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Effect of resource availability and grid integration on wind energy development

GOKUL IYER, HAEWON MCJEON, AND LEON CLARKE

Snowmass meeting

GCAM:
The Global Change Assessment Model

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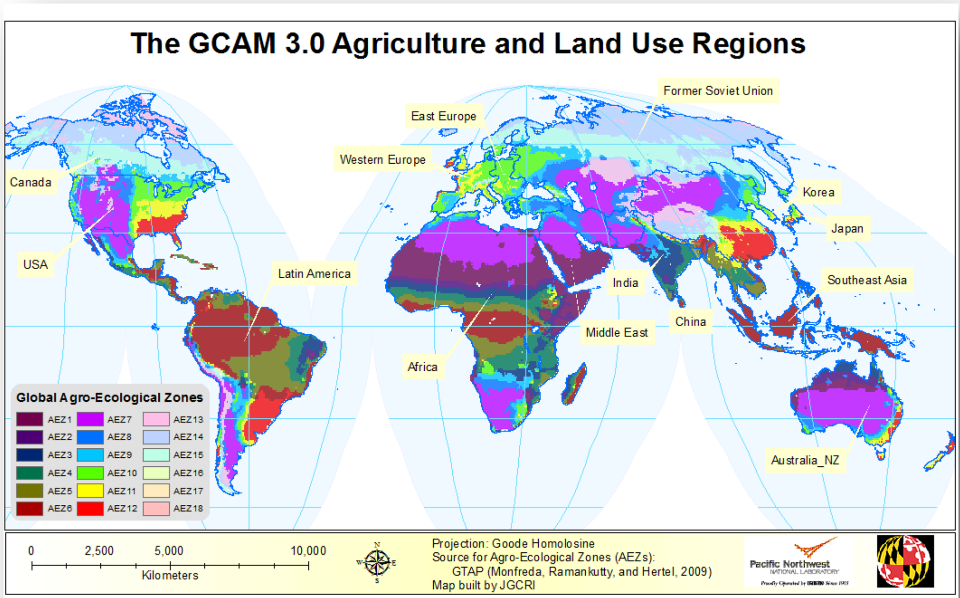
14 Region Energy/Economy Model Regions

151 Agriculture and Land Use Model Regions

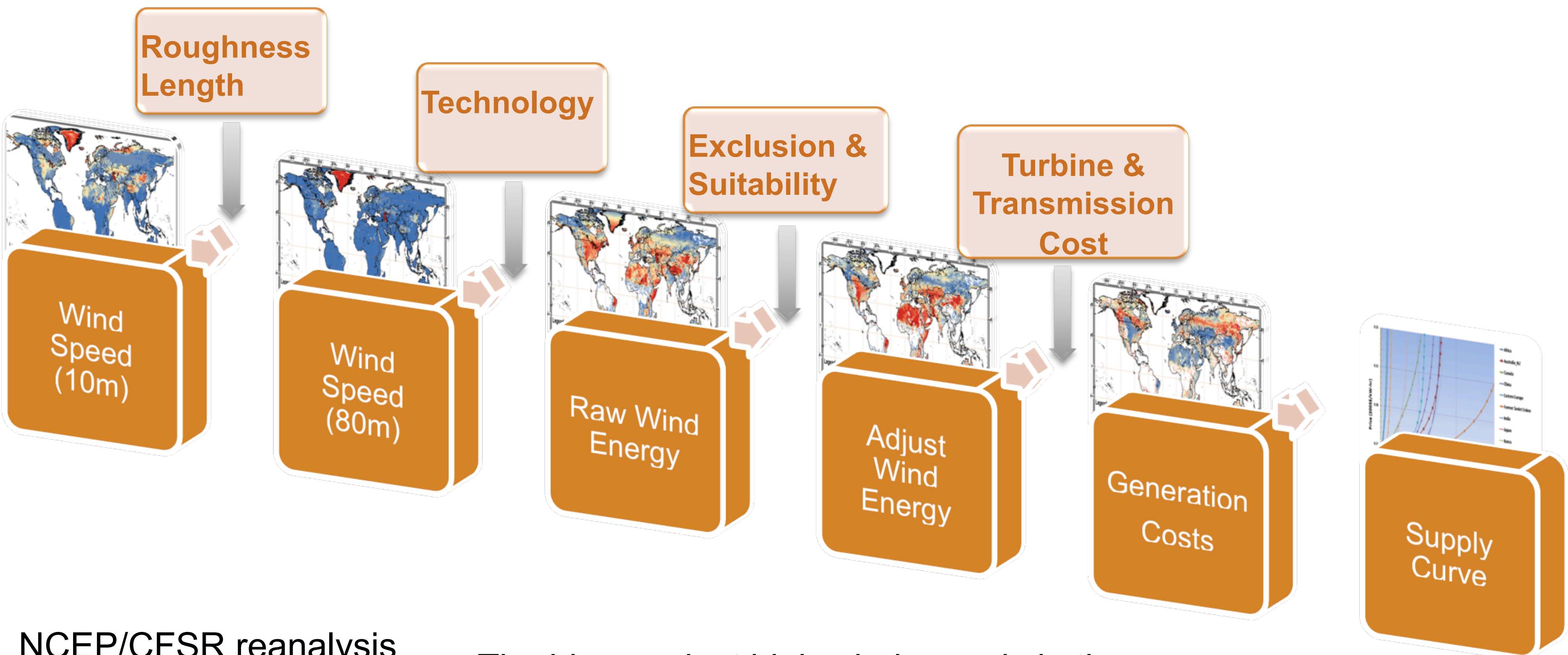


- GCAM is a **global integrated assessment model**
- GCAM links **Economic, Energy, Land-use,** and **Climate** systems
- Emissions of **16 greenhouse gases and short-lived species:** CO_2, CH_4, N_2O, halocarbons, carbonaceous aerosols, reactive gases, sulfur dioxide.
- Runs through **2095** in **5-year time-steps.**
- GCAM is implemented using **object-oriented programming**, providing a robust and flexible platform for future work.
- Documentation available at: **wiki.umd.edu/gcam**

- Started in 1978 – a DOE-SC investment to address the need for an explicit research tool to assess the link between human energy systems and carbon emissions (part of the Carbon Cycle Program back then).
- 1984 first integration of GCAM (then called Edmonds-Reilly) with the DOE carbon cycle model.
- Formerly known as MiniCAM

Some Themes from Last Year's Talk

Overview of Methodology for Wind Supply Curve



NCEP/CFSR reanalysis
0.3125 degree
1979-2009 (hourly)
PNNL/JGCRI

The bias against high wind speeds in the reanalysis dataset limits the estimates of the cheapest wind.

