MISTRA ELECTRIFICATION

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Trends in turbine sizes and its effect on onshore wind deployment

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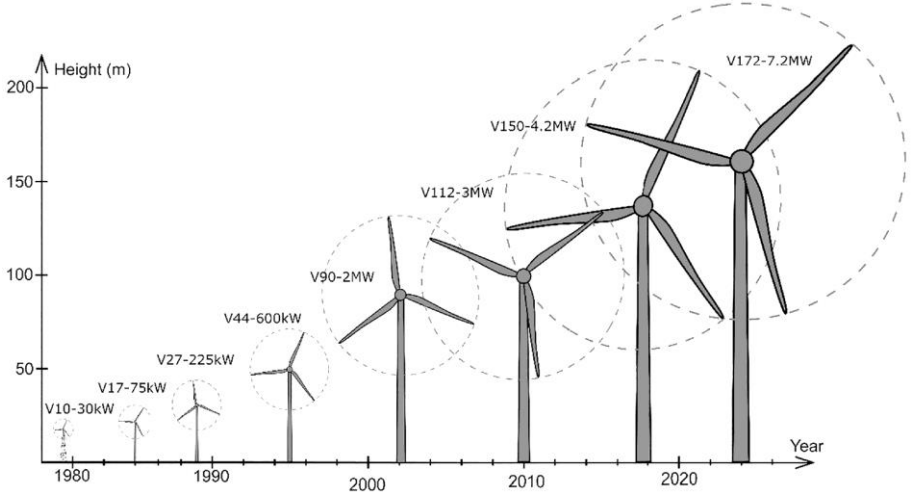
Technological advancement and installation pattern

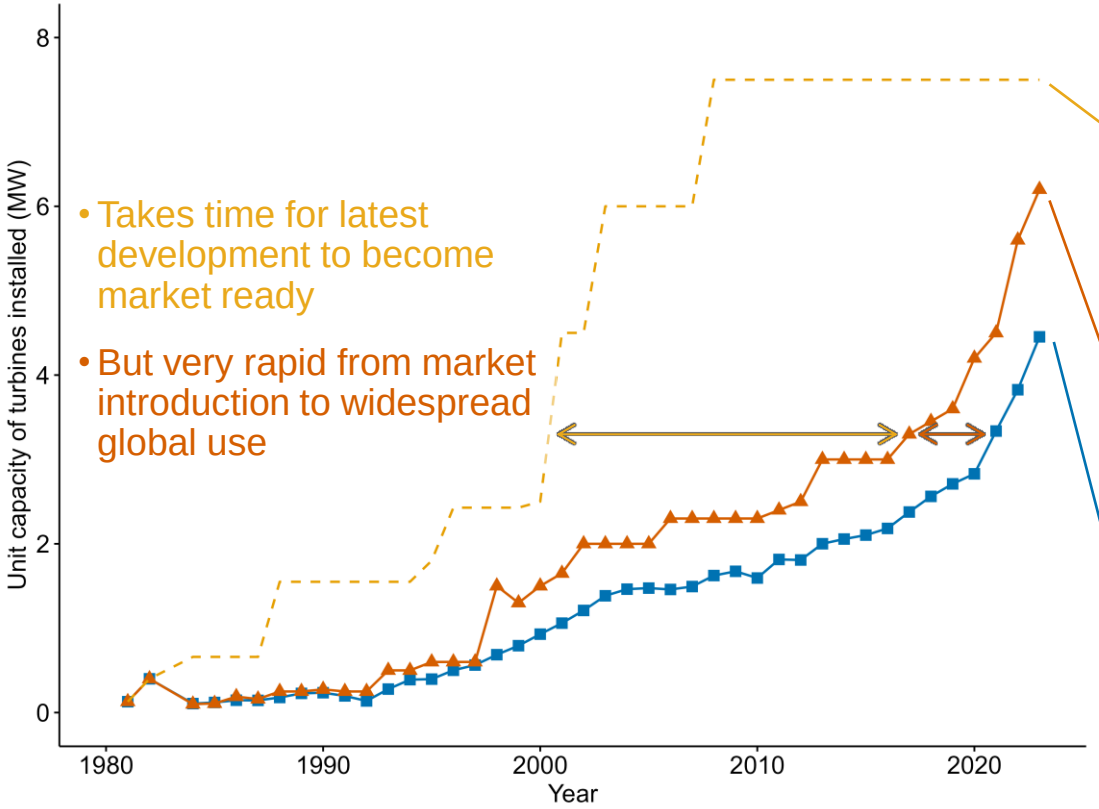
- One of the global advancements in turbine technology is **increasing unit capacity (upscaling)**
- How does upscaling **impact installation**?
  - How fast does advancement in turbine technology reach different countries?
  - Does it affect where the turbines are installed within a country? (the case of Swedish municipalities)



