Renewable and Alternative Energies

Topic 1. Wind energy case study

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Description:

This is a case study for the development of a small wind farm:

- Wind farm with **10 MW** installed power.
- Built up from **five** wind turbines of **2 MW**.
- Hub **height 80** meter.
- Rotor **diameter 80** meter, 3 bladed rotor.
- Octangular foundation, gross dimensions 18x18 meter.
- Nacelle weight 100 ton, tower weight almost 200 ton.
- Life span **20 years**.

Description:

- The **time span** from first initiative to final commissioning of a wind farm is subdivided into a development period and a building period. The duration of the **building period** is **well known**, for **a small to medium size** wind farm (< 15 MW) ¾ **to 1 year** and for a **large** wind farm **1 to 2 year.** The technical life span of a wind turbine is 20 years.

- The duration of the **development period is less predictable**. Depending on the mandatory procedure and the number and kind of objections put forward by concerned parties the required time span may vary from approximately ½ year to more than 5 years.

- The **financing** of a wind farm is a matter of a **special concern**. In the past a stand-alone wind turbine was part of the capital properties of a company. In such a case the wind turbine financing is comparable with the finance of other capital expenses.

Description:

- **Nowadays,** for most wind farms **a separate legal entity is established** with limited equity capital and for the greater part founded on loans. It is clear that under such conditions the financer(s) will demand for extra financial guarantees.

- Generally the development and operation of a wind farm can be subdivided into the following **four phases:**

  1. Initiation and feasibility (concluded by go/no-go).

  2. Prebuilding (concluded by go/no-go).

  3. Building.

  4. Operation and maintenance.

1. Wind farm initiation and feasibility phase:

- Main subject during this phase is that one or more **appropriate sites are selected** for possible siting of a wind farm.

- **Main characteristics** are **investigated** like **number of turbines, installed power and hub height.**

- The **feasibility** study comprises an inventory and assessment of the **main project risks** like the presence of sufficient wind resources, sufficient grid capacity and verification with the municipality zoning plan.

- The phase is concluded with a **go/no-go decision** for the next process step:
  - Site selection and wind assessment.
  - Technical feasibility.
  - Main risk assessment.
  - Permitting requirements of local authorities.
  - Project financing.

1. Wind farm initiation and feasibility phase:

Site selection and wind assessment:

- In order to develop and construct an economical feasible wind farm an inevitable first step is to **obtain one or more appropriate areas of satisfactory dimensions**.

- Already for a medium size wind farm, e.g. 5 wind turbines of 2 MW, a substantial area is required. **Depending on the rotor diameter the required mutual distance between the wind turbines is 300 to 500 meters. To limit losses, to limit nuisance or for safety reasons, the distance to the nearest company buildings is also at least 300 to 500 meters**.

- Next step, immediately following pre-selection of the area, is to **assess the corresponding local long term wind climate.** Generally speaking, potential wind farm sites are **preferably vacant areas at the flat land or on top of hilly areas.** In all cases the sites should be characterized with high and recurrent wind resources.

1. Wind farm initiation and feasibility phase:

Site selection and wind assessment:

- The **estimated wind distribution results in a yearly energy yield** representing the gross income of the wind farm.

- The **yearly energy yield** is calculated by **multiplying the wind turbine power curve with the wind distribution function at site:**

$$E_{\text{yearly yield}} (\text{kWh}) = \Sigma_i \, f(w_i) \cdot P(w_i) \qquad i = 1, \ldots n$$

With:

f: wind distribution function (yearly hours per wind speed interval).

P: wind turbine curve (power output as function of speed wind).

w_i: wind speed at interval or "bin"i, common interval size is 0.5 to 1 m/s.