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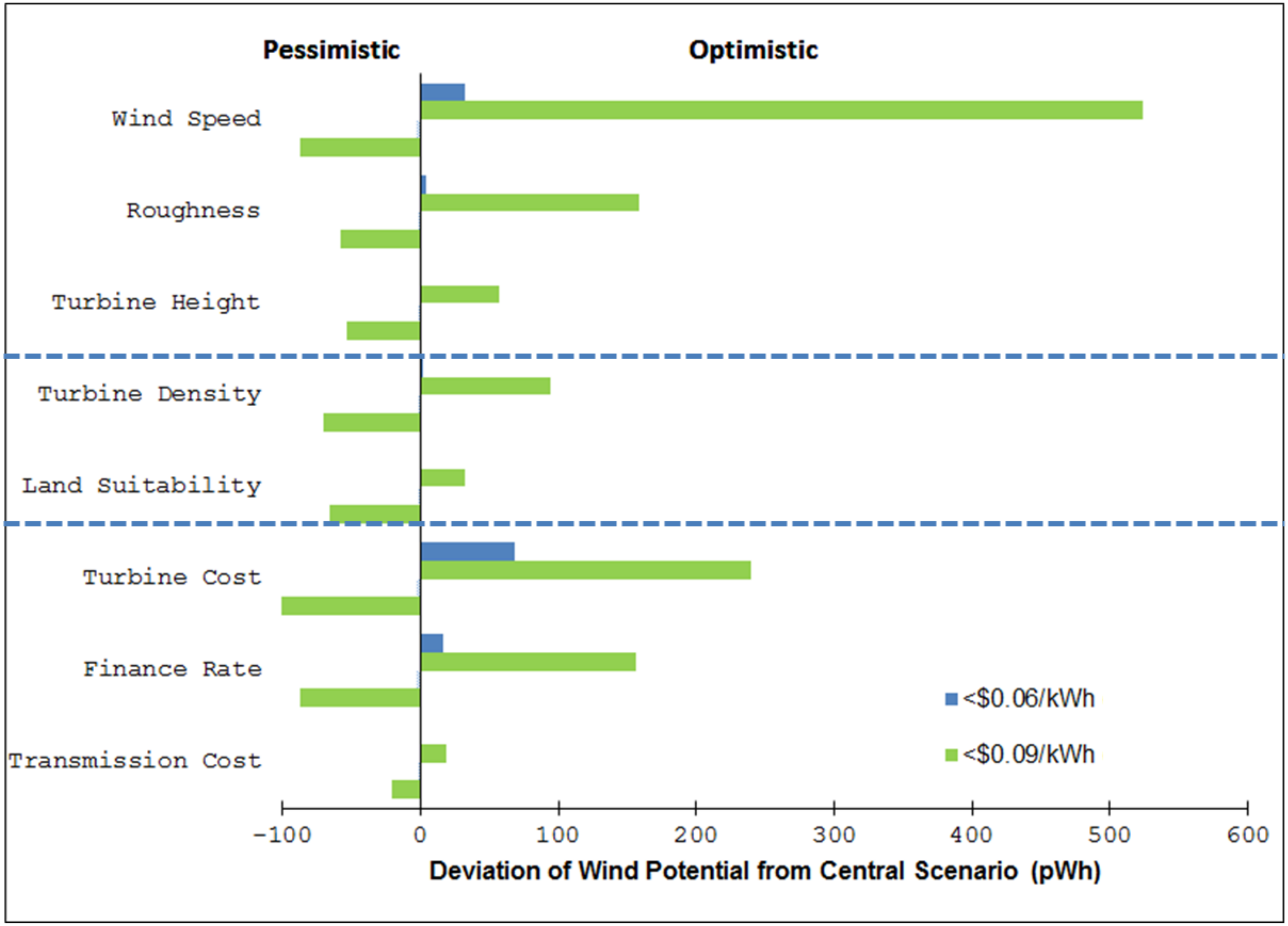
Sensitivity of wind energy potential



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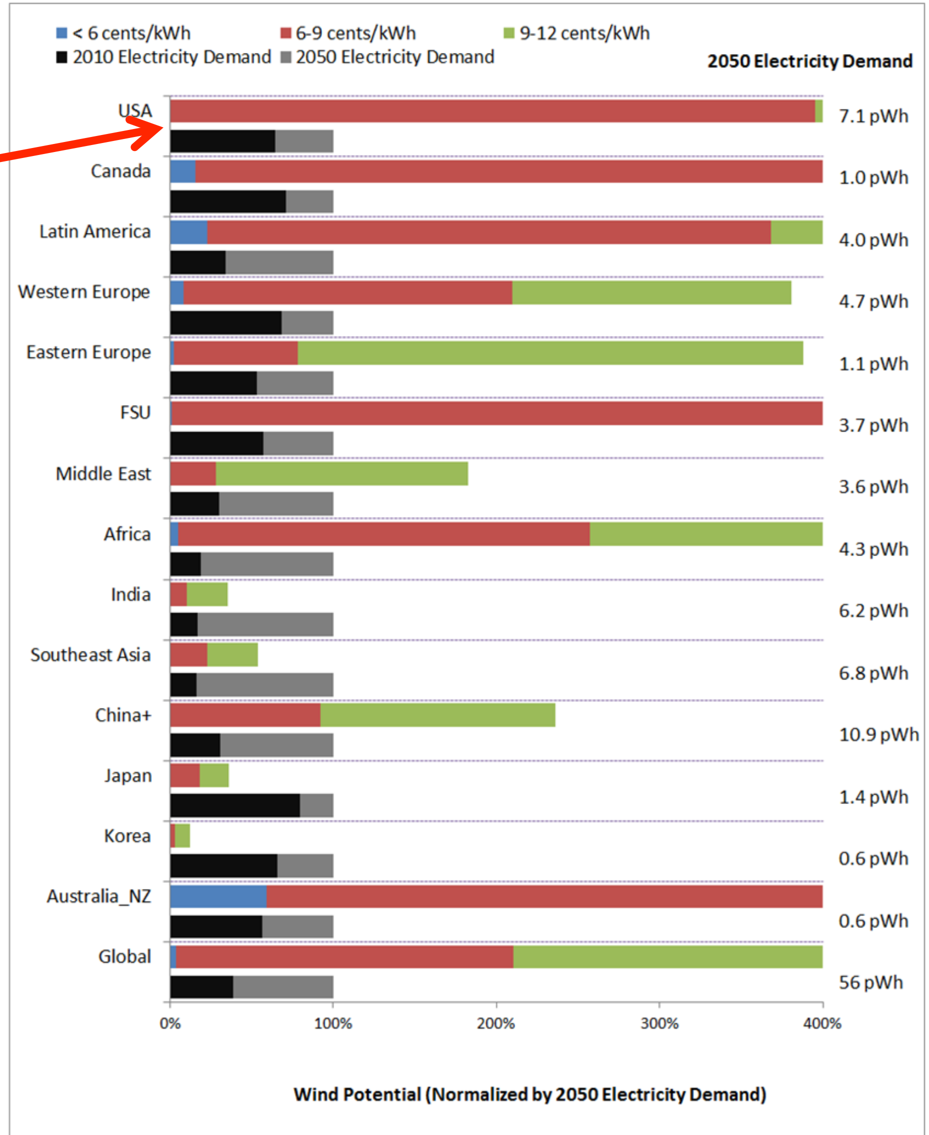
Wind Energy Potential in the Central Case

The bias against high wind speeds in the reanalysis dataset limits the estimates of the cheapest wind.

In three of the four comparison regions examined in this study, the CFSR data set used here missed 90% of the area with winds power class 5 and above.



