Wintegrate

Wind energy and wind conditions in the built environment

The case for urban wind turbines

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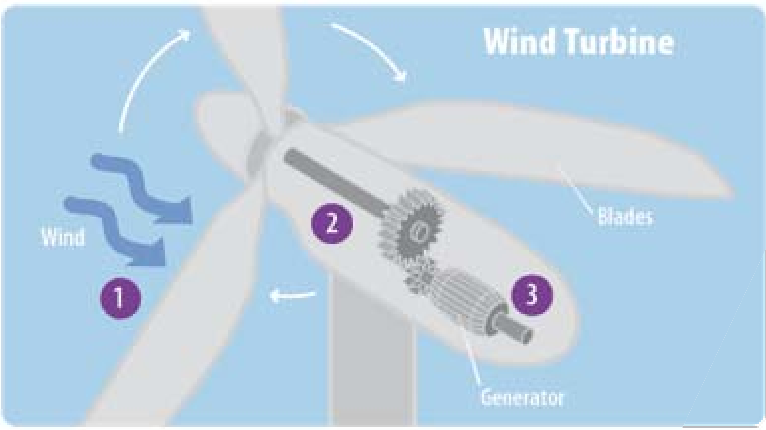
Overview

- A brief introduction to wind energy
- The economics of wind turbines
- Estimating the annual energy production
- Small and medium-sized wind turbines
- The wind potential in Brussels
- Summary and conclusions

A quick introduction to wind energy

Quick introduction to wind energy

- A wind turbine is a machine that converts the flow of air into electricity
- The wind drives a rotor that is connected to a generator



- The working principle of a generator is the same as that of a bicycle dynamo

The power in the wind

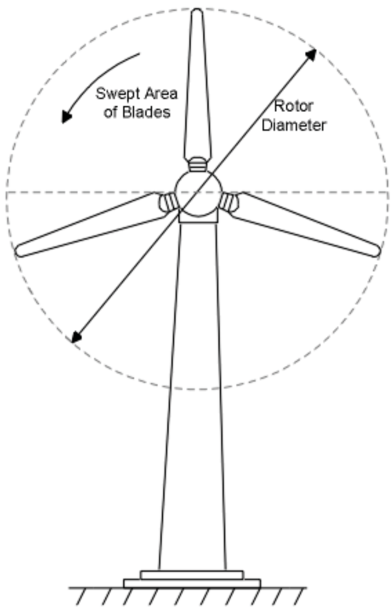
- Wind has energy because it is moving:

$$E = \frac{1}{2}mv^2$$

- When will a lot of kinetic energy flow through the rotor per unit of time?
  - When the rotor has a large surface S

    and/or

    the wind speed v is high
- Power proportional to $v^2 \times v \times S = v^3 \times S$

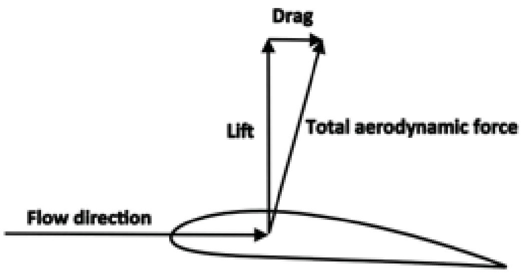


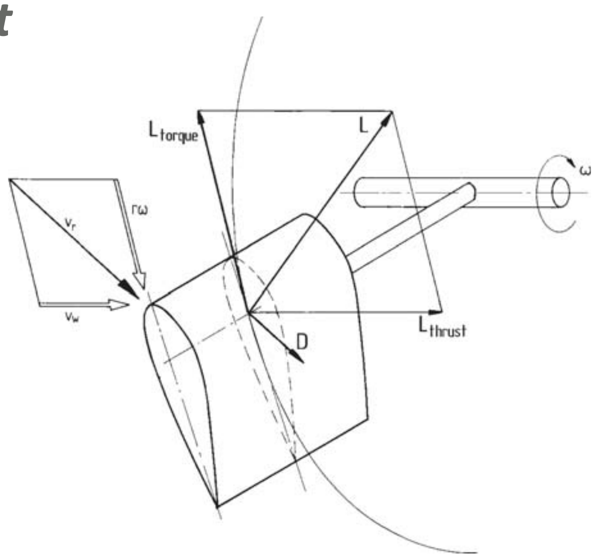
The power in the wind

- Power proportional to $v^3 \times S$
- This explains a few basic facts about wind energy
  - A bigger wind turbine produces more power (that's why wind turbines keep getting bigger)
  - The dependence of power on wind speed is strong:
    - » If the wind speed doubles, the power increases by factor of 8
    - » If the wind speed increases by 25%, the power doubles
  - Wind energy is variable