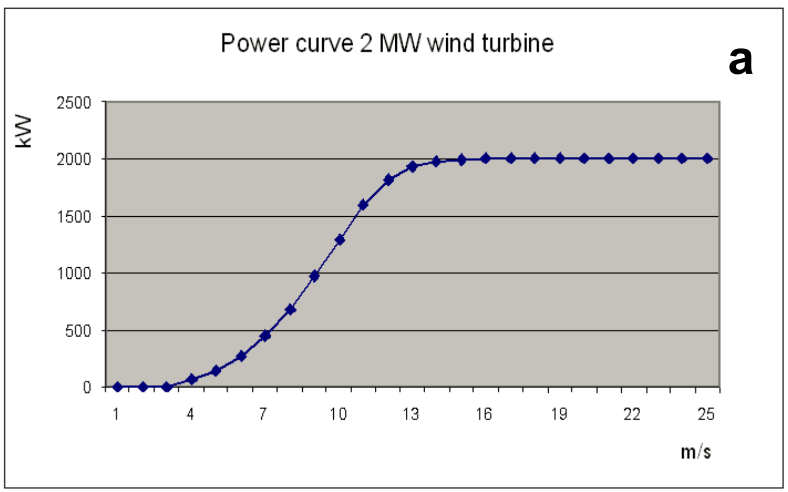
i: number of wind intervals "bins" between cut-in and cut-out wind speed; generally from 3 to 25 m/s.

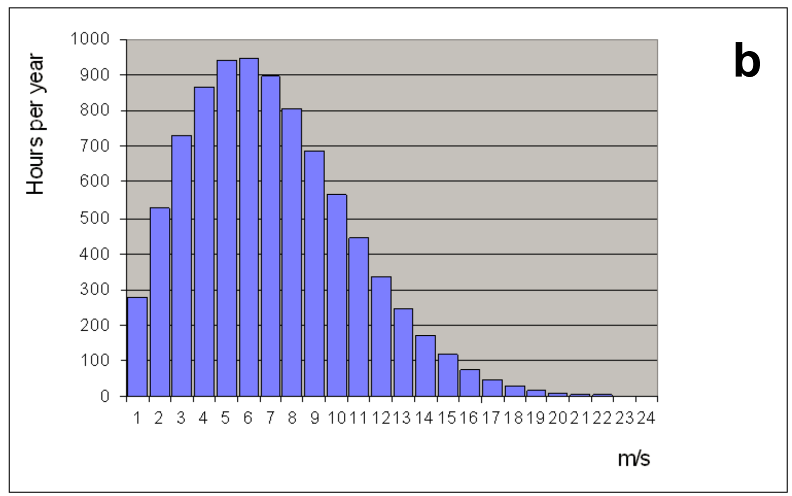
1. Wind farm initiation and feasibility phase:

Site selection and wind assessment:

- **Figure a:** shows a power curve (PV) of a 2 MW wind turbine with optimal efficiency, i.e. without noise reduction measures that usually lead to less energy generation.

- **Figure b:** shows the most commonly used wind speed distribution based on the statistical Weibull function with shape factor 2 and average wind speed of 7 m/s.





1. Wind farm initiation and feasibility phase:

Site selection and wind assessment:

• Based on the PV curve from figure a) and Weibull wind speed distribution with shape factor 2.0 the gross energy yield corresponding to 7 to 8.5 m/s is presented in the table:

Average wind speed (m/s)	7	7.5	8	8.5
Wind Farm Power (MW)	10	10	10	10
Gross Annual Energy Yield (MWh)	27,000	31,000	34,000	37,000
Equivalent full load hours	2,700	3,100	3,400	3,700

• Yearly gross energy yield of the 10 MW wind farm:
- 7.0 m/s average wind speed at hub height.
- Wind speed according Weibull distribution function, shape factor 2.0.
- No noise reduction measures required.
- Gross energy yield 27,000 MWh.
- Equivalent with 2,700 full load hours (utilization 0.31).

1. Wind farm initiation and feasibility phase:

Technical feasibility:

- Modern wind turbines are available in the **power range from 0.75 to more than 3 MW** having rotor **diameters** varying **from 55 to more than 100 meter**. Generally, the **hub height** varies **from 0.9 to 1.25 times the rotor diameter**.

- At a first screening the outer dimensions of the available terrain are of importance. **Wind turbines require a mutual spacing of at least four to five rotor diameters**. A flat and undisturbed area is preferred because buildings, trees and other obstacles lead to a lowering of the wind speed.