Wind energy supplies at less than 9 cents/kWh are quite large in many regions relative to projected electricity demand. In other regions, wind supplies are more constrained.

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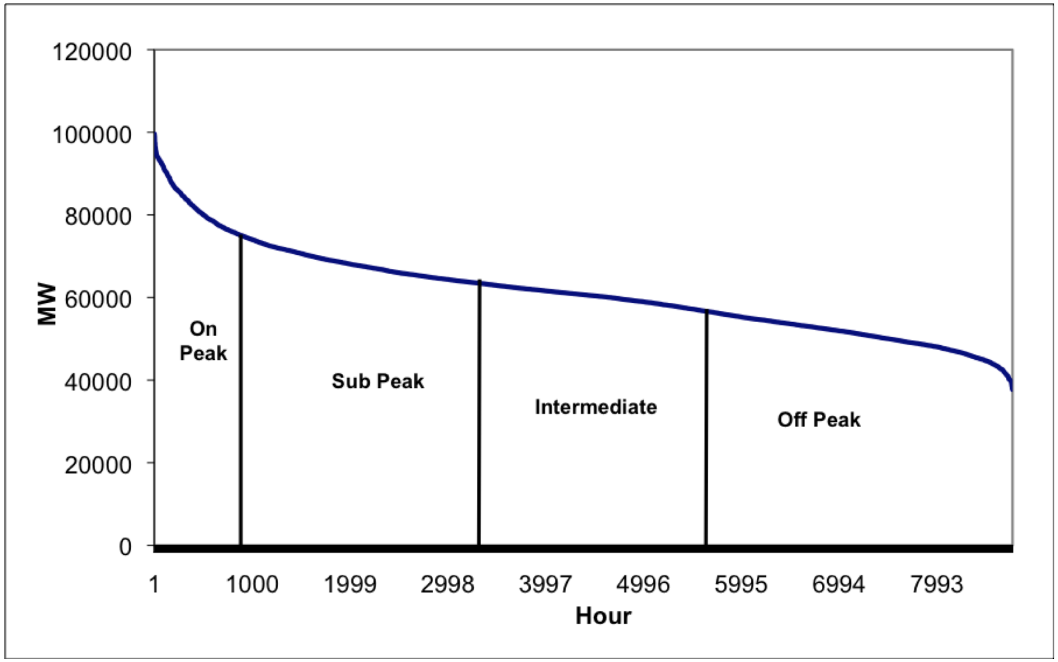
Wind integration in GCAM

For the U.S., GCAM splits the load duration curve into four segments.

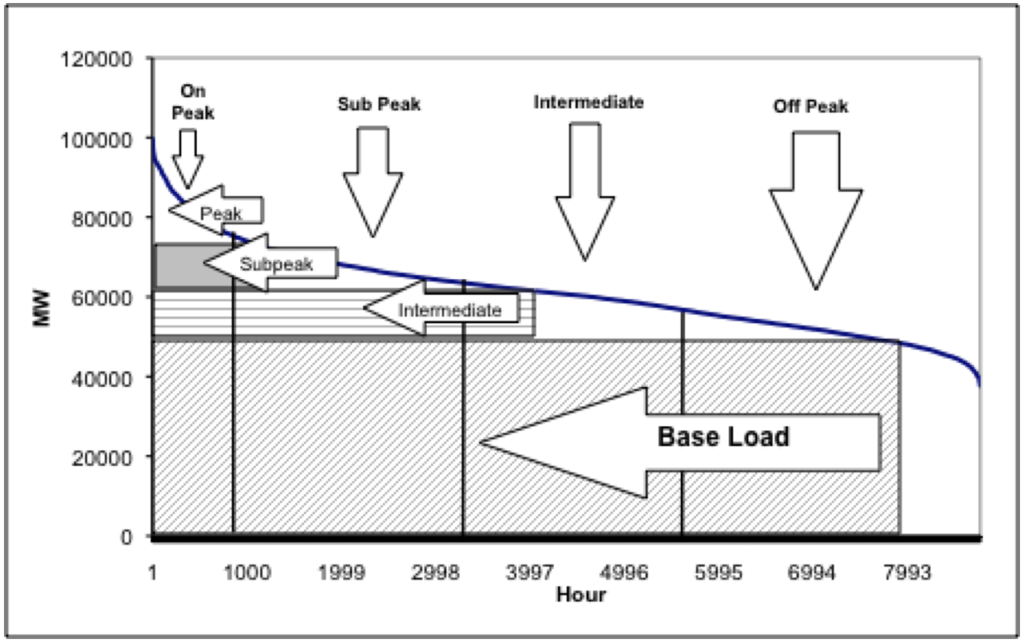
- The load duration curve divided into 4 segments: off-peak, intermediate, subpeak, and peak
  - Note that the load duration curve does not currently respond to changes in demand sectors.
- We have built a prototype implementation of this approach internationally, but we are currently using a single market with two wind options.
  - One issue is how to think about load duration curves outside of the U.S.



Illustrative conception of load duration curve.

Electricity Generation Technologies Supply into "Horizontal" Segments.

- Baseload generation supplies to all four sectors; intermediate to three, sub-peak to two, and peak to one.
- Each technology is assigned to a specific horizontal segment
  - For example, nuclear power supplies only to baseload; wind supplies baseload; solar PV w/o storage supplies subpeak, CSP w/ thermal storage is intermediate.
  - Some technologies (gas, coal) can supply more than one segment, but with different capacity factors.
- System storage (modeled as battery) buys from one vertical segment and sells to another.

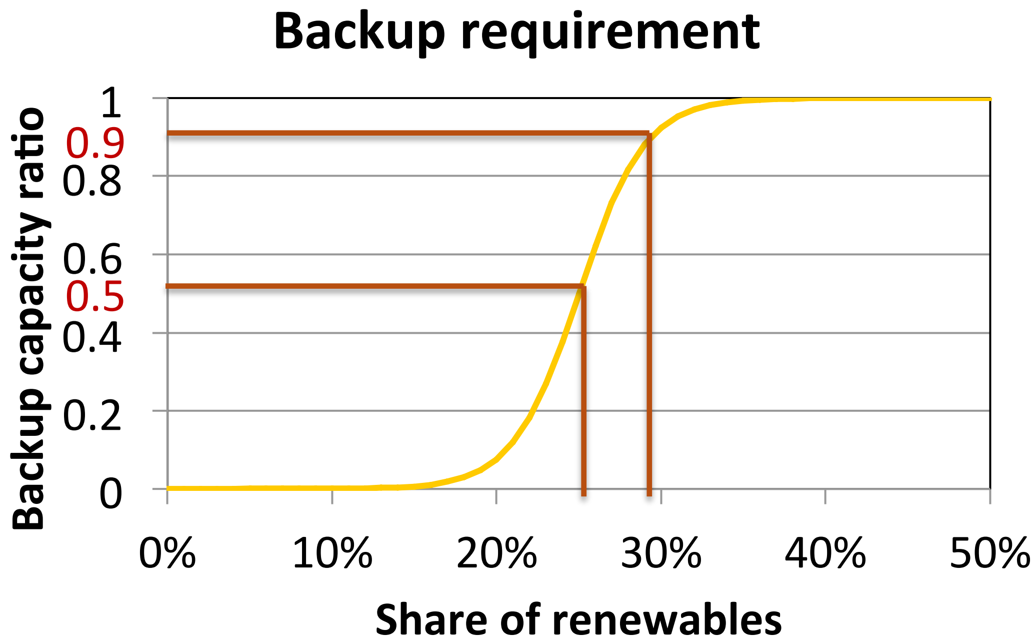


Backup requirements for intermittent resources

- Increasing wind penetration means you need more backup generation
- We typically assume gas turbine backup, but we have assumed storage based backups as well.
  - Backup requirements increase with increase in share of renewables (not just wind)