Vestas onshore turbine evolution
(Source)

Upscaling trend in turbines installed globally

28 countries ~ 86% onshore wind generation



- Takes time for latest development to become market ready
- But very rapid from market introduction to widespread global use

Technological frontier
Largest turbines installed, mainly testing units

Countries with strong R&D: DE, DK

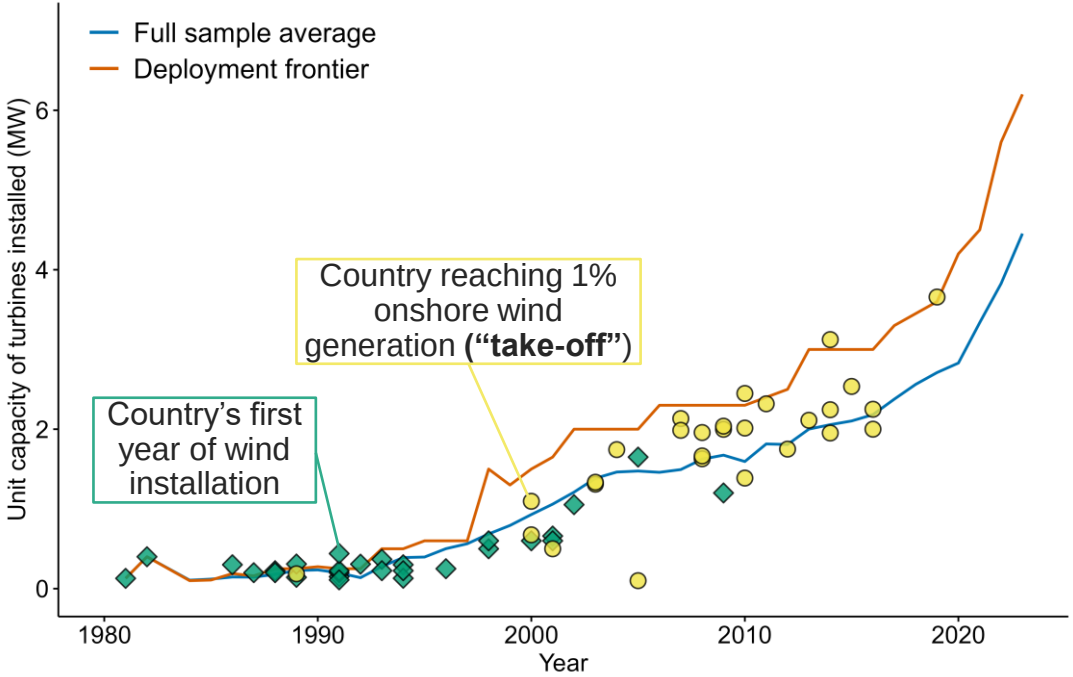
Deployment frontier
90th percentile of turbines installed, largest turbines commonly in commercial use