The force that turns the blades

- The force that turns the rotor blades is the same force that allows aeroplanes to fly: ***lift***





Power of wind turbines

- Wind turbines cover a wide range in powers (*P*)
  - *P* < 1 kW: marine, telecom
  - 1 kW < *P* < 10 kW: small SMEs, agriculture, households
  - 10 kW < *P* < 300 kW: SMEs, agriculture, community energy
  - 300 kW < *P* < 10 MW: utility-scale energy production, often in wind farms

Power and energy

- In good conditions
  - A 1000 kW turbine will produce around 3 500 000 kWh/yr
  - A 100 kW turbine will produce around 350 000 kWh/yr
  - A 5 kW turbine will produce around 13 000 kWh/yr
- The average Belgian household consumes 3500 kWh/yr of electricity

The economics of wind energy

The economics of wind energy

- **Levelised cost of energy (LCOE)**
  - Definition

$$\text{LCOE} = \frac{\text{TLCC}}{\text{TDEP}}$$

TLCC: Total lifetime cost

TDEP: Total discounted energy production

  - Cost and benefits are *discounted:*
    - » *a euro gained today is better than a euro gained tomorrow*
      ➥ *cost and benefits count for less if they occur later in time*

- If the LCOE is lower than the selling price of electricity, then an investment can be deemed economically viable

The economics of wind energy

- **Payback period**
  - How long does it take to recoup the investment?
  - The first year n for which we have
    - Investment
    + (Cash flow)yr 1
    + (Cash flow)yr 2
    + …
    + (Cash flow)yr n > 0
  - The cash flows in the future also need to be discounted: **dynamic payback period**
  - If you neglect this (but you shouldn't): **static payback period**

The economics of wind energy

- **Internal rate of return** (IRR)
  - Net present value (NPV)

$$\text{NPV} = -\text{Investment} + \sum_{n=1}^{N} \frac{\text{CF}_n}{(1+r)^n}$$

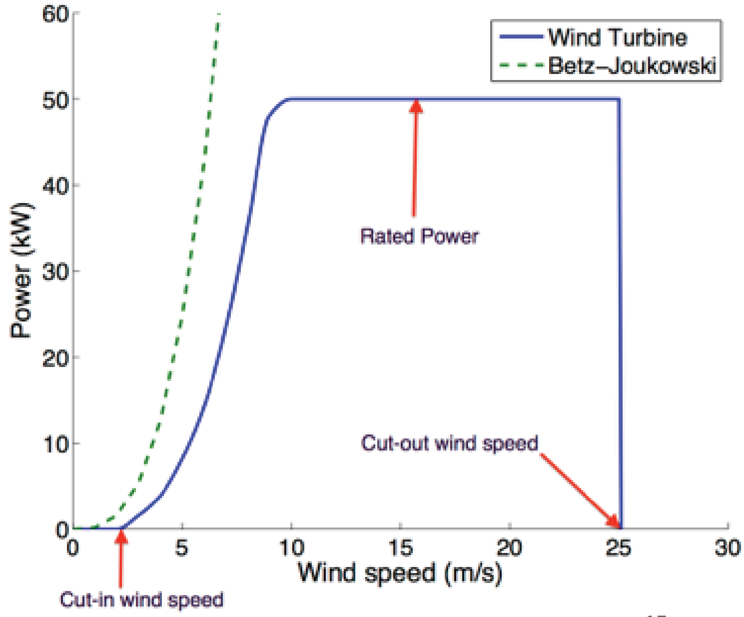
  - IRR: the discount rate r for which NPV = 0