	Mid-share (share =0.5)	Capacity limit (share =0.9)
Base case	25%	29%

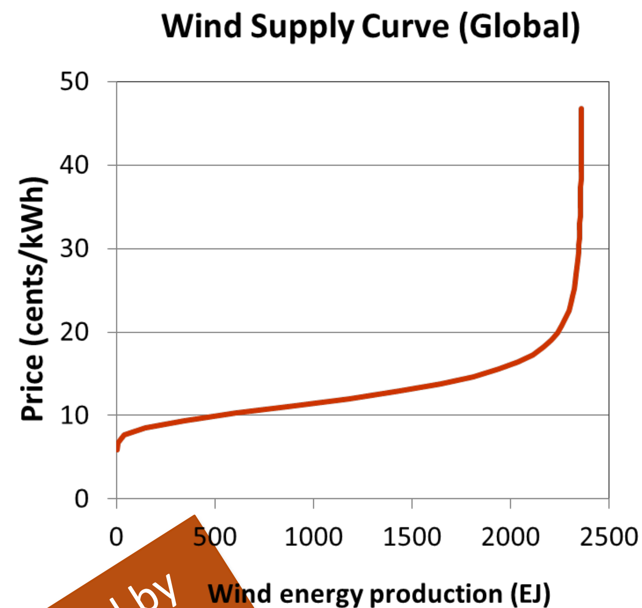
$$Backup\ Ratio = \frac{1}{1 + e^{Midshare - elecshare}}$$

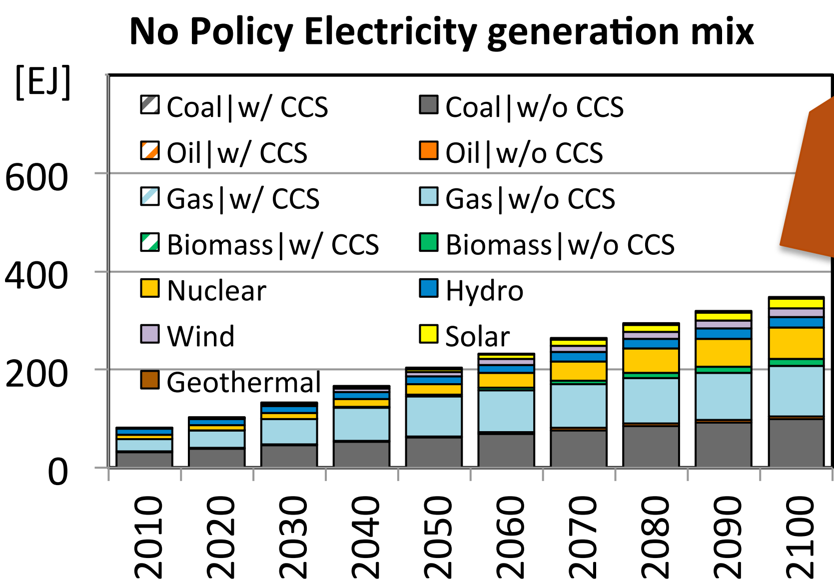


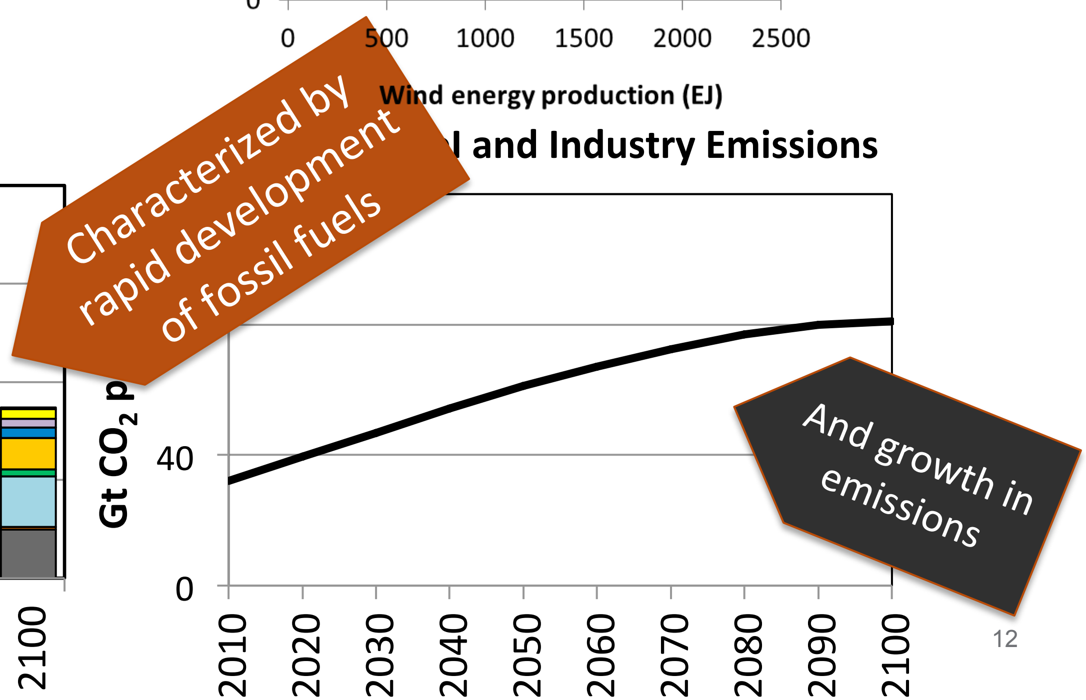
Renewable initiatives Scenarios

No Policy

- Standard model assumptions (business as usual)
- No carbon price
- Standard wind supply curve







