EGU General Assembly 2020
Online | 4–8 May 2020

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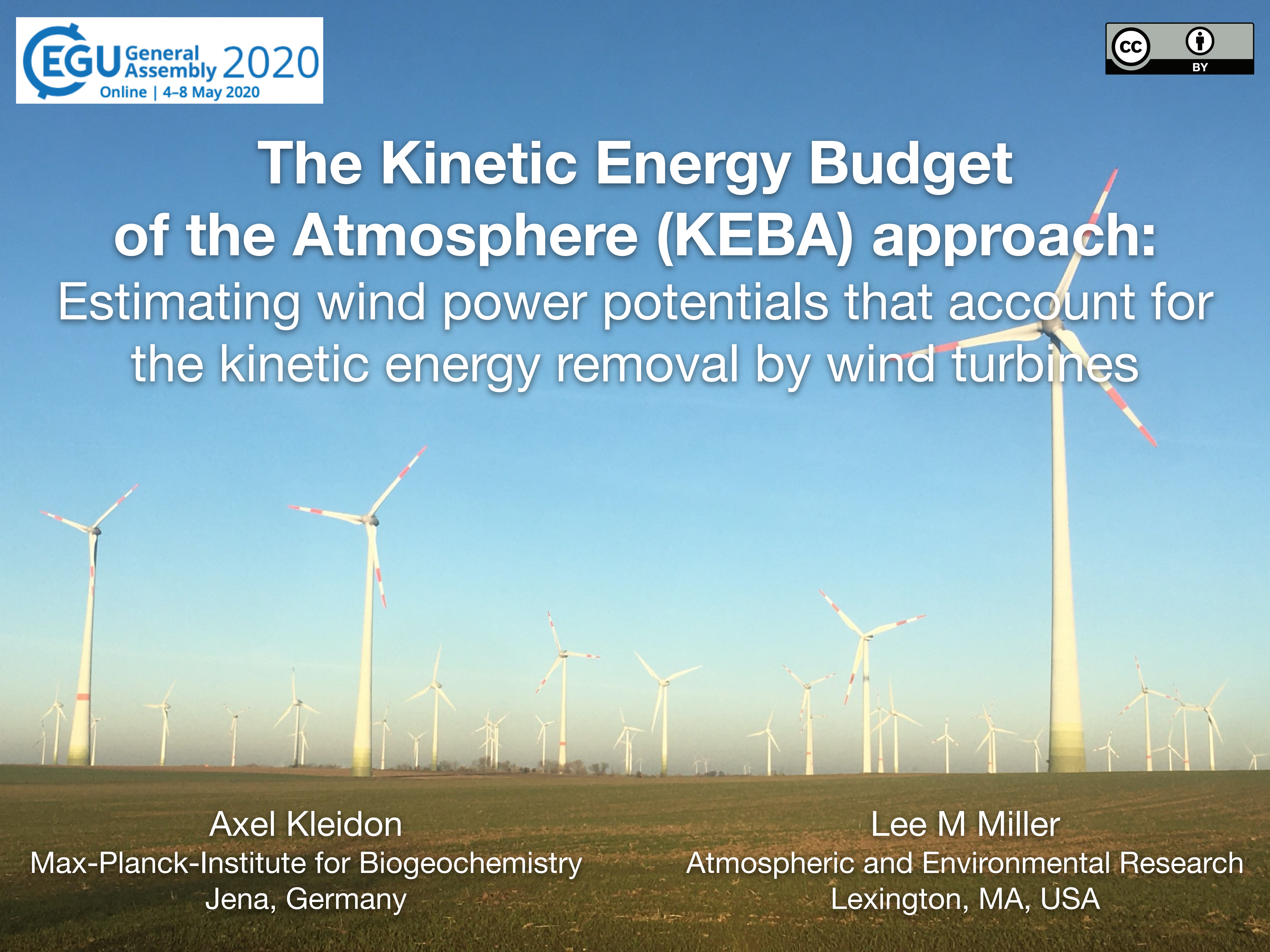

The Kinetic Energy Budget of the Atmosphere (KEBA) approach:

Estimating wind power potentials that account for the kinetic energy removal by wind turbines