The economics of wind energy

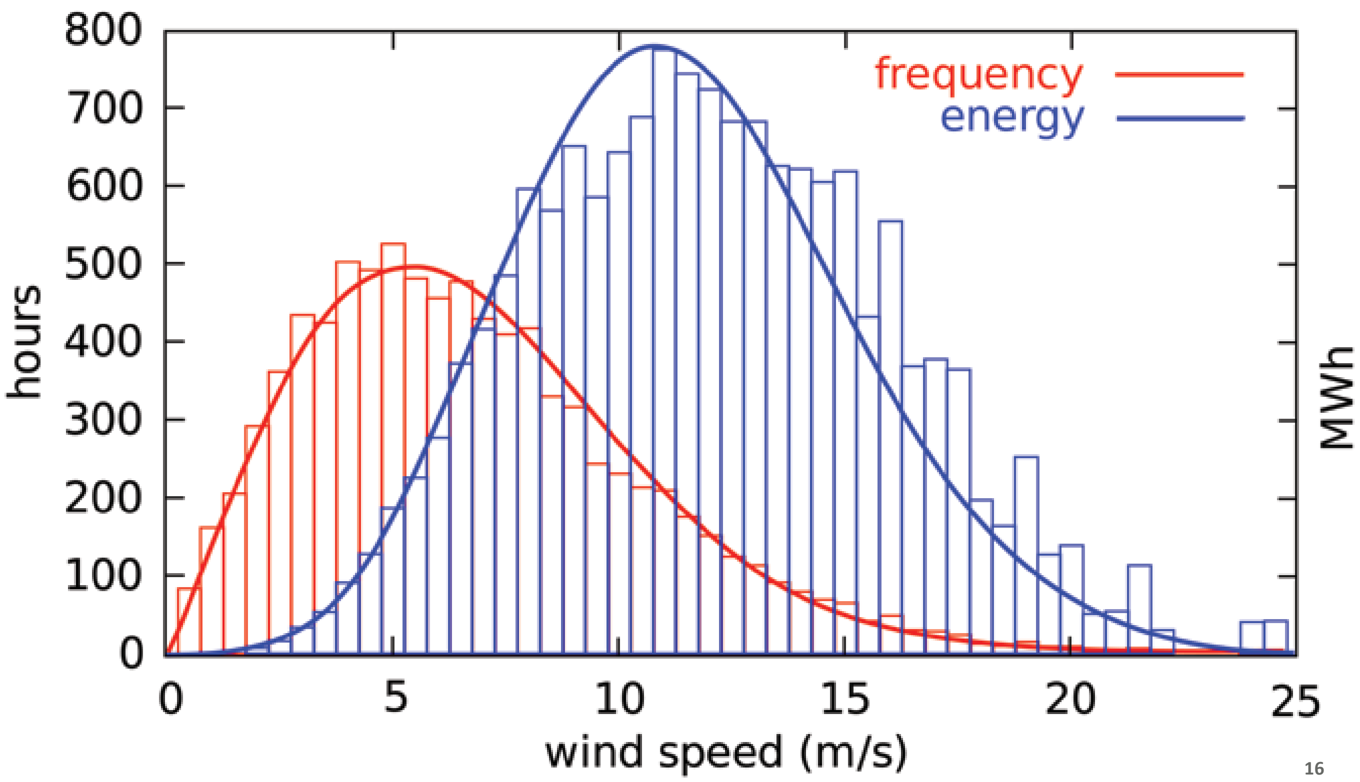
- To decide on the viability of a wind turbine project, cost and benefits need to be estimated carefully
- The most difficult part: annual energy production of the wind turbine on a given location

Wind turbine power curve

- Wind turbine is characterised by a **power curve**
  - Electrical power output as a function of the wind speed
  - Essential for estimation of energy production

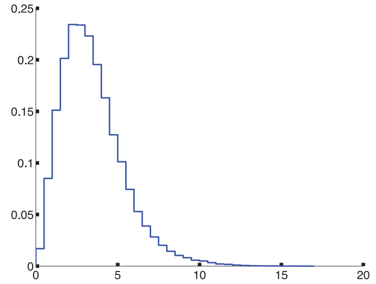


Wind speed distribution

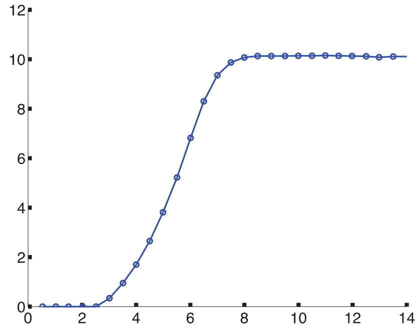


Estimating the annual energy production (AEP)