Flagship

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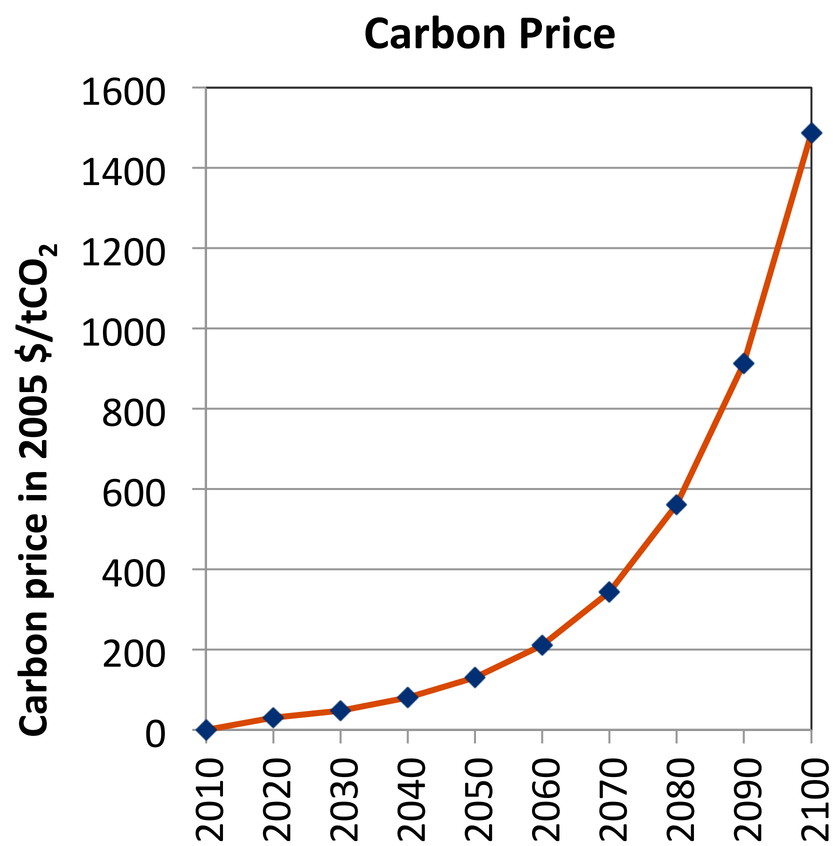
- Standard model assumptions
- Carbon Price policy



Flagship

- Standard model assumptions
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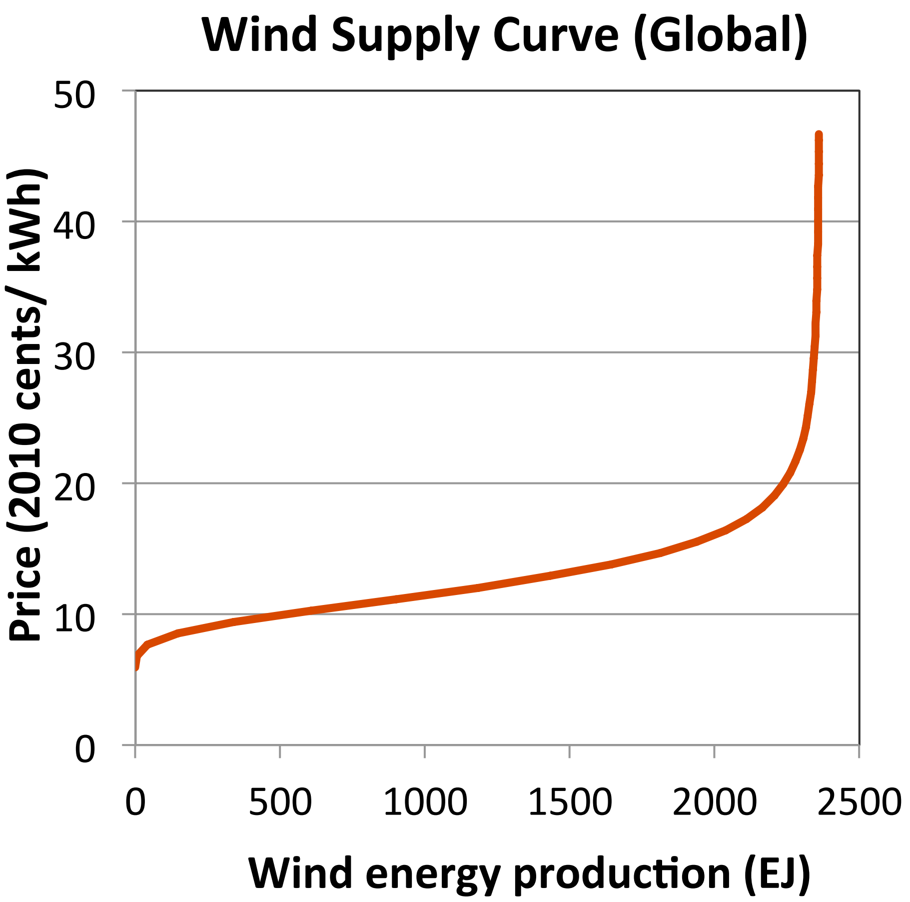

New Wind

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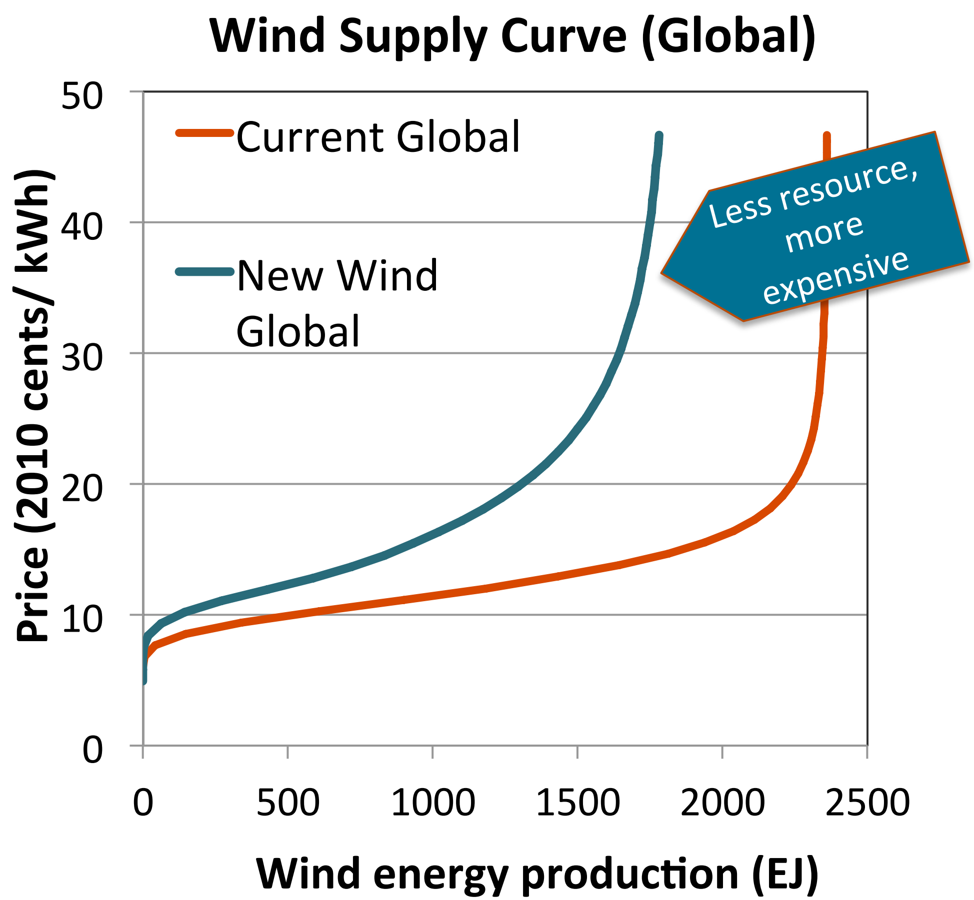
- Wind supply curve based on NREL estimates of Wind power potential
  - Based on the NCAR's Climate Four Dimensional Data Assimilation (CFDDA) database
- Protected, urban, and high-elevation areas are excluded in the data
- Data by country, resource quality and distance to nearest large load or power plant

