A Computational Fluid Dynamics based framework to assess the wind energy potential of an urban landscape: a case study in Brussels

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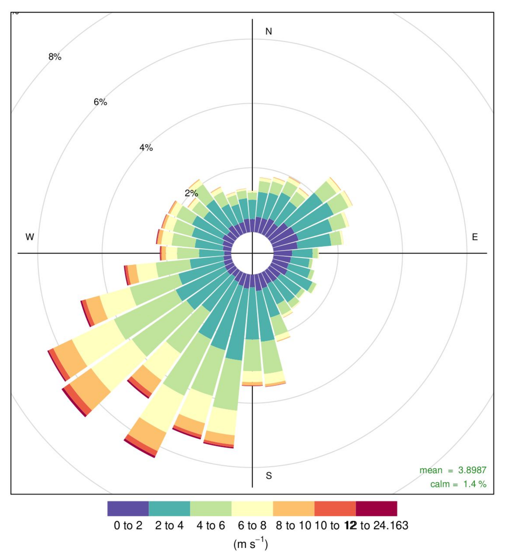
Introduction : Wind is a clean and renewable energy source that has the potential to significantly contribute to the electricity supply in urban areas. Electricity generation through Micro Wind Turbines (MWTs) in an urban setting is not often implemented given their expected low performance due to low wind speed. However, accurate positioning of wind turbines can often result in a satisfactory performance.

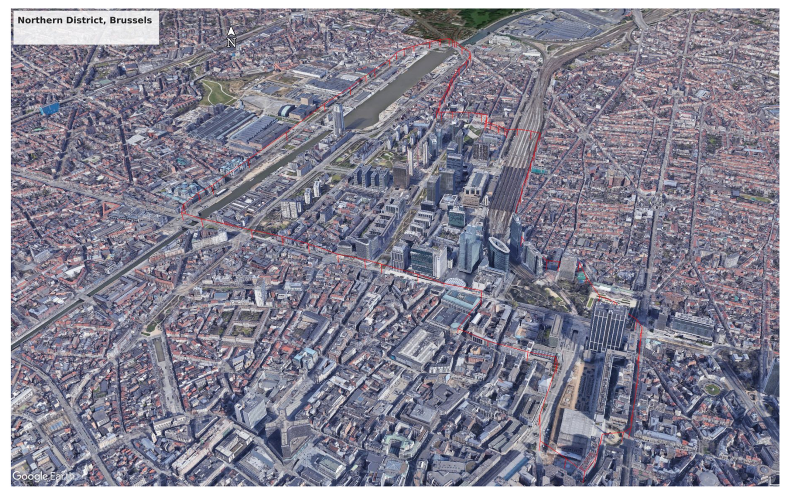
In the present work, a framework is detailed to assess the wind energy potential of an urban neighborhood using Computational Fluid Dynamics (CFD) and applied to the Northern District of Brussels, Belgium, a neighborhood that has the ambition to become a Positive Energy District. Assessing the wind energy potential of an urban area requires knowledge of local wind properties (speed, direction, turbulence) to a high spatial resolution, as conditions even on a single roof are not uniform. CFD is a powerful tool that can be used to discern wind patterns and aid in an accurate assessment of the wind energy potential. By using CFD, it is possible to accurately predict the wind speed, direction and turbulence within an urban landscape, taking into account the effects of buildings, terrain and other structures

Methodology :