- Assess the wind resources
  - » Wind measurement campaign



- Combine hub-height wind measurements with the power curve



Money from energy production

- Energy can be sold to the grid (not very rewarding)
- Avoided costs represent a monetary value (and hence a positive cash flow)
- Support measures such as green current certificates increase the cash flow
- Secondary benefits such as greening of company image have economic value that is difficult to quantify, but important

Small and medium wind turbines

Small and medium-sized wind turbines

- **IEC 61400-2 Small wind turbines**
  - "a system of 200 m² rotor swept area or less that converts kinetic energy in the wind into electrical energy"
  - d ≲ 16 m
  - P_{rated} ≲ 50 kW
- **Medium-sized wind turbines**
  working definition: 50 -300 kW

Small and medium wind turbines

- Challenge of small and medium wind turbines:
  - immature market
  - low-cost
    → low budget for resource assessment and siting
    + limited time for measurements
  - generally complex environment

Rule 1: Know the market

VUB database of small wind turbines

- Turbines < 100 kW
- 762 turbines and counting
  - Most extensive survey to date
  - HAWT
  - VAWT
  - Other concepts

VUB database of small wind turbines

- Typical entry: main characteristics of turbine
  \+ comments: measured P-curve, cut-in or start, ...

Image	Naam	Bedrijf	Vermogen	Rotor diameter	Cut-in	Cut-out	Jaarlijkse Productie	Prijs	Mogelijkheid met netconnectie	P-curve
	FD6.4-5kW	ReDriven	5000 W	6,4 m	2 m/s start	19 m/s	6184 kWh/jaar (U_{gem} = 4 m/s) Berekend	€ 10660 Excl. mast	Ja	Ja

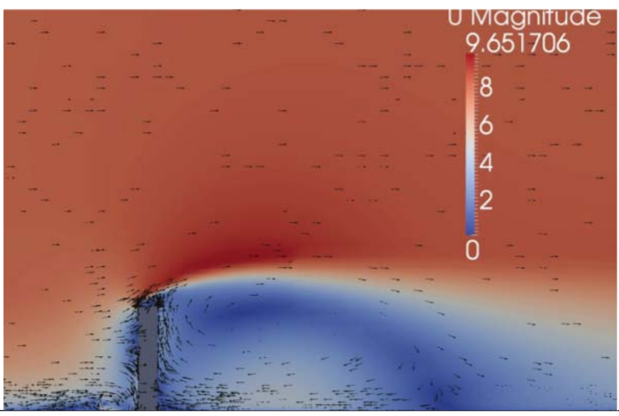
- Basis for comparison between small turbines, with estimate of annual production
- Select turbines for test fields
- Help clients select small turbines

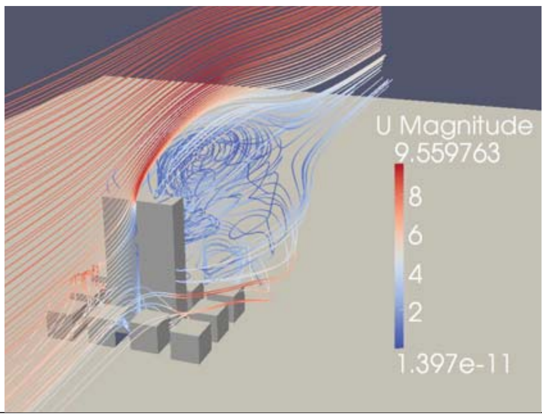
Rule 2: know the wind resource

- Estimate the available wind resource
  with the aim of predicting the energy production for an appropriate wind turbine
- This is in practice not always easy to do cheaply and reliably

Rule 3: proper micrositing

- Optimal location and height of the turbine
  - 3-D model of the site or building
  - Combined with computational fluid dynamics (‘virtual wind tunnel’)