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Motivation

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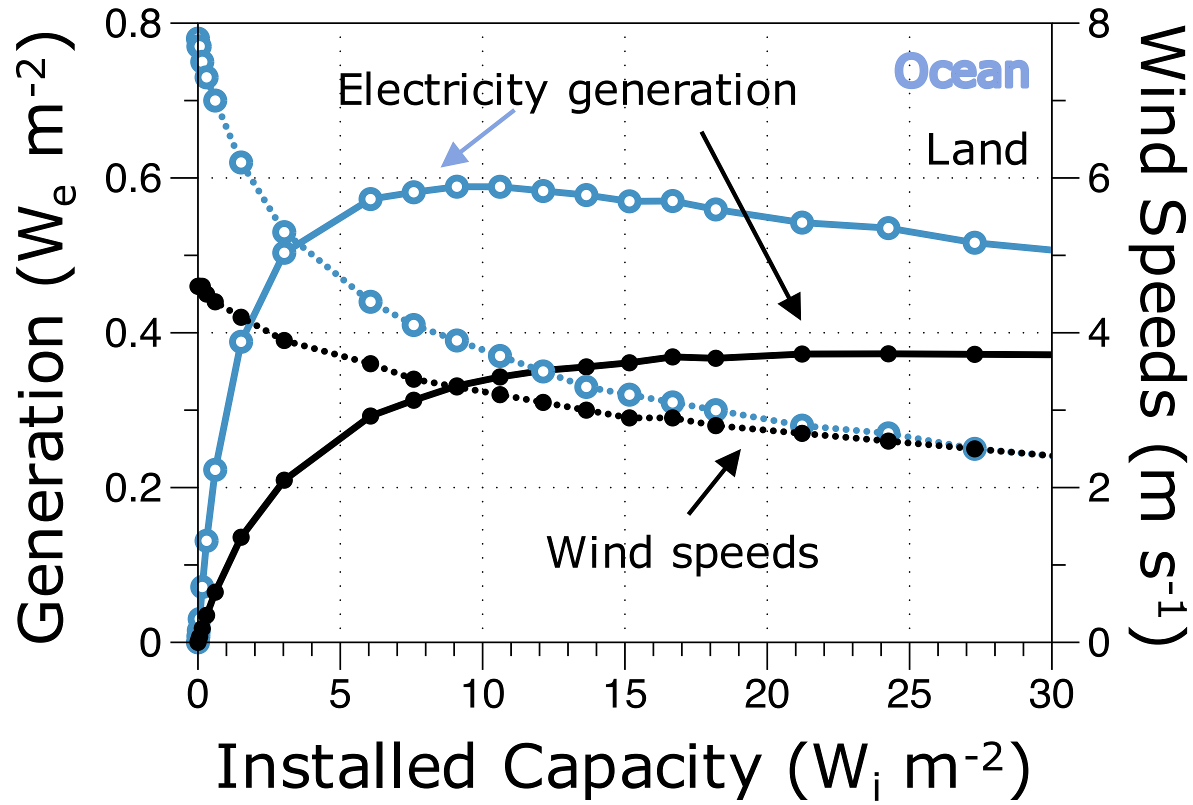
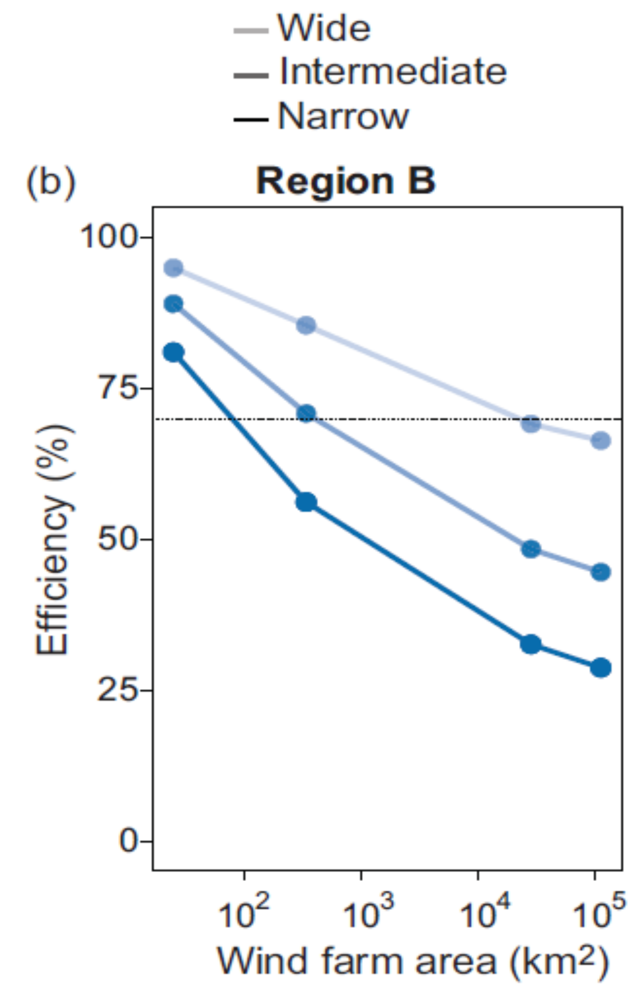
Atmospheric model simulations show that turbine yields decline as wind energy use expands in scale because of wind speed reductions





Modified after:
Miller and Kleidon (2016) *PNAS*
https://www.pnas.org/content/113/48/13570

From:
Volker et al. (2017) *ERL*
https://iopscience.iop.org/article/10.1088/1748-9326/aa5d86

How can these yield reductions due to interactions with the atmosphere be accounted for?