- Next to the terrain orography it is well-advised to examine the local grid properties at an early phase. Main question is the **distance to the nearest medium or high voltage substation with sufficient feed in capacity**. It is advised to make already during the feasibility phase an appointment with the local grid operator to discuss grid connection including corresponding cost and planning.

1. Wind farm initiation and feasibility phase:

Main risk assessment:

- In most countries it is **prohibited** that wind turbine rotors **rotate above roads, railway tracks and water ways**. A **minimum distance** has to be observed from wind turbines **to public infrastructure**. In northern countries and countries with continental climate specific **attention** has **to** be paid to probable **icing problems**. Ice developed on rotating rotor blades can be thrown far from the turbine and harm persons or result in material damage.

- Local authorities and concerned parties may demand for an **additional risk analyses** in case in the vicinity of the planned wind farm at least one of the following items count:
  - Transport, storage or processing of hazardous goods.
  - Pipelines for transport of hazardous goods (also underground).
  - Dwellings, company or public buildings.
  - Roads, railway tracks and water ways.
  - Medium and high voltage conductor.
  - Danger of icing.

1. Wind farm initiation and feasibility phase:

Permitting requirements of local authorities:

- The wind farm site has to **meet national, regional and local requirements**. In most countries **special legislation** is formulated for the environmental planning and the building aspects.

- During the wind farm planning phase it is necessary to meet special zoning plan requirements. For instance it may be decided that a specific zoning plan prohibit wind turbines or have laid down maximum heights for buildings. Under such conditions it has to be discussed with the local authorities possible ways and procedures to adopt the zoning plan to make the installation of a wind farm feasible.

- In most European countries wind turbines have to be **certified according to national or international safety standards** especially developed for wind turbines. Manufacturers have to demonstrate approved certification by a valid "type-certificate".

1. Wind farm initiation and feasibility phase:

Project financing:

- Wind turbines **investment and operational costs are fully proportional with the installed capacity**. Investment costs per MW installed are about 1.25 M€ and yearly operating cost somewhat more than 40 k€ per MW.

Non-recurring investment costs - price level 2006 -	Costs per wind turbine [K€]	Wind farm costs [K€]
Preparatory costs	100	500
5 wind turbines of 2 MW each	2000	10000
Wind farm civil and electrical infrastructure	200	1000
Grid connection	200	1000
TOTAL INVESTMENT (year 1)	2500	12500
Refurbishment (at year 10)	250	1250
TOTAL	**2750**	**13750**

1. Wind farm initiation and feasibility phase:

Project financing:

- Yearly recurring **operating and maintenance costs:**

Yearly recurring operating costs - price level 2006 -	Costs per wind turbine [K€]	Wind farm costs [K€]
Wind turbine service, maintenance and insurance	50	250
Local taxes and contribution grid connection	10	50
Land lease	15	75
Daily management	5	25
Own electricity consumption	5	25
TOTAL	**85**	**425**

1. Wind farm initiation and feasibility phase:

Project financing:

- **Investment and operational costs** for a 10 MW wind farm (at 2006 levels):
  - Initial investment costs 12.5 M EUR (1.25 M EUR/MW).
  - Annual operational costs 0.425 M EUR (42.5 k EUR/MW).
  - Estimated refurbishment costs halfway through the life span 1.25 M EUR; i.e. 10% of the initial investment.

- In most cases the wind farm is financed by a m**ix of capital (equity) and a bank loan**. The amount of equity is usually limited to 20 to 40% of the total investment. It may be attractive for companies, investment groups and individuals to invest in wind energy for possible tax reduction benefits.

- A number of national governments in Europe have introduced **incentives** to promote electricity production by renewable sources, for example, by **introducing tax allowances** for investments in "green" energy sources.

2. Pre-building phase:

Wind farm design including energy yield predictions:

- During this phase all preparatory **work** is done needed **to start the building phase**.
- The wind farm developer has to apply for **all necessary permits and a power purchase agreement** (PPA) has to be settled for selling the produced wind energy.
- The contractors for **delivery of the wind turbines and** corresponding **civil and electrical infrastructure have to be selected**. And last but not least, the **project financing has to be arranged**.
- Based on the wind resource assessment the **most promising wind farm locations are studied in more detail**.