Step 1 : Statistical analysis of meteorological wind data

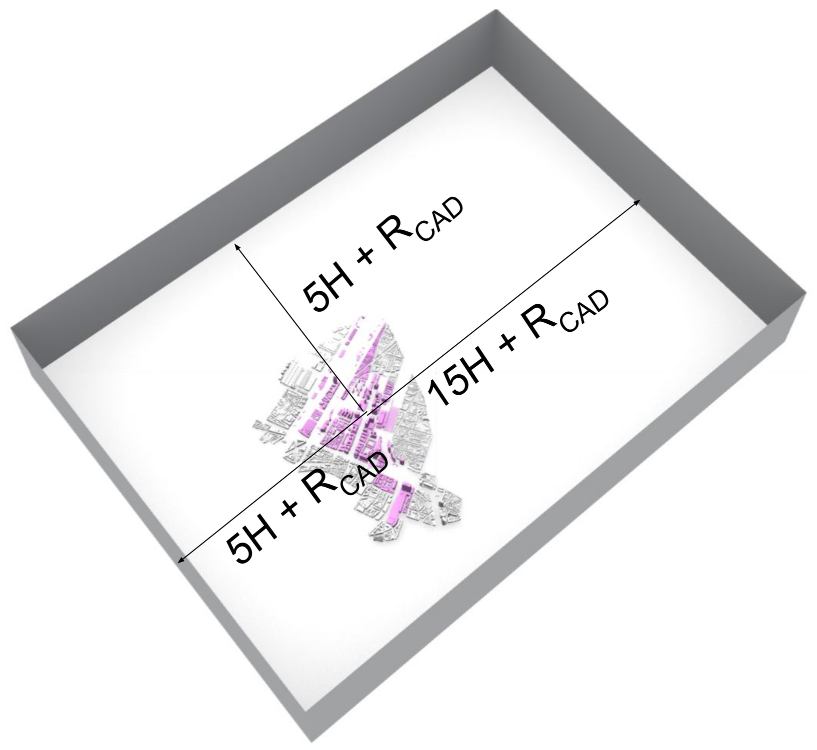


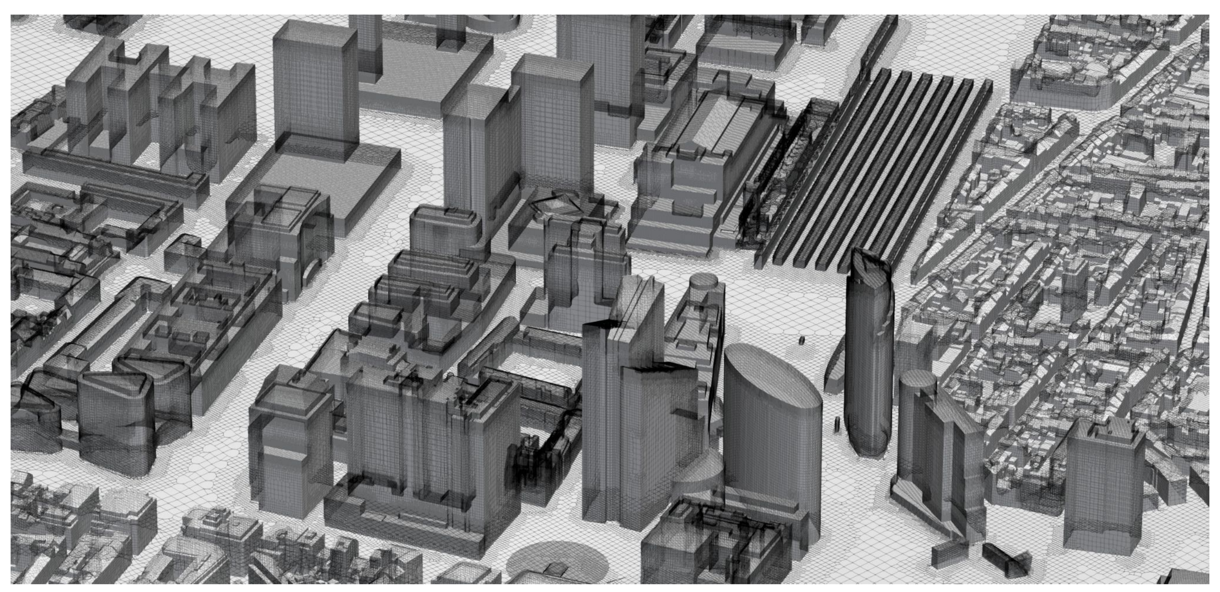
Northern District, Brussels



Step 2 : Wind simulations with CFD [1,2,3]

- **Mesh size** - 52 million cells
- **Solver** - Steady-state, incompressible, FVM based solver (OpenFOAM v7)
- **Turbulence model** - Modified k-ω SST RANS model with improved ABL formulations [4]





Step 3 : Generation of approximate local Weibull velocity distributions for each direction