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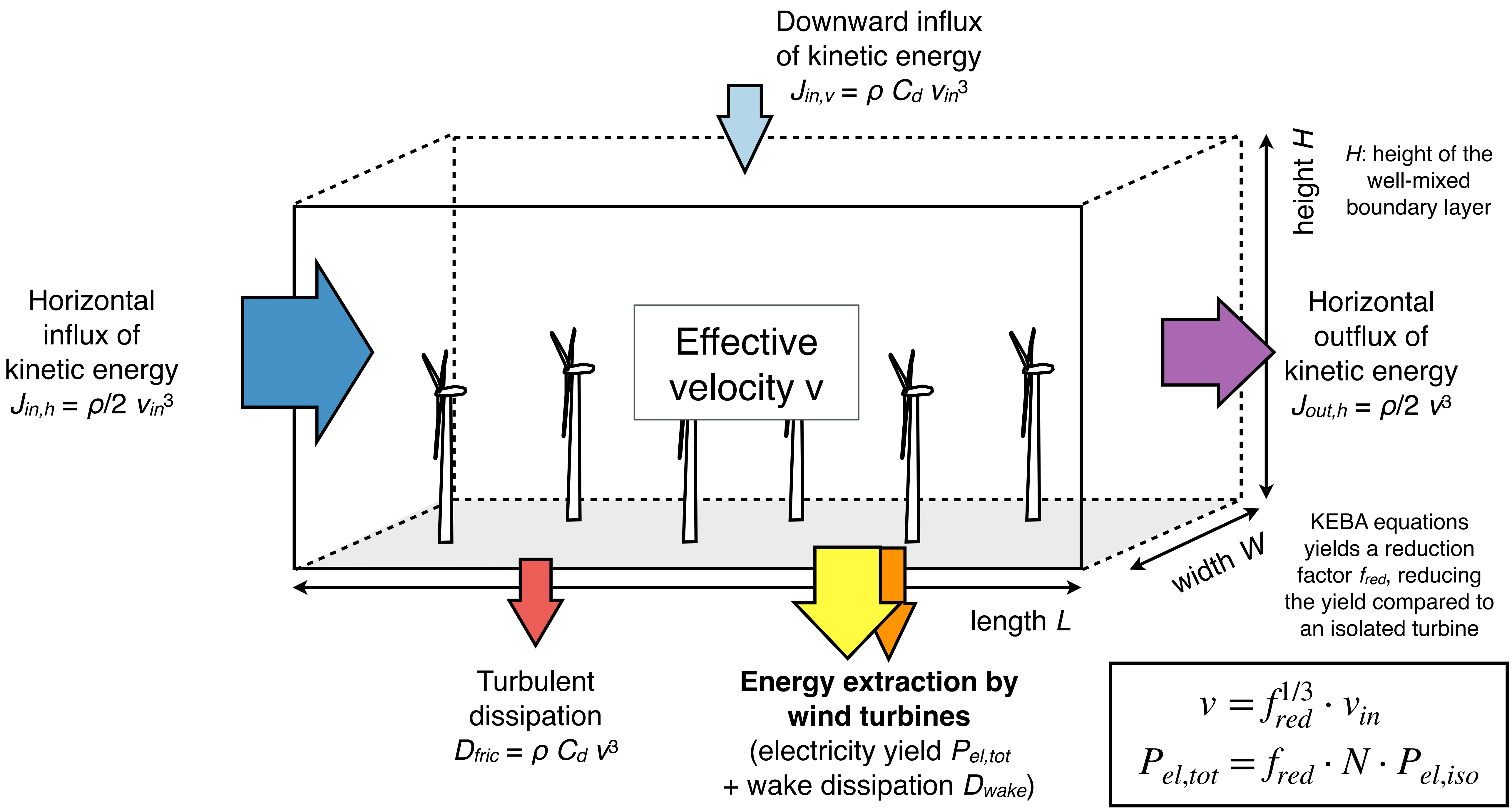
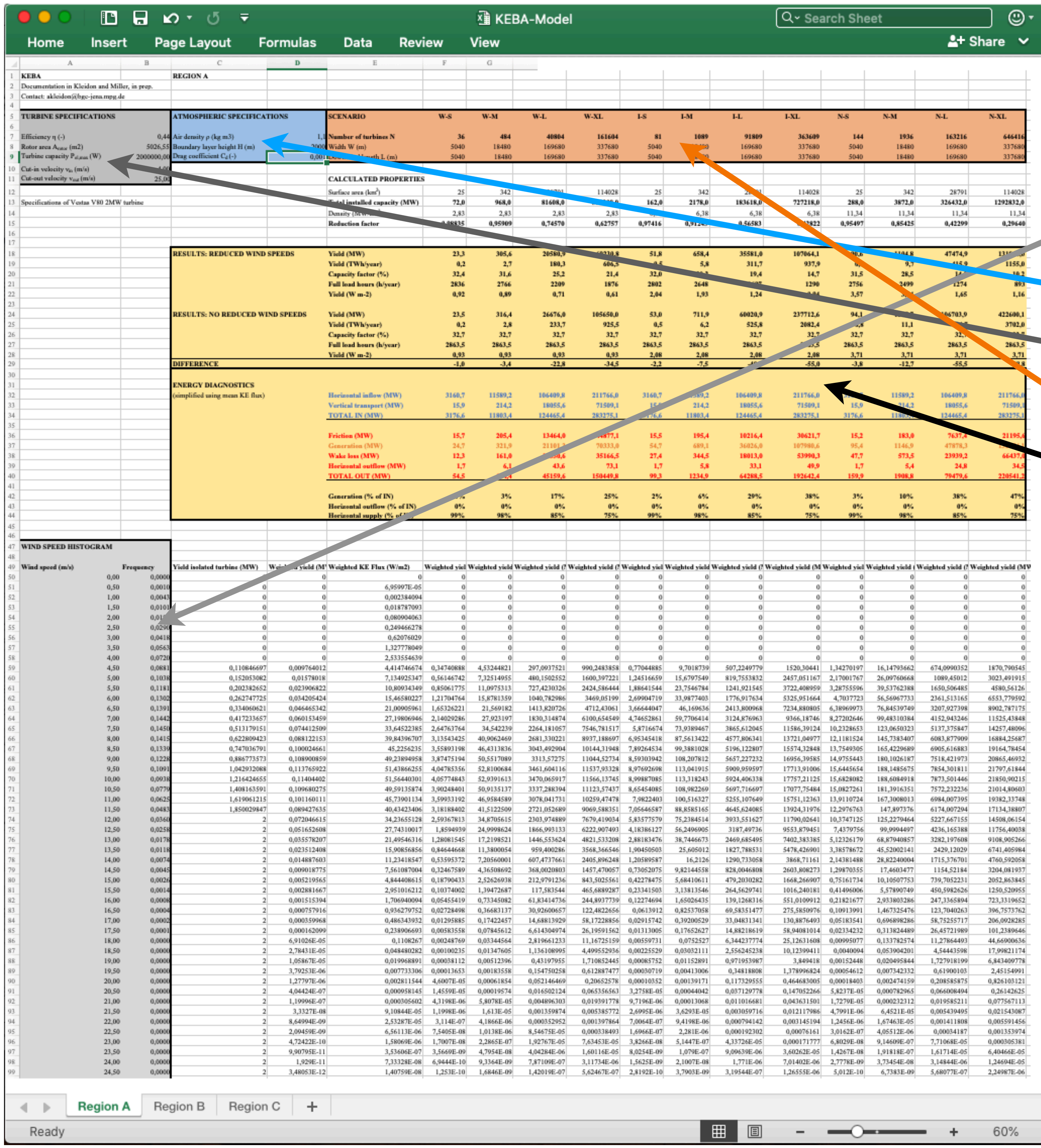
The KEBA Model