2. Pre-building phase:

Wind farm design including energy yield predictions:

- The gross energy yield of the wind farm is dominated by the local wind distribution and the siting of the wind turbines.

- To **calculate** the net **energy yield** it is needed to determine the **anticipated losses**. The gross annual energy yield has to be adjusted for:

  \- **Wake losses**.

  The wind speed downstream the rotor, the so-called wake, of the turbine is lower compared to the undisturbed wind speed resulting in a somewhat reduced performance of downstream sited wind turbines. The wake is characterized by extra turbulence which may lead to premature damage of main structural components.

  It is common practice to estimate the wind farm wake losses in the range of **3 to 4%** of the gross energy yield.

2. Pre-building phase:

Wind farm design including energy yield predictions:

- **Grid losses:**

  Grid losses are defined as the electrical losses between wind turbine switchgear and public grid connection. Depending on the lay-out the electrical losses are in the range of **2 to 3%** of the gross energy yield.

- **Availability:**

  The availability of a wind turbine is defined as the time the wind turbine is in operation or ready for operation with external conditional, for instance too low wind or grid loss, preventing the system from energy generation.

  The technical availability of the turbine is 97% or higher.

- Yearly net energy yield of the 10 MW wind farm:
  - Gross energy yield 27,000 MWh.
  - 3% wake losses.
  - 3% grid losses.
  - 97% availability.
  - Net energy yields 24,500 MWh.

2. Pre-building phase:

Permitting procedures:

- **Environmental permit:**

  The wind farm must comply with all **regulations relating to environmental permitting**. For the environmental license a site plan and various environmental studies, amongst others on plant and animal life, are necessary.

- **Noise:**

  The noise impact of the wind turbines on the environment is **one of the major permitting issues**. Wind turbines produce noise, mostly caused by the rotor blades and drive train. The distance to nearby located dwellings has to be sufficient to assure that the noise level at the house front is below the statutory norm.

  Most of the authorities demand also **shadow casting examinations**. Shadow flickering is caused by sunlight reflecting on non-rotating blades or tower. Shadow casting is due to periodically –about once per second– interrupting the sunlight by the rotating blades.

2. Pre-building phase:

Permitting procedures:

- **Safety:**
  It is **not allowed** for wind turbines **to rotate above roads or railway-tracks**. In case icing on the rotor blades and nacelle may cause danger for persons and material in the near environment, protective measures have to be taken. A well-known measure is rotor standstill during icing up and release for starting up after visual observation all ice has disappeared.

- **Building permit:**
  Besides an environmental permit also a **building permit is necessary** for the wind farm. As part of the application most authorities require information on the visual impact of the wind farm on the environment. Visualizations of the planned wind farm in the existing environment serve as input for this assessment. Another part of the application is a detailed description of the wind turbines including foundation, exact locations of the wind turbines in the terrain, overview of the civil and electrical infrastructure and a copy of the valid type-certificate.

2. Pre-building phase:

Grid connection:

- Usually not each individual wind turbine is connected to the public grid separately. For the **wind farm an internal grid is designed and installed**. The voltage of the internal grid is preferred **at medium voltage level**, between 10 to 20 kV, in order to limit the losses. In most cases the wind turbines are electrically connected in a loop to ensure redundancy.

- The wind turbine generators operate mostly below 1000 V and each wind turbine is equipped with a transformer to transform the power from low to medium voltage level. The **wind turbine transformer is located in the nacelle** or **tower base or** in special **housing** next to the tower.

- It depends on the public grid voltage if a central wind farm transformer is required to transform the medium voltage to grid voltage or only a switchgear installation including accountable metering provisions.

2. Pre-building phase:

Feed-in contract:

- In all cases a **power purchase agreement (PPA) or feed in contract is necessary**. The feed in tariff is composed from a contribution for producing and delivery of electricity and in most cases increased with an extra allowance for generating renewable energy or corresponding carbon credits. Depending at one hand on the wind resources and on the other hand on the investment and operational cost **a feed in tariff of at least 60 EUR/MWh is required** and for an **economical viable project a tariff of 80 to 90 EUR/MWh** is needed.