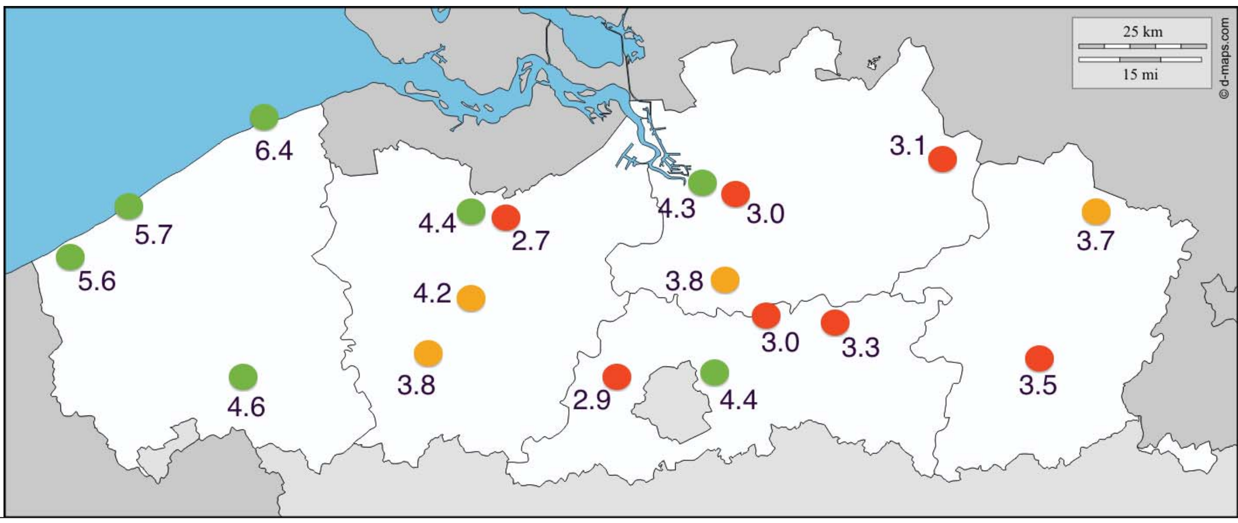


Small and medium wind turbines: resource assessment + siting

- Feasibility
  - Turbine choice
  - Resource assessment
  - Turbine siting
  - Technical feasibility
- Use measurements and numerical simulations
  - Resource assessment: measurements
  - Micro-siting: numerical simulations

Viability map, example for Flanders

- Viability map for SMEs
  - Values indicate average wind speed [m/s]
  - Turbine with rated power 10 kW (Hub height 18 m)
  - Red (IRR<8%), Orange (8%≤IRR<12%), Green (IRR≥12%)



The potential for wind energy in Brussels

Wind potential in Brussels: global wind conditions

- Wind maps based on terrain information and meteo data

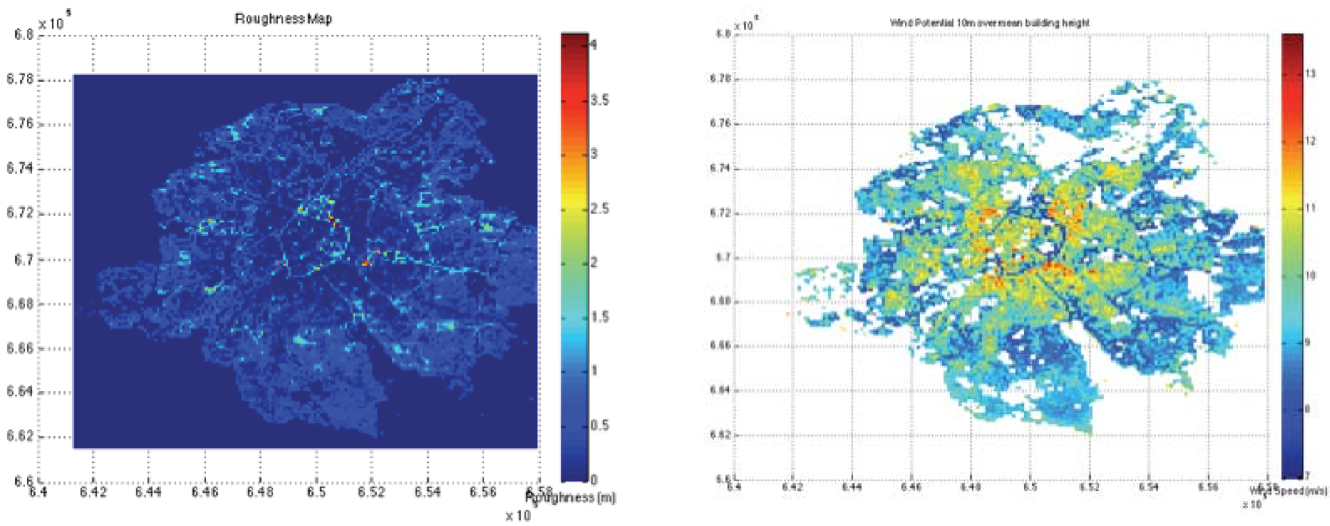
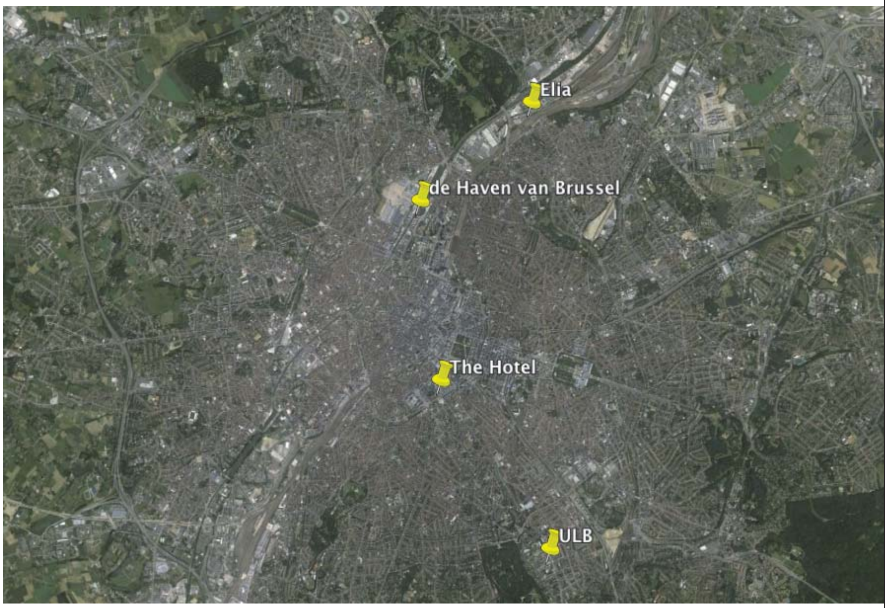