Budgeting the kinetic energy of the lower atmosphere yields analytic expressions to predict wind speed and yield reductions



The KEBA Model



The KEBA equations are implemented in an Excel spreadsheet, including:

wind forcing

atmospheric characteristics

turbine characteristics

scenario specifications

yield estimates (yellow)

Testing KEBA

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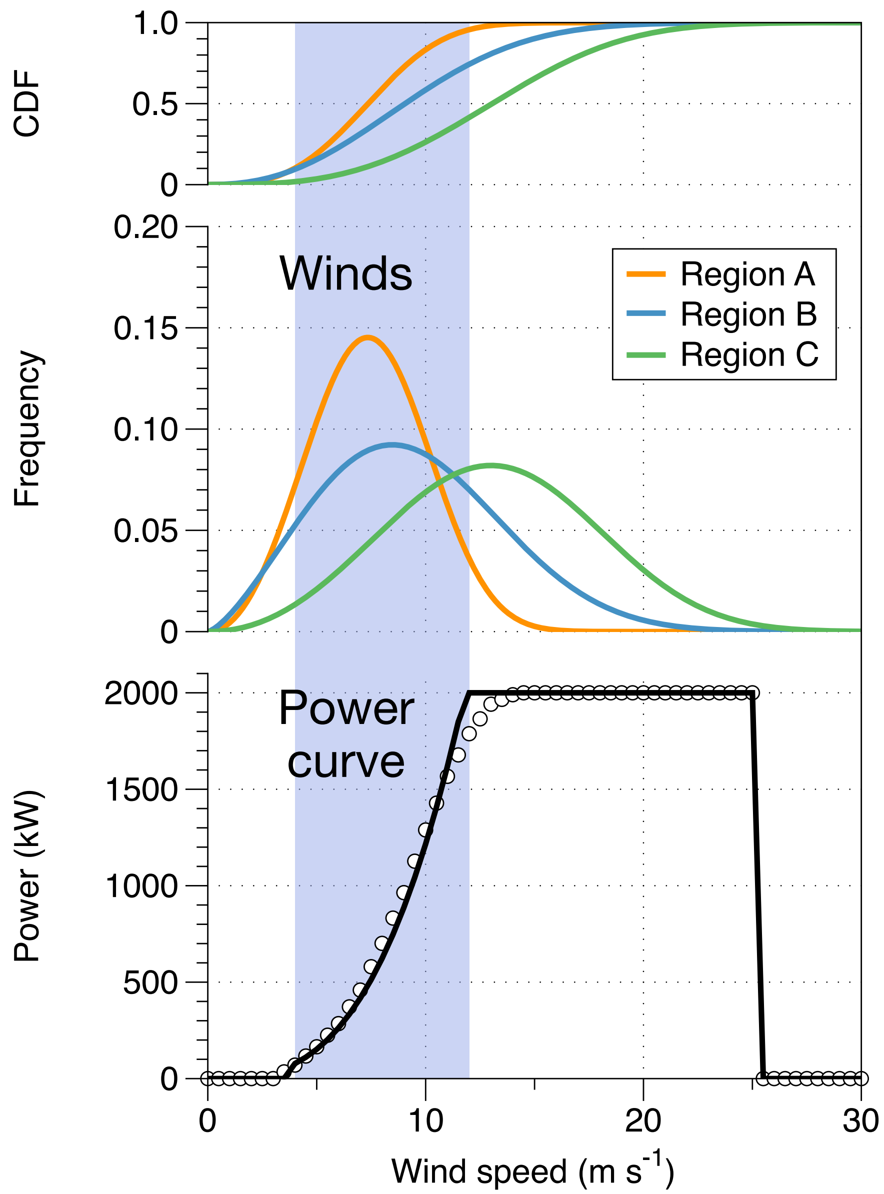
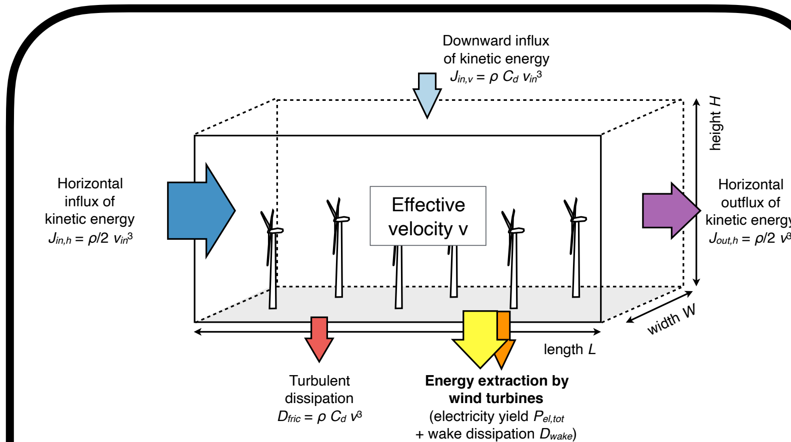
Wind forcing from 3 Regions:
Central US, North sea,
Strait of Magellan