Selection of suppliers:

- Based on the scope of supply and own working procedures the wind farm developer has to decide for a **public tendering procedure or to decide to send only a pre-selected number of wind turbine suppliers** a request for tendering. All necessarily information for the tendering has to be included in the "tendering enquiry documentation" also abbreviated to TED.

2. Pre-building phase:

Project financing:

- For most sites in Europe wind energy is not yet cost effective. To **promote wind energy incentives are essential**, the most applied promotion measures are:
  - Subsidies (governmental or local) on investments in renewable energy sources.
  - Tax benefits for investing in renewable energy sources.
  - Reduced interest tariffs on loans for renewables.
  - Subsidies on the production of renewable energy (increased feed in tariff).

- In case the financing is based for the greater part on loans the financers may ask for additional securities to guarantee that the loan can be repaid.

2. Pre-building phase:

Project financing:

- **Cash flow calculations** with two different feed in tariffs are carried out for the 10 MW. In the calculations the financing costs are not taken into account. All expenses and incomes are based on **price level 2006** so the influence of inflation is implicitly included in case expenses and income increases yearly with equal ratio.

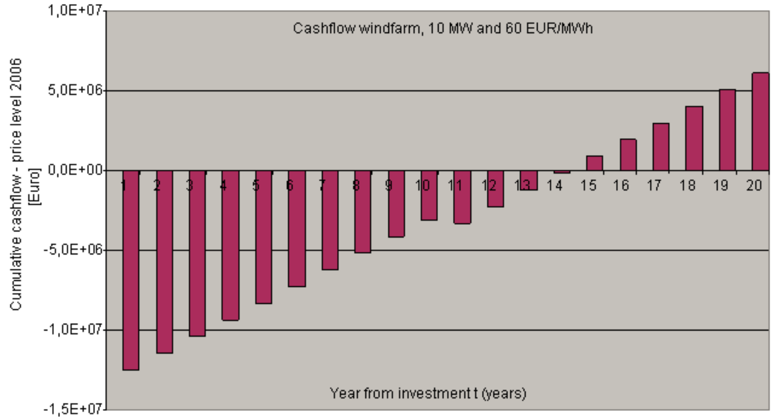
- Cash flow calculations for the 10 MW wind farm based on 20 year life span and price level 2006:

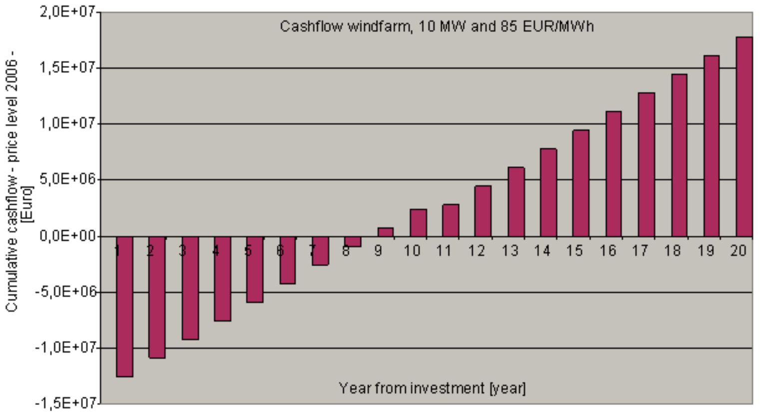
Feed in tariff	60 €/MWh	85 €/MWh
Gross income	1.47 M€/yr	2.08 M€/yr
Recovery period	> 15 year	> 9 year
Net present value over 20 year (NPV)	6.1 M€	17.7 M€
Internal rate of return (IRR)	4%	11%

2. Pre-building phase:

Project financing:

- The calculations show that a feed in tariff of **60 €/MWh is needed to pay all costs without generating profit**. Presuming the project is fully financed by a bank loan the project generates just sufficient cash to pay yearly interest (4%) and repay the loan and yearly operating costs. **At a tariff of 85 €/MWh the project generates value for the owner (7%)** in case the yearly financing costs ask again 4%.