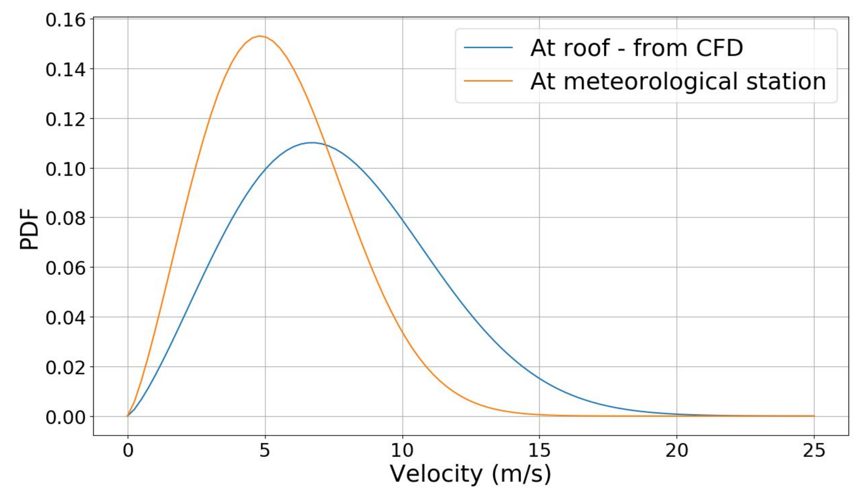
$$PDF_{station}(V) = \frac{k_{station}}{c_{station}}\left(\frac{V}{c_{station}}\right)^{k_{station}-1} e^{-\left(\frac{V}{c_{station}}\right)^{k_{station}}}$$

$$PDF_{local}(V) = \frac{k_{local}}{c_{local}}\left(\frac{V}{c_{local}}\right)^{k_{local}-1} e^{-\left(\frac{V}{c_{local}}\right)^{k_{local}}}$$

k - Weibull shape parameter
c - Weibull scale parameter

$$k_{local} = k_{station}$$
$$c_{local} = c_{station}\left(\frac{V_{local}}{V_{station}}\right)$$

From [5]

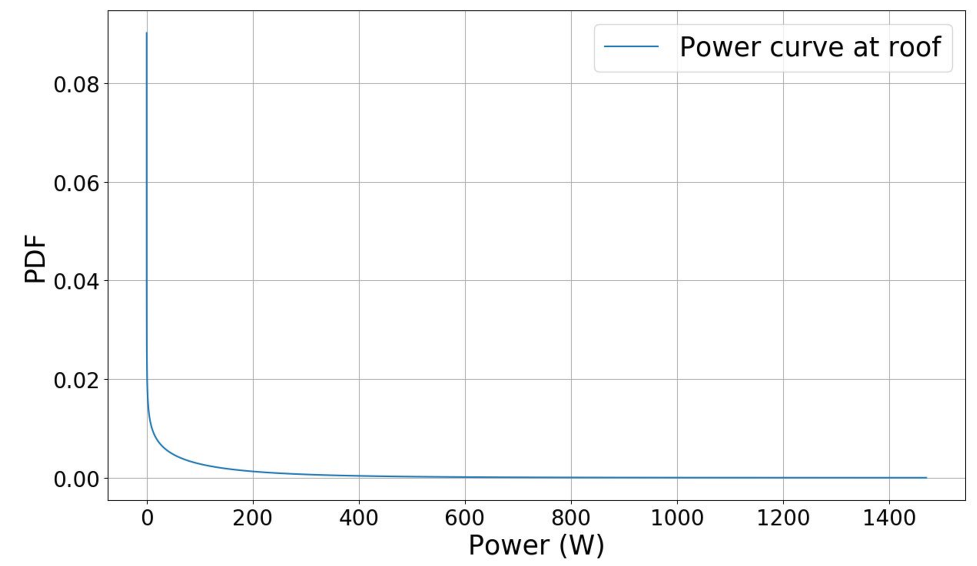


Step 4 : Generation of local power probability distribution for a specific turbine and integration of the distribution to get Annual Energy Potential (AEP)

$$Power\ PDF_{local}(P) = Velocity\ PDF_{local}(V) * \left|\frac{dV}{dP}\right|$$

$$P = 0.5\rho V^3 CpA$$

Air density (ρ)
Efficiency of turbine (Cp)
Turbine swept area (A)