2 MW turbine

Scenarios:
3 spacings (W, I, N)
4 sizes (S, M, L, XL),
ranging from
L = 5-340 km

Input: Wind climate, atmospheric characteristics, power curve, scenarios



KEBA model

Output:
Electricity yields, wind speed reduction, energy fluxes

WRF simulations from: Volker et al (2017), *ERL*
https://iopscience.iop.org/article/10.1088/1748-9326/aa5d86

Energy Yields

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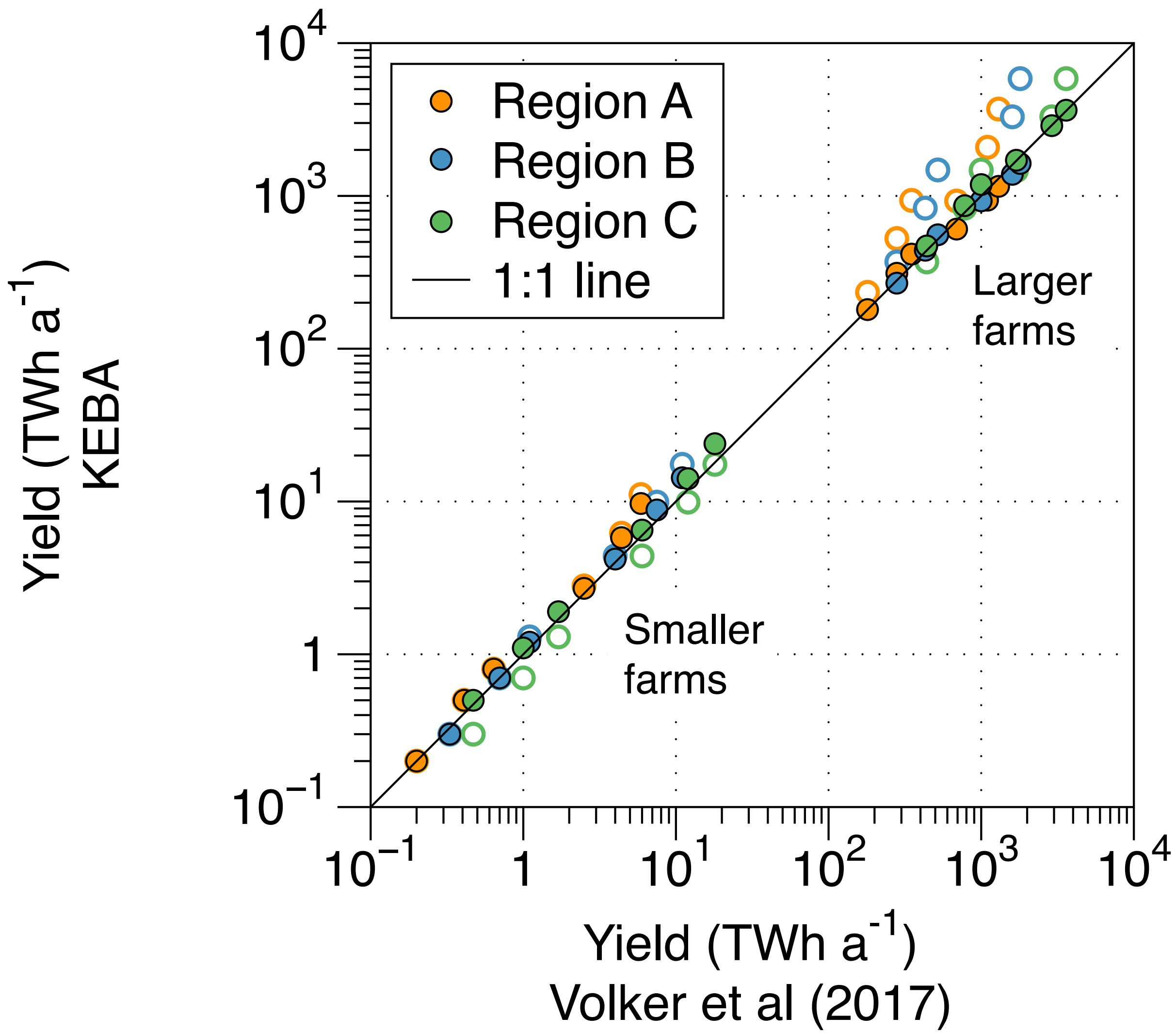
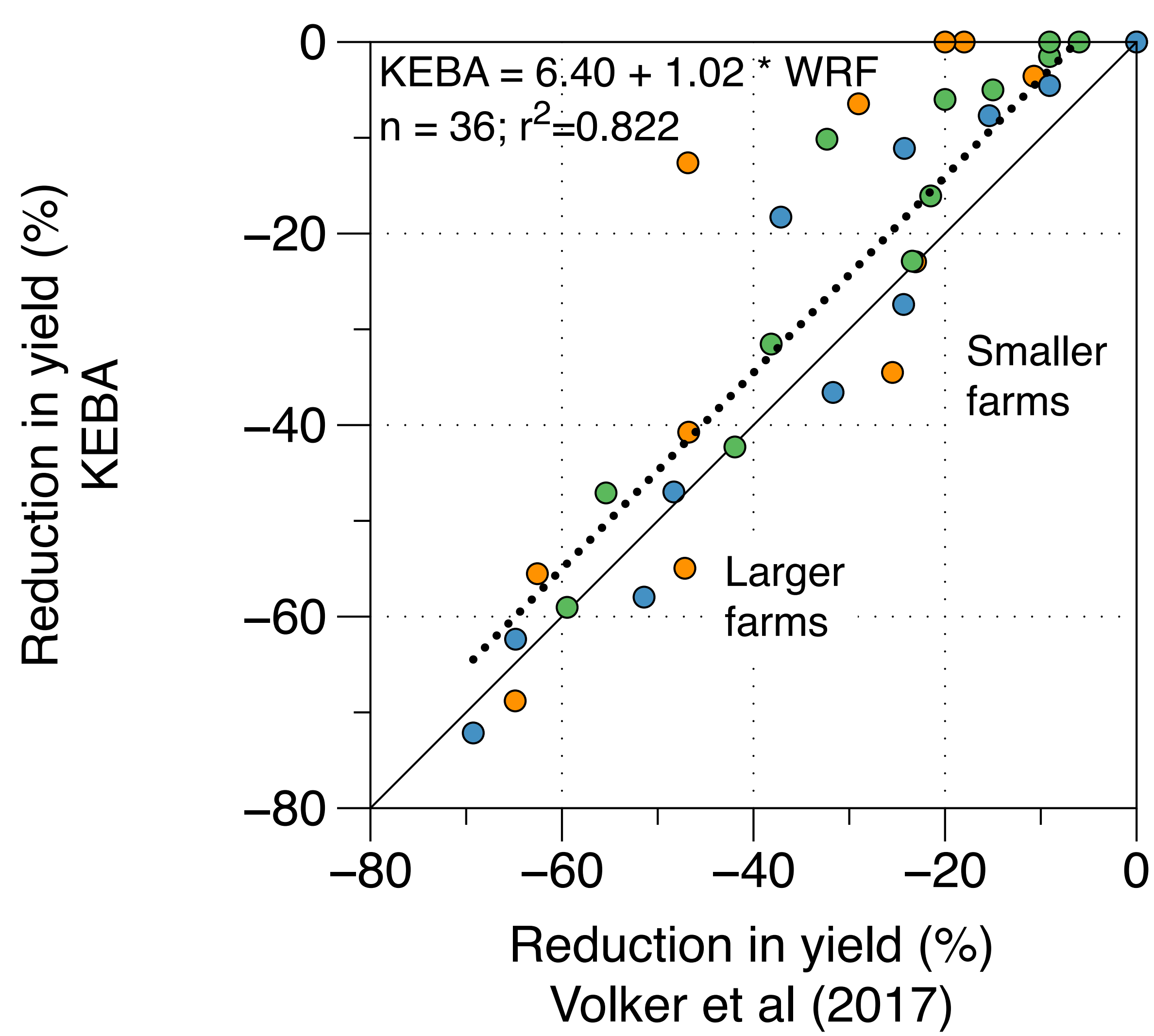
KEBA estimates compare very well to WRF-based estimates of Volker et al. (2017) across a set of sensitivities

