiency of the wind plus peripheral conditions need be known. A proper wind forecast and yield prognosis are important items.

To solve these tasks, professional but often expensive programs are sold on the market, such as the windPRO 2.9 issued by the Danish EMD. To offer a convenient alternative for students and researchers as well as project developers, authors presented the software based on Excel named as WindCalc 1.5 which is still under development. As an object of investigation, the wind farm Rüdersdorf near Berlin had been examined. Task was to investigate whether (i) the 20 years old field can be repowered by modern technology, under the limitation (ii) that the nine wind turbines to replace only by one new system, (iii) taking into account the same electric yield. It could be shown, that the tool can be sufficient to solve such technical questions in a quick and financially convenient way (see Figure 4).

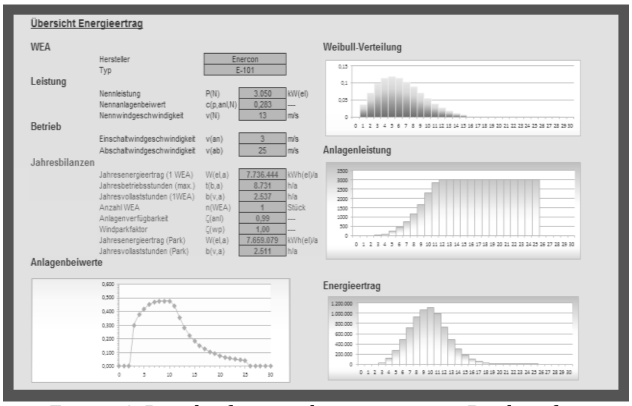



Figure 4. Results for simulation scenario B taken from WindCalc 1.5 (repowering of the Rüdersdorf wind farm)

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