Limits of electricity generation from wind: characterizing transitional scales in wind farm power density

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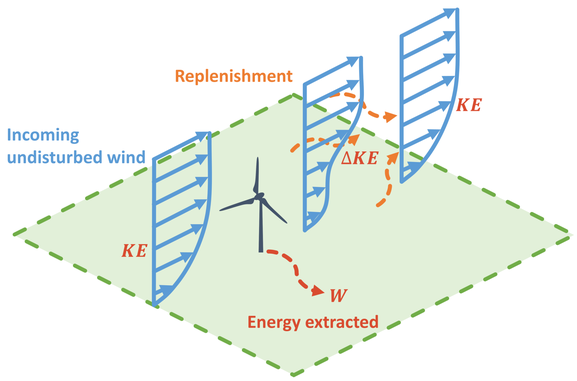
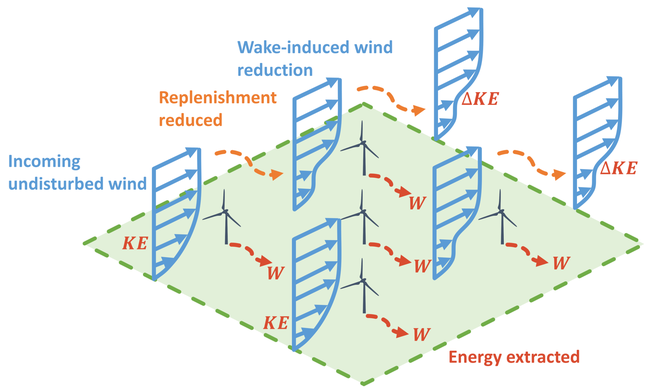
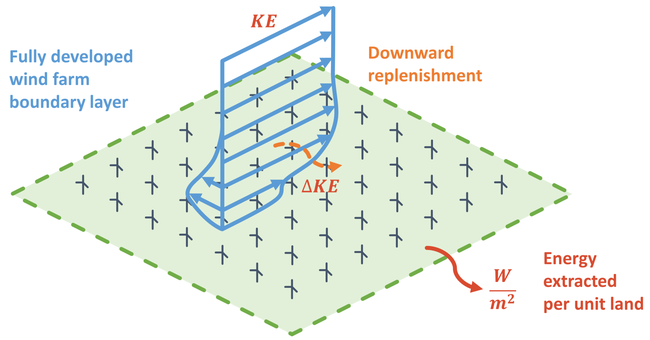
Turbine scale → Wind farm micro scale → Wind farm meso scale



- A wind turbine extracts part of the kinetic energy from an incoming undisturbed wind
- Kinetic energy is then replenished in the wake region from the sides and aloft



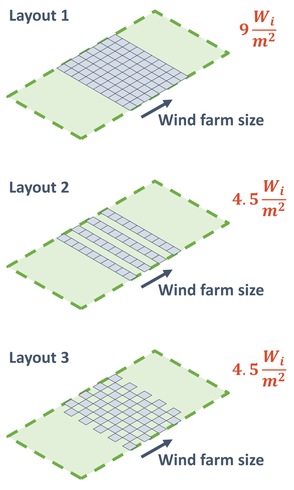
- Wind turbines extract part of the kinetic energy from the incoming wind
- The incoming wind may be slower because of the upstream turbines
- Kinetic energy is then replenished in the wake regions mostly from aloft



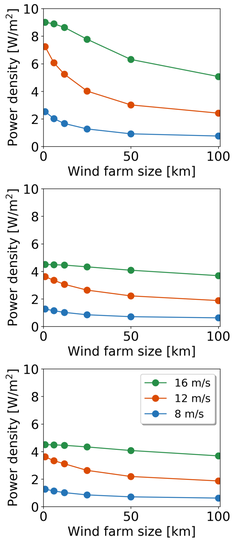
- A wind farm boundary layer develops
- Coriolis force becomes important
- Wind turbines extract part of the kinetic energy from the overlying wind
- Kinetic energy is replenished only from aloft

Investigation through numerical experiments

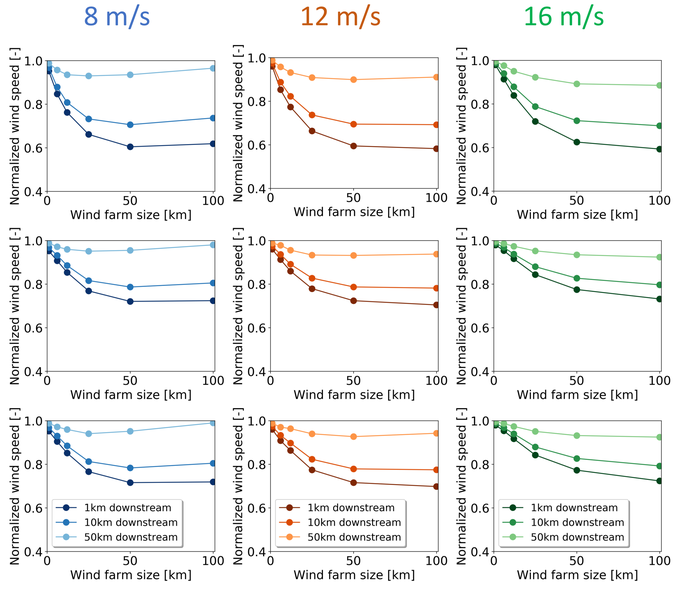
Numerical setup in WRF 4.0



Dependence of power density on layout, wind farm size and wind speed



Wind speed reduction downstream the wind farm



Key findings

- The power density of small wind farms can be much higher than large ones
- Wind farm micro scale can be identified for dimensions not exceeding 10-20 km
- For such dimensions, optimization techniques, both for layout design and operation, can be applied to improve energy extraction
- Above approximately 50 km, wind farm performance reaches saturation
- The kinetic energy available and its downward transport depend mostly on the overlying wind speed