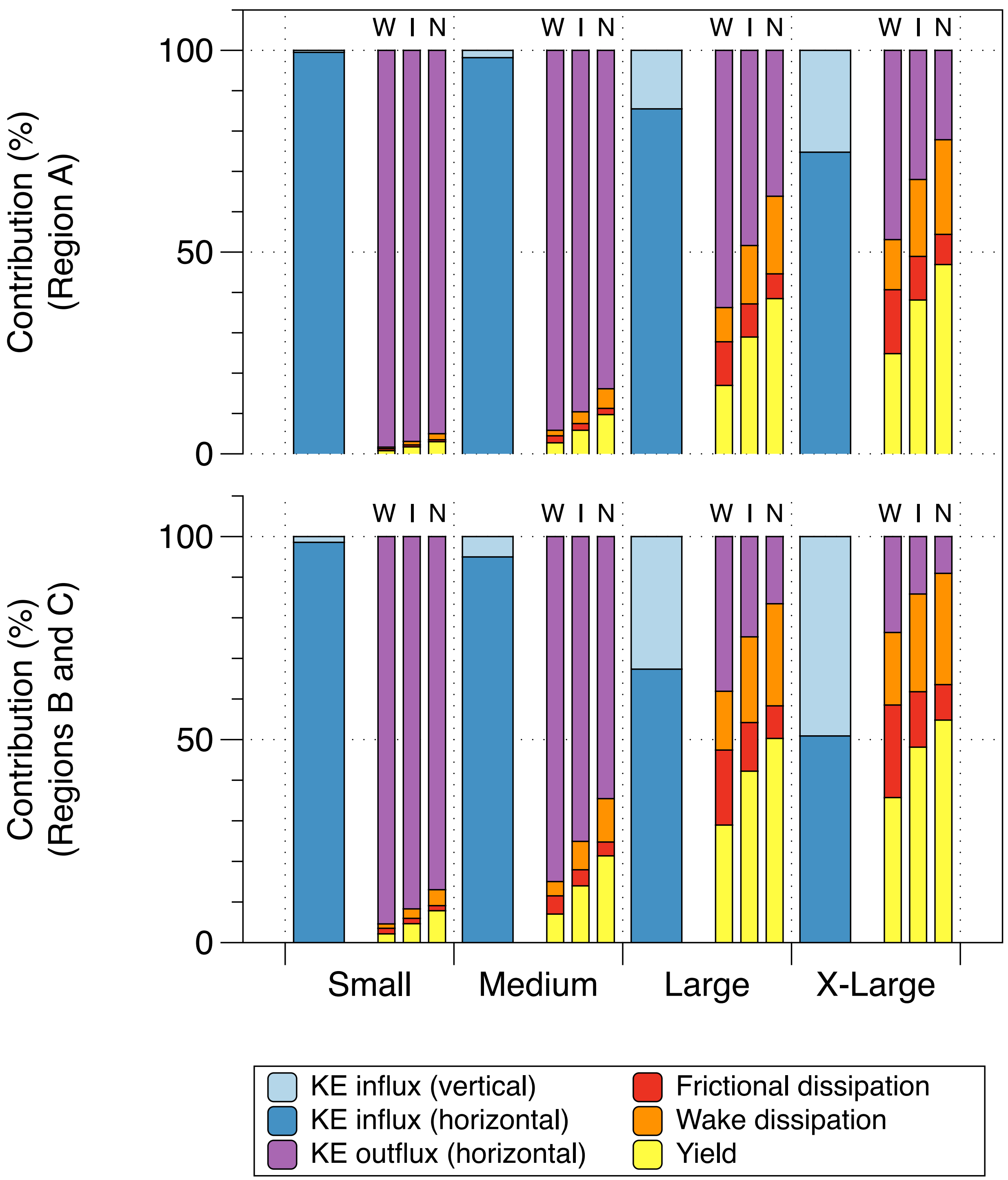
Absolute yields
(open circles: no wind reductions)