Global market: no specific countries

Average size of turbines installed

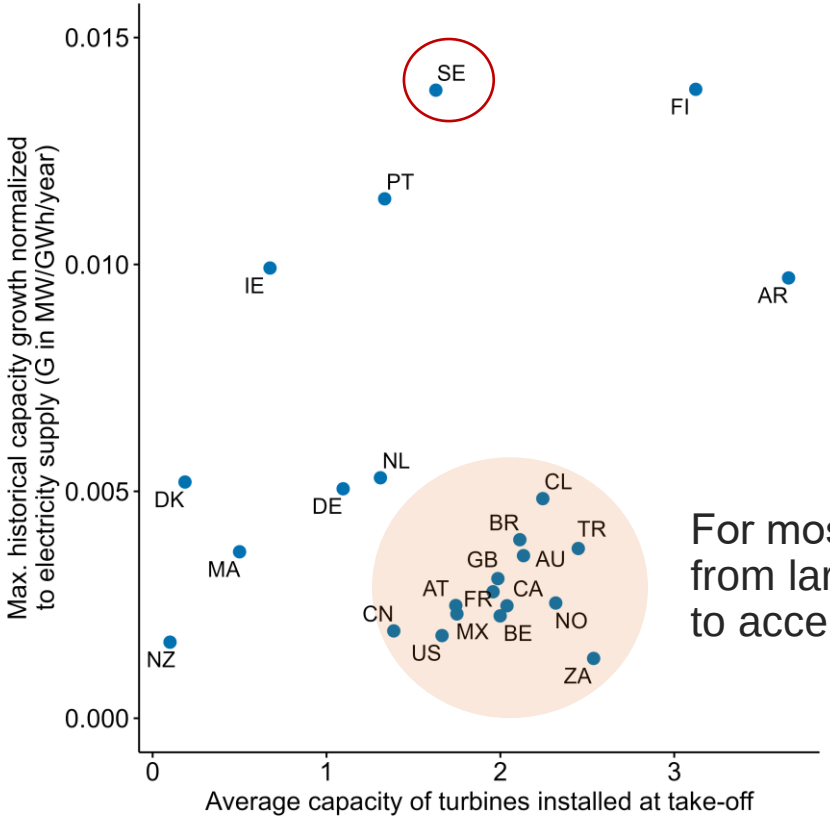
Upscaling trend in turbines installed globally

28 countries ~ 86% onshore wind generation



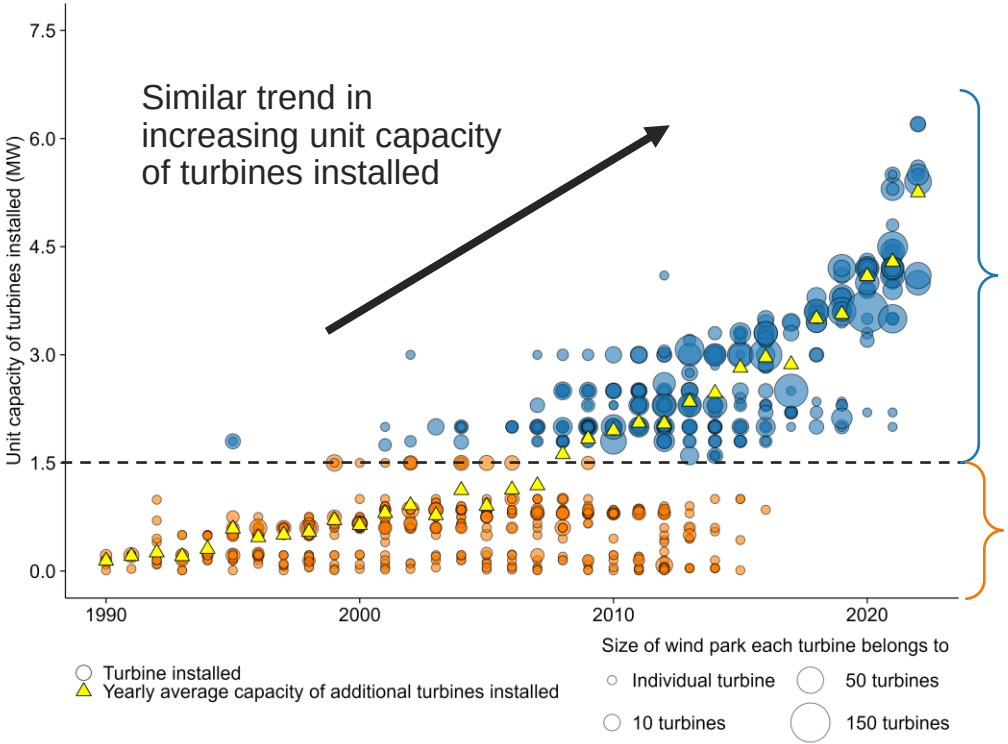
Countries at early phase of wind deployment were able to install larger turbines at deployment frontier, skipping older, smaller generations of turbines