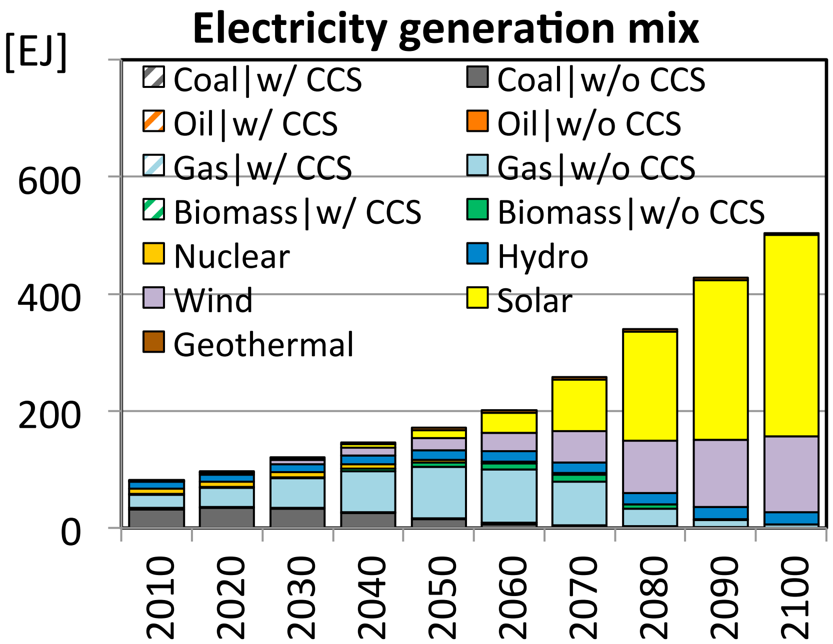


Assumes turbines are operational all the time and that no energy is lost due to closeness of turbines

- Standard model assumptions

- Carbon price policy
  - Same as “Flagship”

- ***Nuclear phase-out and no CCS***



Generous and strict RE Integration

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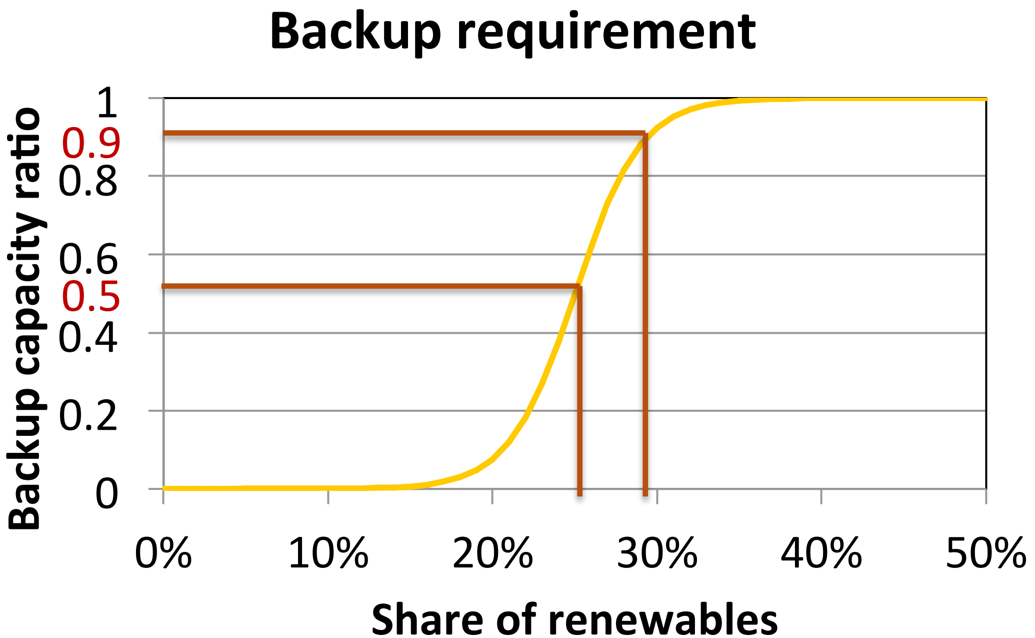
	Mid-share (share =0.5)	Capacity limit (share =0.9)
Base case	25%	29%

$$Backup\ Ratio = \frac{1}{1 + e^{Midshare - elecshare}}$$



Generous and strict RE Integration

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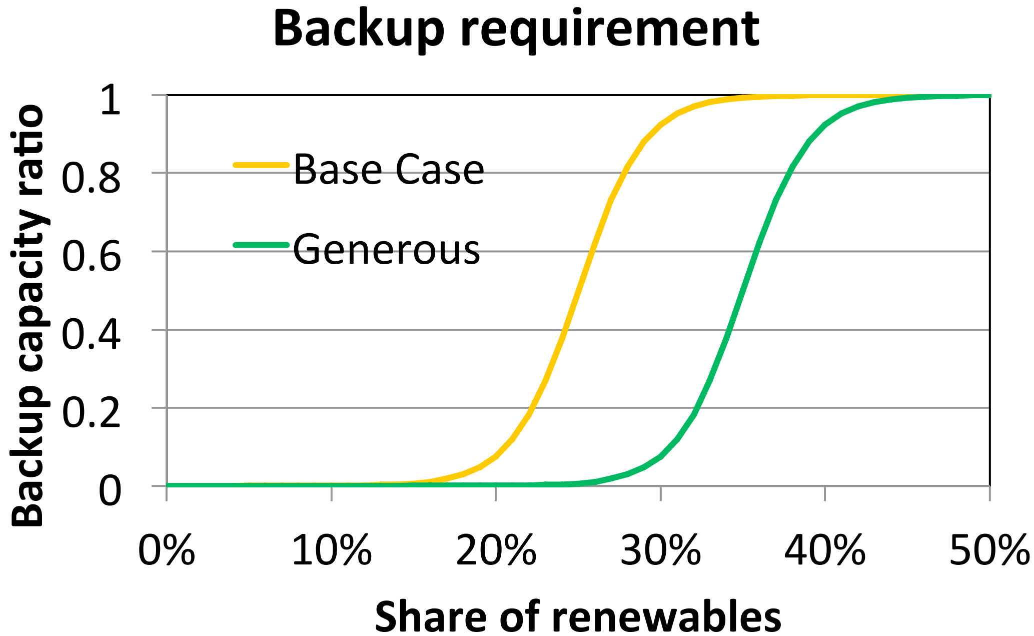
  - Backup requirements increase with increase in share of renewables (not just wind)