Relative reductions
(compared to no wind reductions)



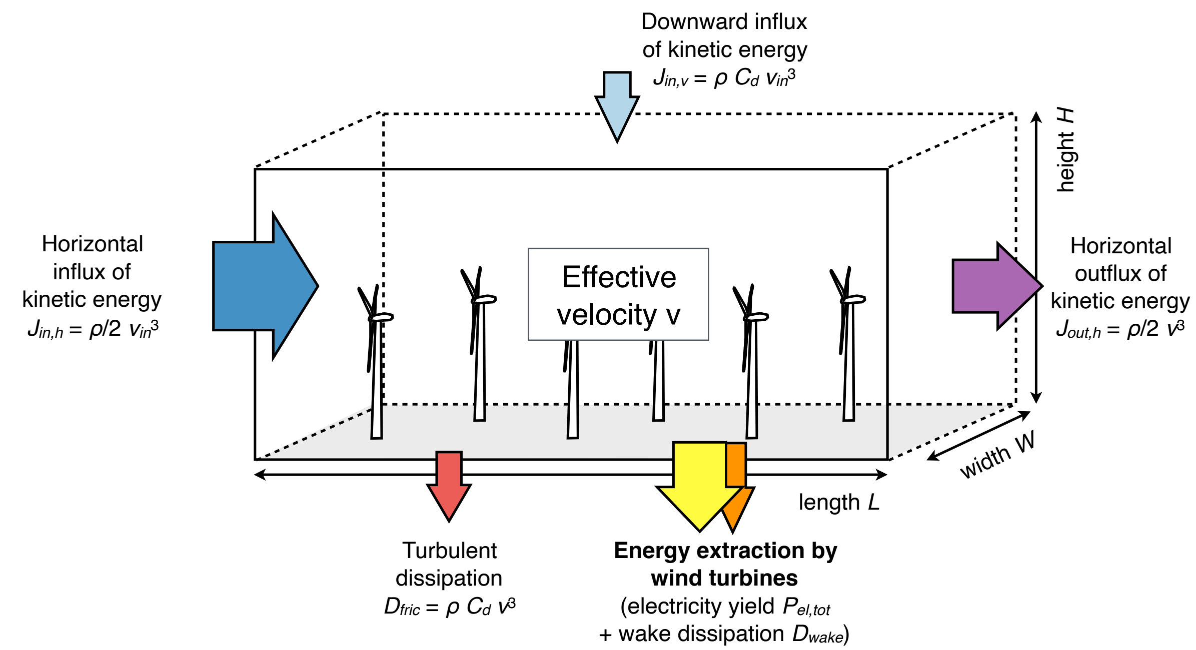
Interpreting KE Budgets



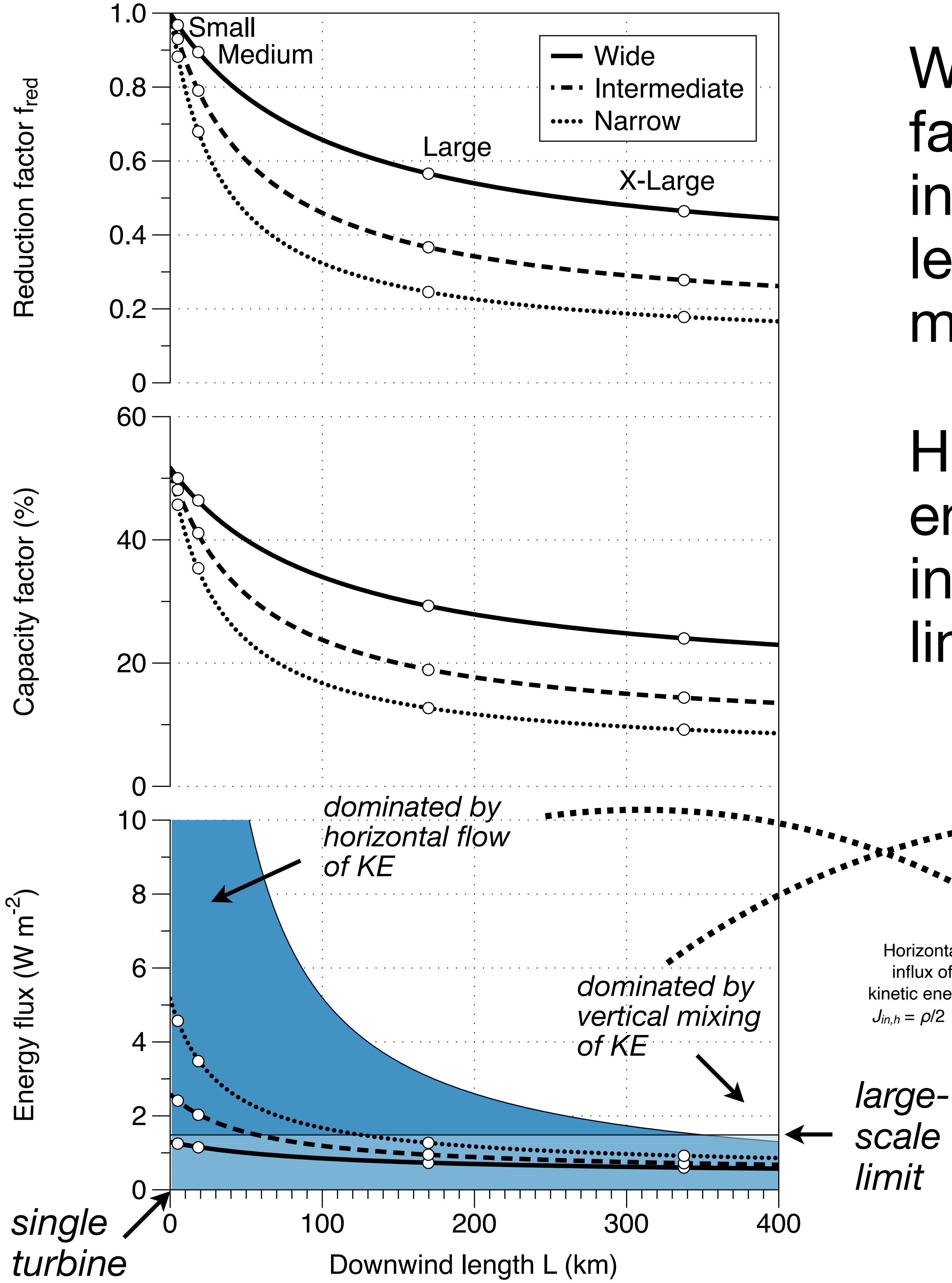
Diagnosed kinetic energy (KE) fluxes show that yields (yellow) of large wind farms (> 100 km) get close to how much wind energy enters the box (blue).