Figure 1: Roughness map (left) and wind speed at 10 m above mean building height (right) for the Brussels Region.

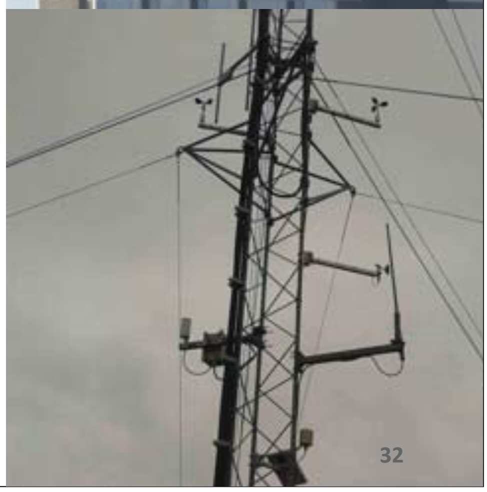
Wind measurements: site selection

- **Result**
  - 4 sites were selected:
    - » Hilton
    - » ULB Campus Solbosch
    - » Elia
    - » Port of Brussels



Wind measurements: results

- The Hotel:
  - building height 94 m
  - close to porte de Namur
  - Over 1 yr of measurements
  - Average wind speed: 5.8 m/s
  - This is comparable to the wind at the Belgian coast (at normal hub height)



Wat would a wind turbine on The Hotel produce?

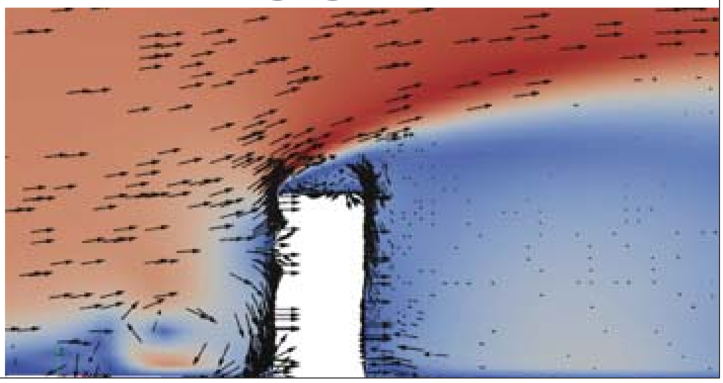
- The Hotel:
  - Yearly production
    - » Sonkyo Windspot : 14200 kWh/yr
    - » Ennera: 8170 kWh/yr
  - Dynamic payback time
    - » KMO: Sonkyo Windspot & Ennera :
      7 jr
      (10-12 yr without support)
  - IRR:
    - » Sonkyo Windspot: 17.2 %
    - » Ennera: 15.1 %