Larger turbines and onshore wind growth



For most countries, “headstart” from larger turbines do not lead to accelerated growth

Upscaling in turbines installed in Sweden

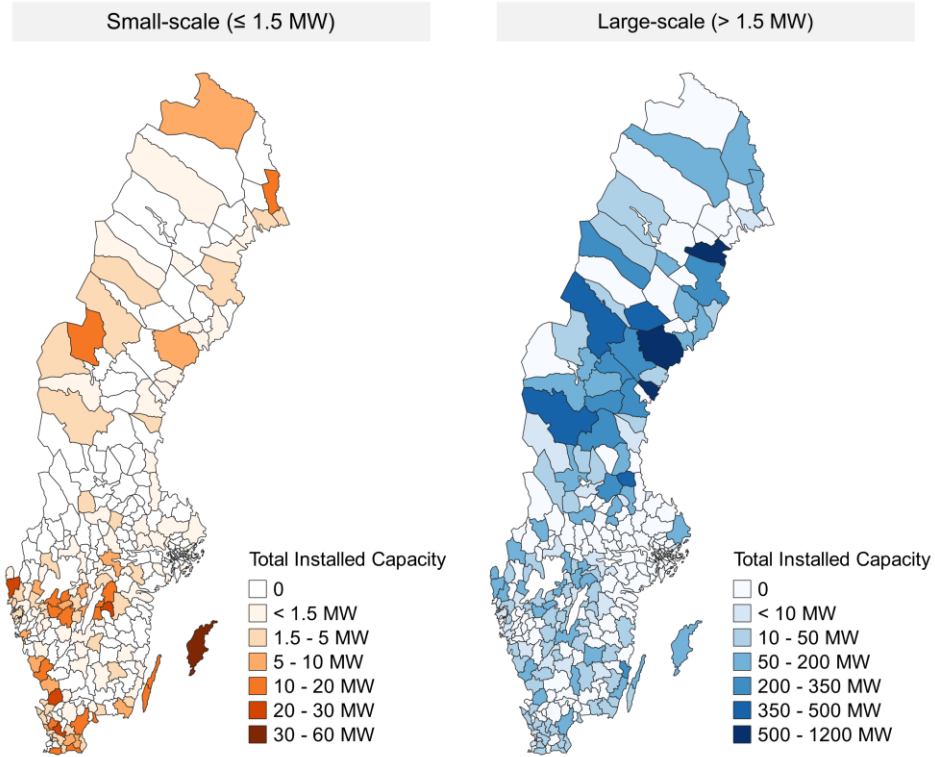


Why is this interesting?

Large-scale
Unit capacity > 1.5 MW
Larger turbines projected in the coming years → what is relevant

Small-scale
Unit capacity ≤ 1.5 MW
Obsolete technologies no longer deployed in SE

Upscaling affects turbine placement



- Large spatial variation: earlier, smaller turbines **vs** more recent, larger turbines
- Even between neighboring municipalities with similar wind resource & other land characteristics
- **What municipal characteristics have shaped this variance?**
  - Given the upscaling trend, may be important to distinguish which observation is still relevant for future wind deployment

Municipal characteristics
Top 10% wind speed
Land area (< 1000 m altitude, in km^2)
Agricultural land use (in % of total area)
Protected natural area (WDPA cat. 1A, in % of total area)
Electricity price area
Population density
Years since initial wind development
Presence of small-scale wind power
Presence of hydropower
Employment rate
National area of interest for wind power (in % of total area)
Electoral participation to municipal election
Share of votes for Green Party to municipal election

Statistical analysis (linear regression) to determine:

- Effect on total installed capacity of different turbine sizes in each municipality (aggregated effect, not where each turbines are)
- Both technical and non-technical characteristics
- Positive or negative? How strong? Or no effect?