Hence, wind speeds and yields per turbine are reduced.

Energy fluxes (left) have the same color as arrows in the KEBA diagram (below)

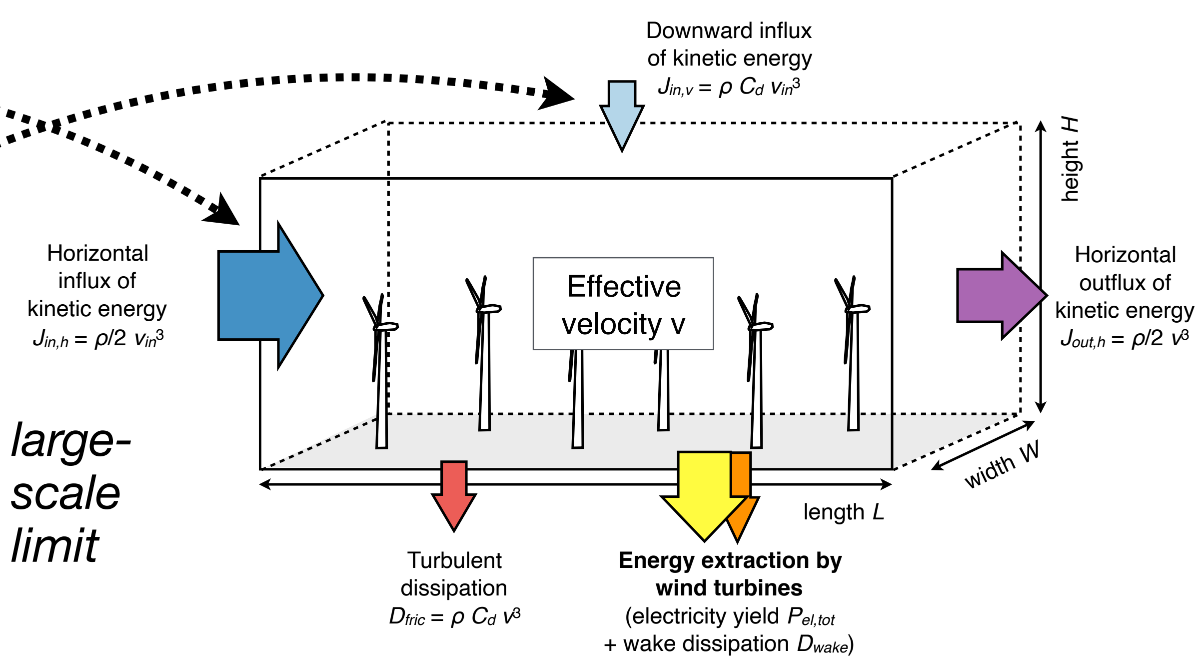


Larger Scales = Less Wind Energy



When downwind length of wind farms increases, the horizontal inflow of kinetic energy becomes less important, while the vertical mixing becomes more important.

Hence, at larger scales, the wind energy yields converge from initially large (> 1 W m^{-2}) to a low limit of < 1 W m^{-2} per surface area.



Summary

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The Kinetic Energy Budget of the Atmosphere (KEBA):

A physics-based method to account for wind speed and yield reductions in large wind farms

Works very well compared to WRF simulations

Provides explanations why wind energy potentials decline to < 1 W m^{-2} at large, downwind scales L > 100 km

More Information:

Application to German Offshore wind energy potentials
https://www.agora-energiewende.de/projekte/offshore-wind-potenzial/

KEBA Spreadsheet available on MPG Data Repository
https://edmond.mpdl.mpg.de/imeji/collection/ctvrVzG7CpKsqBB?q=

Manuscript has been submitted

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