	Mid-share (share =0.5)	Capacity limit (share =0.9)
Base case	25%	29%
Generous	35%	39%

$$Backup\ Ratio = \frac{1}{1 + e^{Midshare - elecshare}}$$



Generous and strict RE Integration

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- We typically assume gas turbine backup, but we have assumed storage based backups as well.
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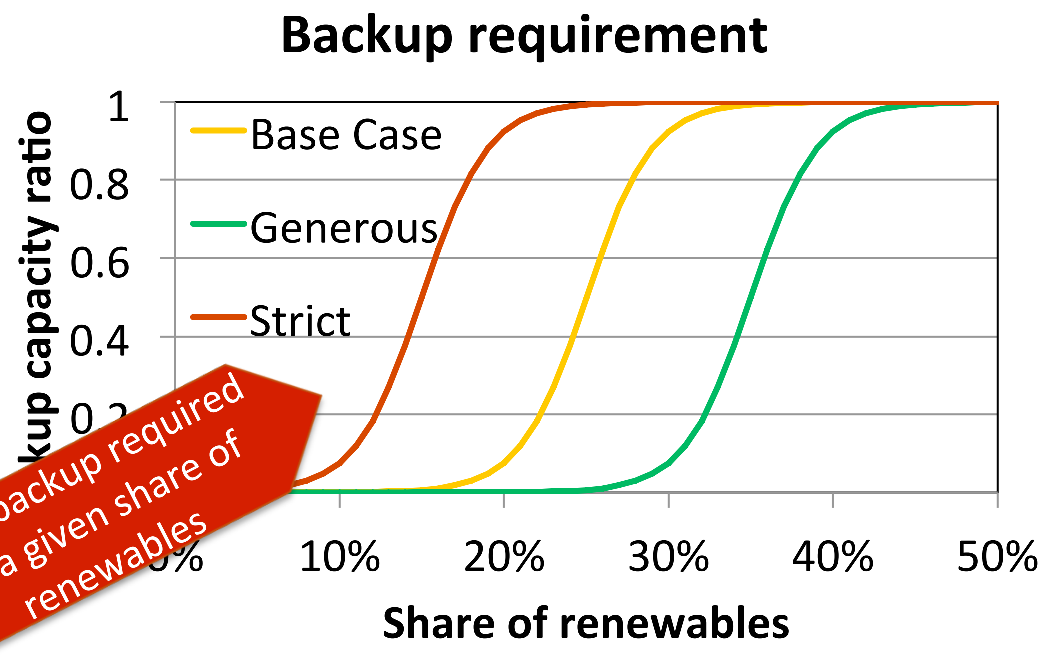
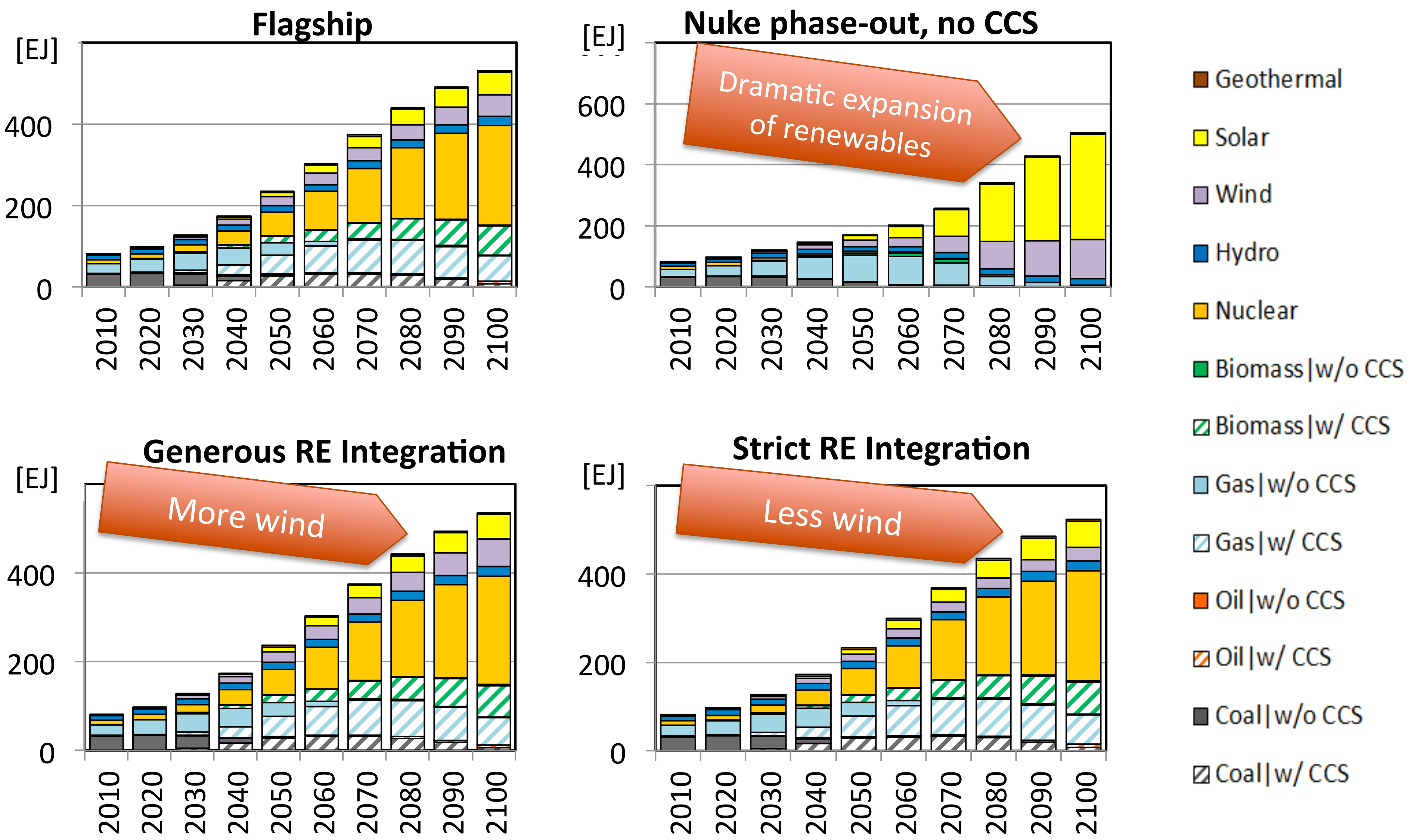
	Mid-share (share =0.5)	Capacity limit (share =0.9)
Base case	25%	29%
Generous	35%	39%
Strict	15%	19%