3. Building phase:

Overview of building process:

- The following assembled **main components are shipped to site:**
  - Foundation anchor or tube.
  - Three or four tubular tower parts.
  - Ground controller and switchgear.
  - Wind farm SCADA system.
  - Transformer (in case of ground based).
  - Fully assembled nacelle (including gearbox, generator, yaw mechanism, mechanical break, converter and if applicable the transformer).
  - Hub and rotor blades.

- For a small and medium size wind farm the time **between purchase order and transport ready is 6 to 9 months**. **Meanwhile** the wind farm civil, including **access roads**, wind turbine **foundations** and substation, and **electrical infrastructure is built**. The time required for **rotor assembly** and constructing of the main structure takes **two to three working days per wind turbine**. Subsequently it takes 7 to 10 working days to finish the installation works and connecting to the grid.

3. Building phase:

Quality control during production and construction:

- It is common use that the contractor assigns a number of so-called **"hold and witness" points for the client**. These hold and witness moments are meant for the wind farm owner to audit the progress and quality of work including the verification that the components are in conformity with the specifications. Hold and witness moments are mostly planned immediately following a project milestone, for instance a main component ready for transport to site. **Mostly hold and witness moments are linked with payments**.

- The following hold and witness points are commonly used:
  - Start of component production including audit of contractors quality system.
  - Factory acceptance test (FAT) of components ready for shipment.
  - Site acceptance test (SAT) of components delivered at site.
  - Several inspections during building at site, connected to milestones.

4. Operation and maintenance:

Starting from date of take-over the owner is responsible for daily operation of the wind farm. Also from that date warrantee and maintenance contracts become valid. The technical and economic life span of a wind farm is anticipated as 20 years.

Daily operation:

- Wind turbines are **designed to operate unmanned**. For normal operation **no operator has to be available at site**. It is common practice that medium and large size wind farms are equipped with a wind farm **control and monitoring system (SCADA)**. By means of modem or internet remote access to the SCADA system is available. The SCADA system provides reports on energy yield, availability and failure statistics.

- Main function of the daily operator is to **verify regularly that the wind farm is in optimal condition and performing according expectation**. Also the operator is responsible that maintenance and repairs are carried out accordance to contract and within reasonable time.

4. Operation and maintenance:

Warrantees and insurance:

- The following **warrantees** are common for the **first five years** following take-over:
  - On delivered goods, including repairs and modifications.
  - Availability of wind turbines and wind farm, values of 95% or higher are common.
  - Warrantee on performance, for the exact wind supply is not to be predicted for a given year the warrantee is given on the power curve. Warrantees of 95% of the certified PV-curve of the wind turbine are common.
- In case the availability or performance is below the warranted value, the difference between actual and warrantee values has to be settled by the supplier. Some suppliers offer warrantees up to 8 to 12 years or at least for a period comparable to the financing period.
- **Insurances** are required for:
  - Third party responsibility.
  - Machine breakdown.
  - Business interrupt.

4. Operation and maintenance:

Maintenance and repairs:

- Modern wind turbines require **twice a year a preventive maintenance service**. For a wind turbine in the MW-segment a planned preventive maintenance service requires **2 to 3 working days** for two engineers.

- The work comprehends amongst others inspection and **testing** of the control and **safety devices, repair of small defects, replacement or filling up of consumables** like bearing grease and gearbox lubrication.

- The **gearbox is the most vulnerable component** and therefore subject of special interest during maintenance. At regular intervals oil samples are taken and investigated on pollution, filters are replaced and gearings are inspected on damages.

4. Operation and maintenance:

Maintenance and repairs:

- The number of repairs differs largely between individual wind turbines and wind farms. The **average yearly number of corrective actions per wind turbine is 3 to 4**. Only those corrective actions are counted that need a visit on site of a service engineer. The cause of failure is equally divided between mechanical and electrical problems.

- Although not formally admitted by the manufacturers it is common practice that **after 10 to 12 years of operation wind turbines need a major repair**. The renovation comprehends cleaning and repair work of the rotor blades and refurbishment of the drive train, i.e. replacement of bearings and if necessary replacement of gearbox parts.