Municipal characteristics	Small-scale wind power (≤ 1.5 MW)
Top 10% wind speed	No effect
Land area	Strong positive effect
Agricultural land use	Moderate positive effect
Protected natural area	No effect
Electricity price area	No effect
Population density	No effect
Years since initial wind development	Strong positive effect
Presence of small-scale wind power	No effect
Presence of hydropower	No effect
Employment rate	No effect
National area of interest for wind power	No effect
Electoral participation to municipal election	No effect
Share of votes for Green Party to municipal election	No effect

- Usual culprit: wind speed, population density, and protected area have no effects!
- Smaller older turbines built in southern municipalities with agricultural areas
- Localized “cumulative learning effect”: more experience with wind leads to more deployment

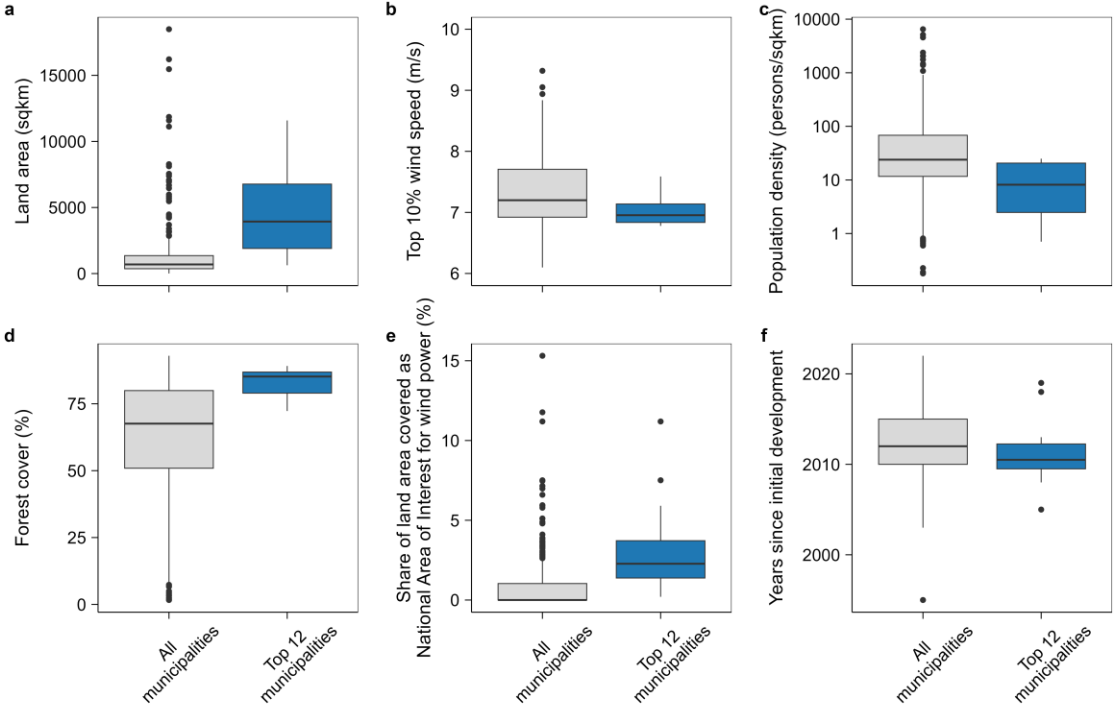
Municipal characteristics	Small-scale wind power (≤ 1.5 MW)	Large-scale wind power (> 1.5 MW)
Top 10% wind speed	No effect	No effect
Land area	Strong positive effect	No effect
Agricultural land use	Moderate positive effect	No effect
Protected natural area	No effect	No effect
Electricity price area	No effect	No effect
Population density	No effect	No effect
Years since initial wind development	Strong positive effect	No effect
Presence of small-scale wind power	No effect	No effect
Presence of hydropower	No effect	No effect
Employment rate	No effect	No effect
National area of interest for wind power	No effect	Moderate positive effect
Electoral participation to municipal election	No effect	Strong positive effect
Share of votes for Green Party to municipal election	No effect	No effect

- Different results for large-scale!
- No local learning: sporadic development, recent larger projects
- Siting recommendation coincides with where wind are being deployed
- High electoral participation may be a proxy of trust in government (& politicians): survey for SE showed it is related to support for wind projects

Closer look at municipalities with most large-scale wind power

Top 12 municipalities
300 MW – 1,2 GW in total installed capacity

What distinguishes them from other municipalities?