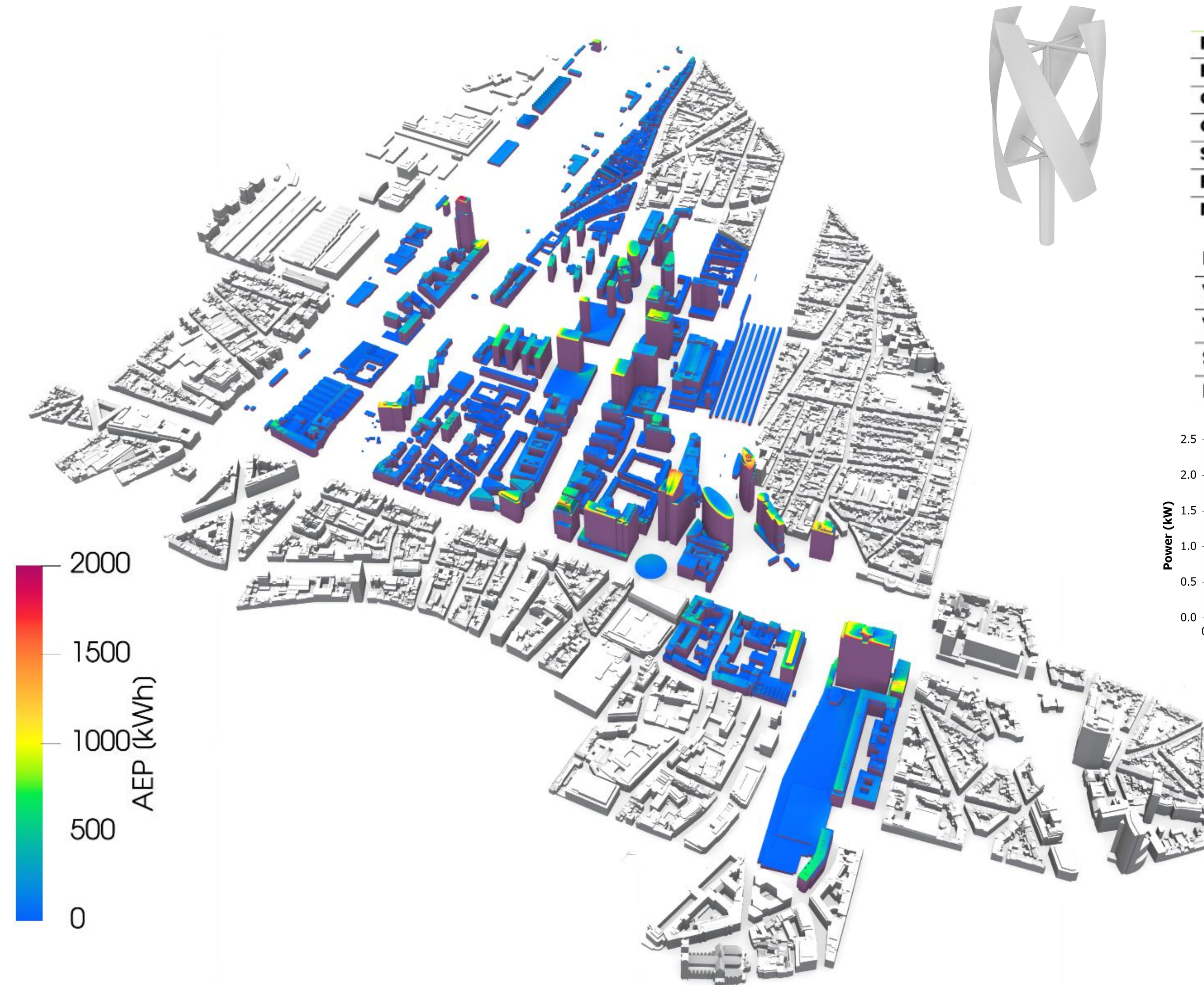
$$Power\ PDF_{local}(P) = Velocity\ PDF_{local}(V) * \frac{V}{3P}$$

$$Power_{total}(\theta) = \int_{Cut-in\ P}^{Max\ P} \left\{P * \left[Power\ PDF_{local}(P)\right] dP\right\}$$

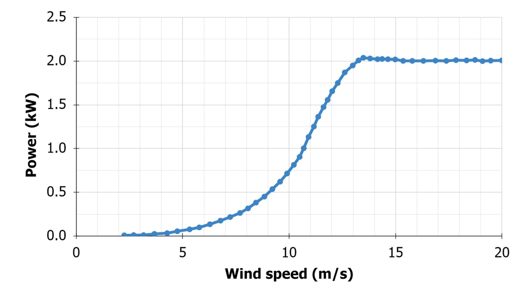
$$AEP = \sum_{\theta}\left[(365 * 24 * f_{\theta}) * Power_{total}(\theta)\right]$$