Wind measurements: results

- Other high-rises (Manhattan-tower): comparable results
- Lower buildings (40 m): conditions much less favourable
- Unclear: potential for medium-sized turbines in semi-open terrain
- 12 m above ground
  (typical hub height < 15 m):
  - mean wind speed 3.7 m/s
  - comparable to Schoondijke (Zeeland)

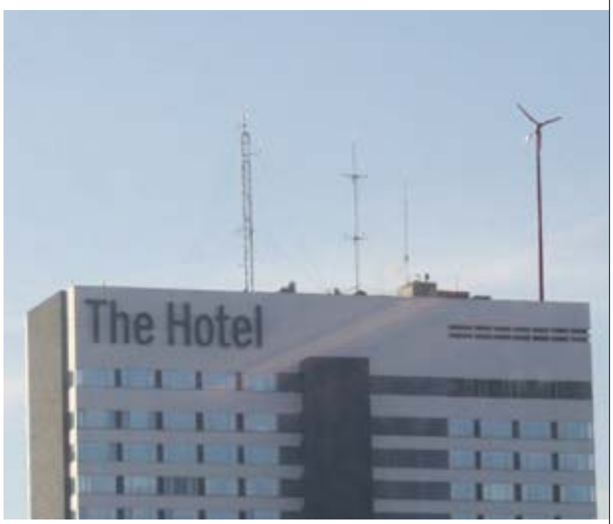
Building-mounted small wind turbines

- Turbine should not affect structural health of building
- Impact on occupants and surrounding should be negligible
- Impact on air traffic should be negligible
- Impact on biodiversity should be negligible
- Turbine should be economically viable



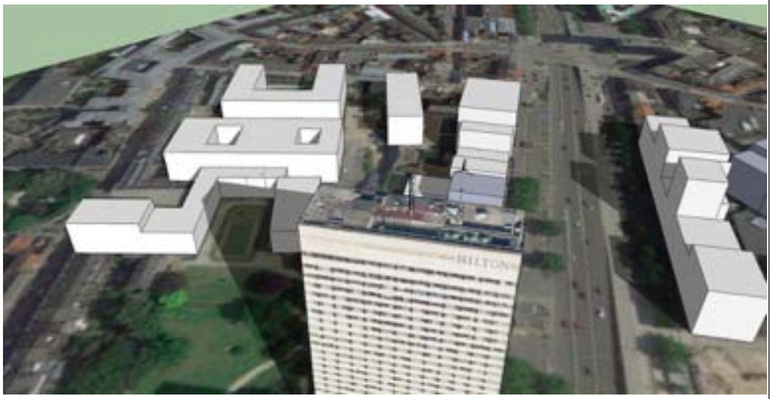
Impact of rooftop-mounted wind turbines

- Structural effect of vibrations: very limited
- Visual impact
- Noise:
  - direct: inaudible
  - through vibrations: investigation ongoing
- Biodiversity: very little impact
- No risk for air traffic



Shadow flicker

- Guideline
  - *d* = 2 times height
  - max 30 h/yr
  - max 30 min/day
- The Hotel
  - Shadow moves fast enough



Summary of situation in Brussels

- Wind conditions on high-rises comparable to conditions at the Belgian coast
  - Payback times < 10 yr
  - IRR > 15 %
  - This is very good for distributed generation
- BUT: only true for good wind turbines, in a good location, properly installed
- Semi-open terrain not measured
- Impact very limited. Detailed feasibility study always required

Economic impact — long term

- In the long term, and providing the problem of rooftop crowding can be managed, there is the potential for roughly 50 sites for rooftop-mounted wind turbines in Brussels, resulting in a power production of the order of 1.5 GWh/yr

Portland, Oregon (2009)

Summary

- There is a potential for wind energy in the BCR
- Brussels can obtain an international pole position in urban wind energy
- Brussels has the technological assets required
- Now is the time for pilot projects
- The expected economic impact of wind energy in Brussels is significant

Thank you

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