Summary

How does upscaling of onshore wind turbine impact its installation?

- Once latest state-of-the-art turbines are market ready, they spread rapidly globally
- Countries build larger turbines over time but do not have accelerated growth
- Changing pattern of spatial allocation in Swedish municipalities due to upscaling
  - Earlier, smaller turbines: southern agrarian municipalities, localized accumulation of capacity
  - More recent, larger turbines: political factors matter more

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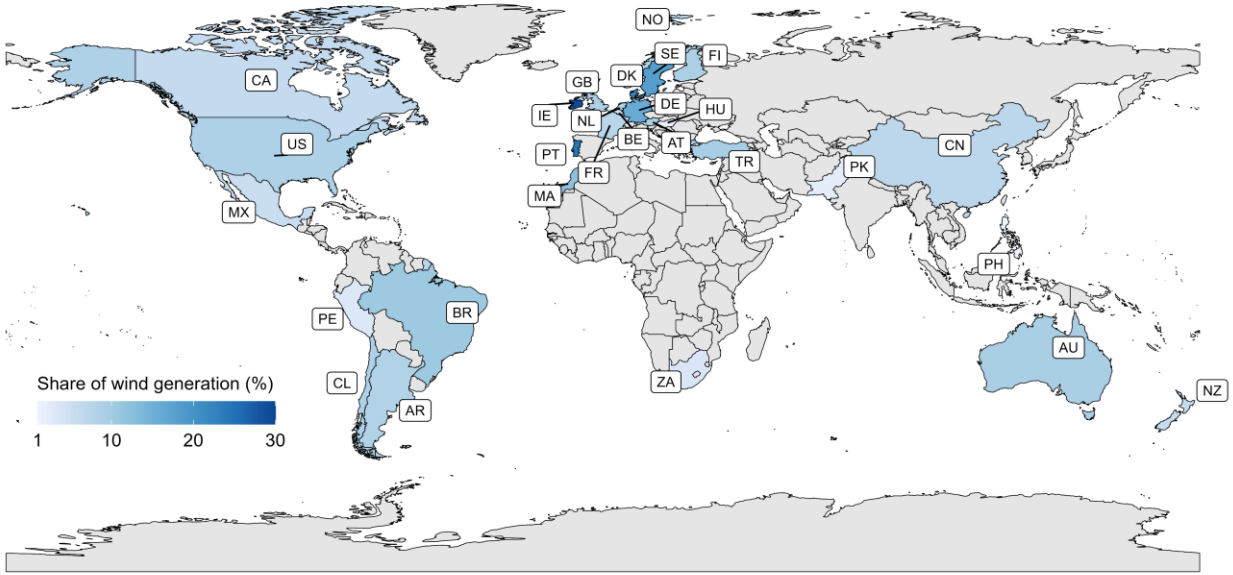
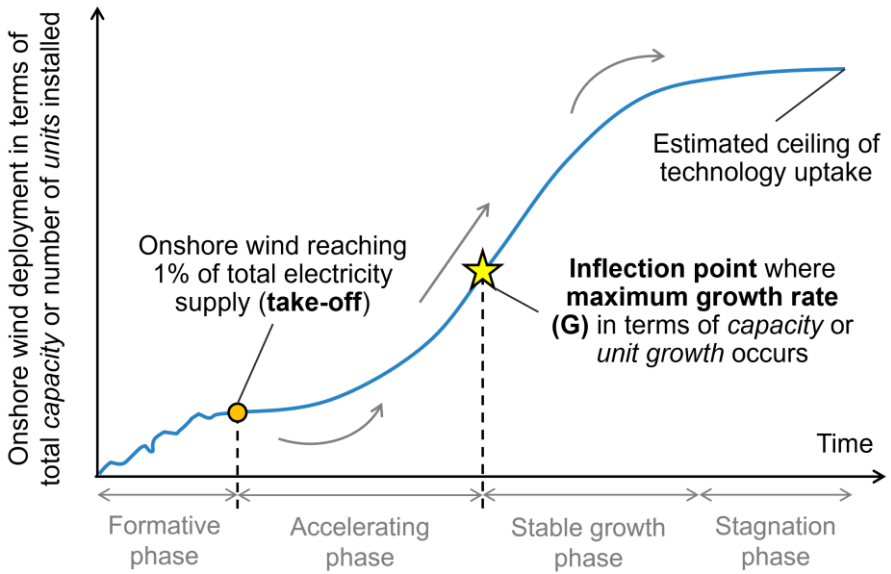
Global turbine data