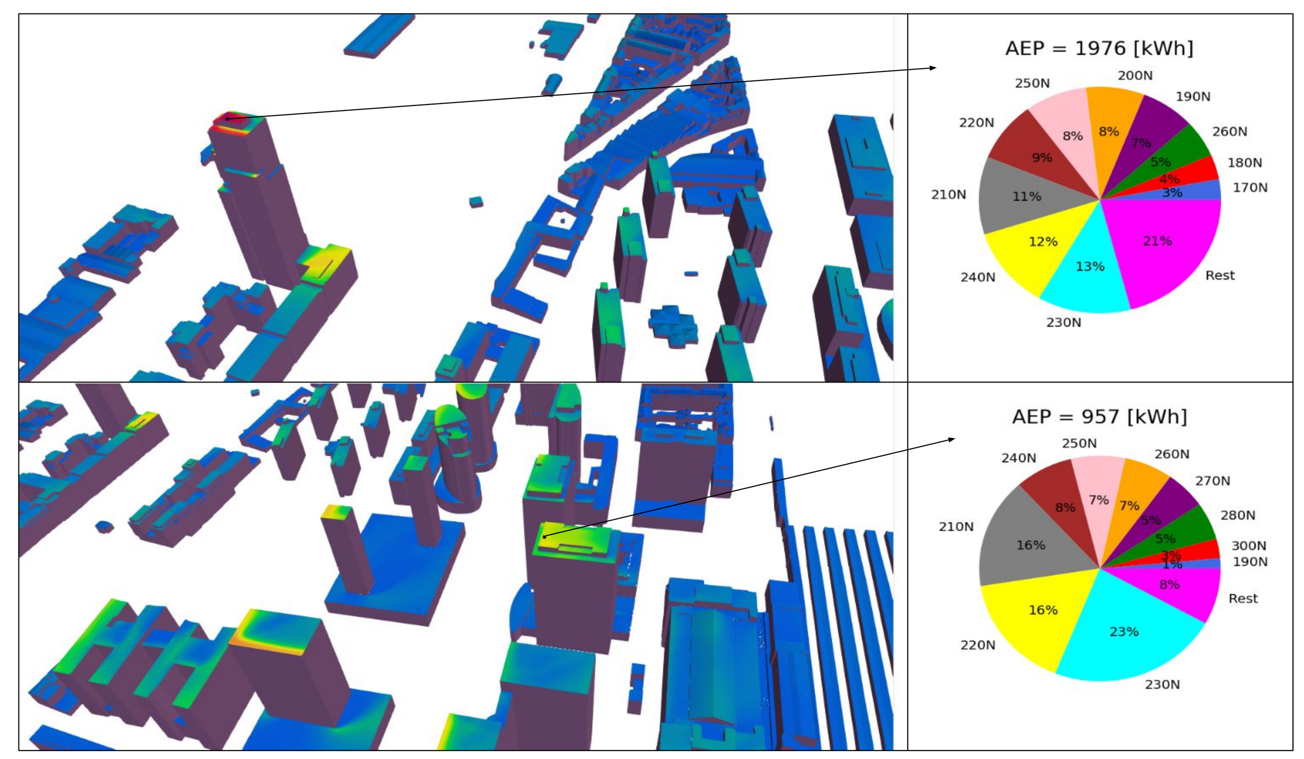
Wind direction frequency (f_θ)

Results :



Rated Power	1.5 kW
Rated Wind speed	12m/s (27 mph)
Cut-in Wind speed	3 m/s (6.7 mph)
Cut-out Wind speed	20 m/s (44 mph)
Survival Wind speed	50 m/s (110 mph)
Rated RPM	200 RPM
Noise at 12m/s	41 dB
Height	3.2 m (10.6 ft)
Width	1.8 m (5.11 ft)
Weight	274 kg (603 lbs)
Swept Area	5.76 m² (62 ft²)
Blade Materials	Fiberglass





Conclusions:

- With CFD it was possible to clearly identify roofs with high wind energy potential
- AEP showed high variability even on a single continuous roof, thus allowing accurate placement of wind turbines for maximum yield

Further studies :

- More refined geometry for the buildings with rooftops of high AEP
- Multiple simulations per direction to obtain more accurate fit of local velocity distribution
- Extend the analysis to include more neighbourhoods

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