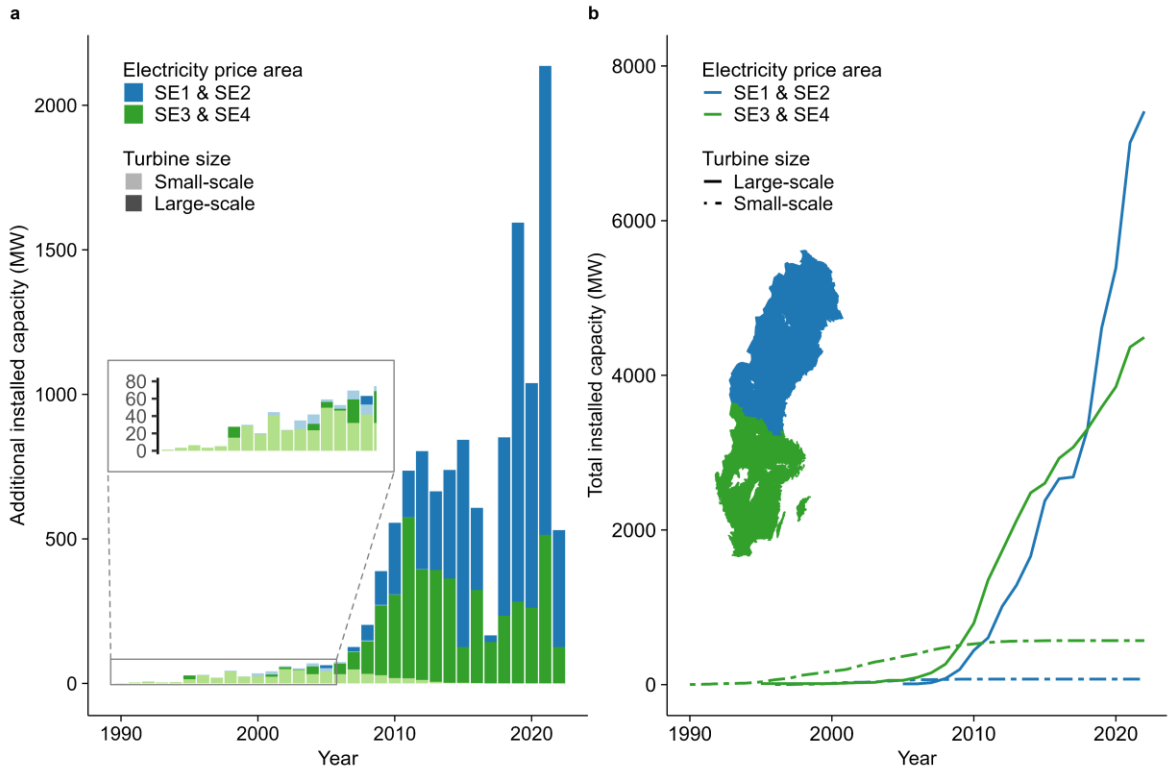
- Global onshore wind park data: turbine size, turbine type, park size (1980 – 2023)
- Countries with min. 1% onshore wind generation & electricity supply > 30 TWh
- Countries with more than 10% of data missing are removed
- 28 countries ~ 86% global onshore wind generation
- Major players ES & IN missing

Diffusion phases and measure of growth



- Robust growth metric measured at inflection point
- Annual country-level data of total installed capacity fitted to logistic/Gompertz curve
- Normalized to electricity supply to enable cross-country comparison (growth rate unit becomes MW/*GWh*/year)
- One caveat for growth measured at inflection point: only for countries that *have passed* the inflection point
- For countries in accelerating phase, average annual growth rate (supply-normalized) over the last three years is used

Spatial allocation of turbines across the electricity price areas over time



Comparison to select EU countries