$$Backup\ Ratio = \frac{1}{1 + e^{Midshare - elecsh}}$$



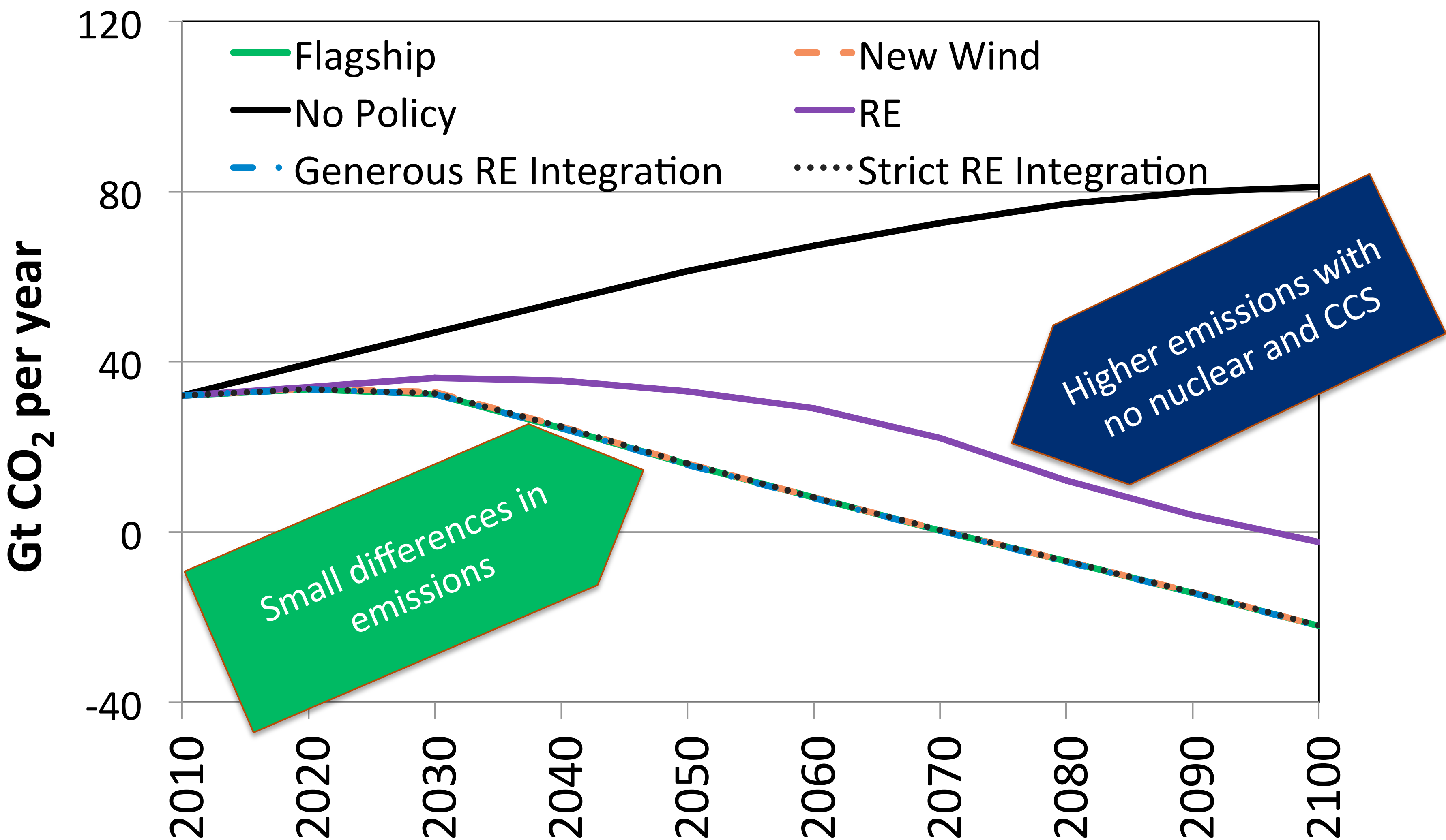
Results

Global Electricity generation



Emissions

Fossil Fuel and Industry Emissions



Global wind Electricity generation

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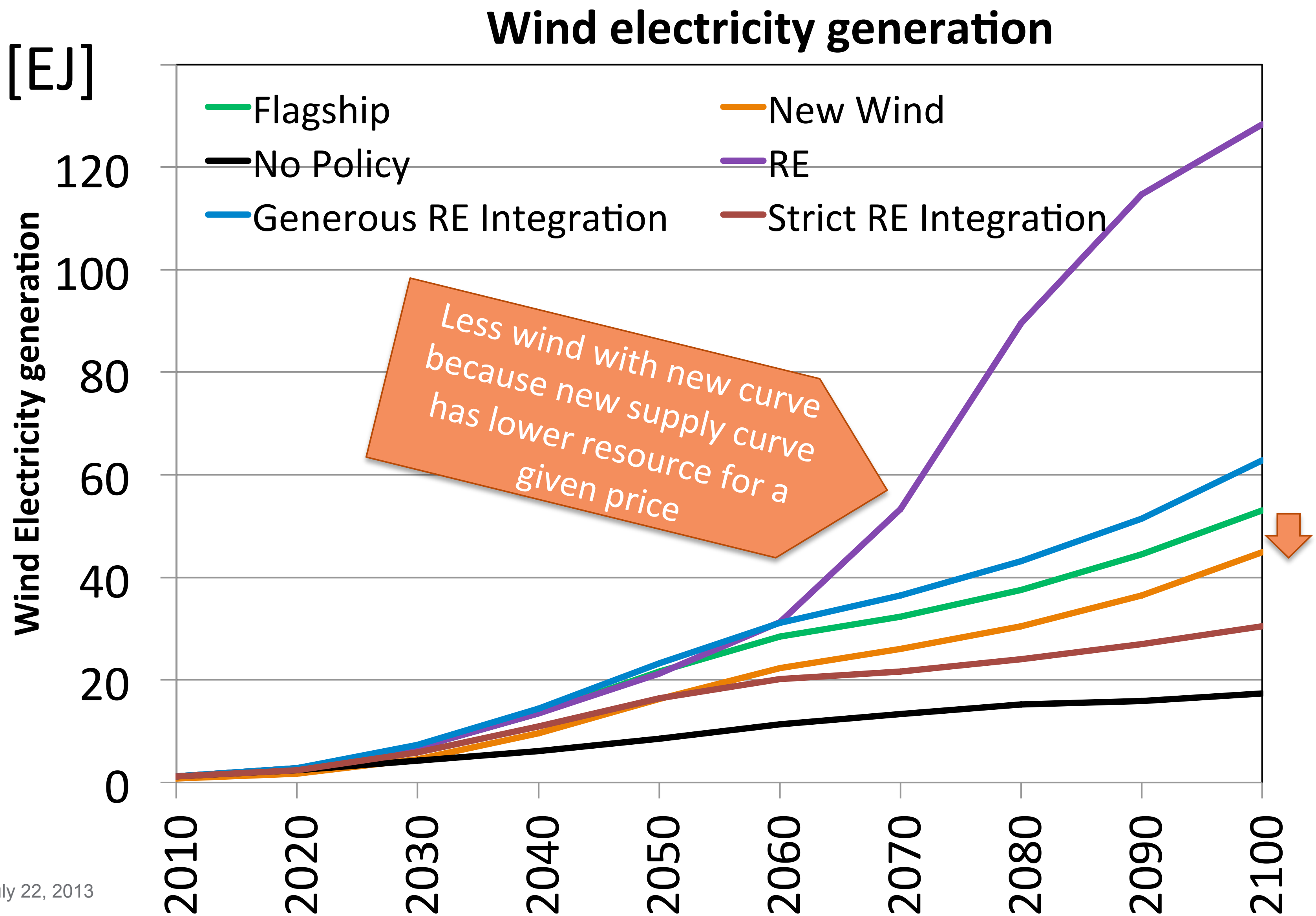
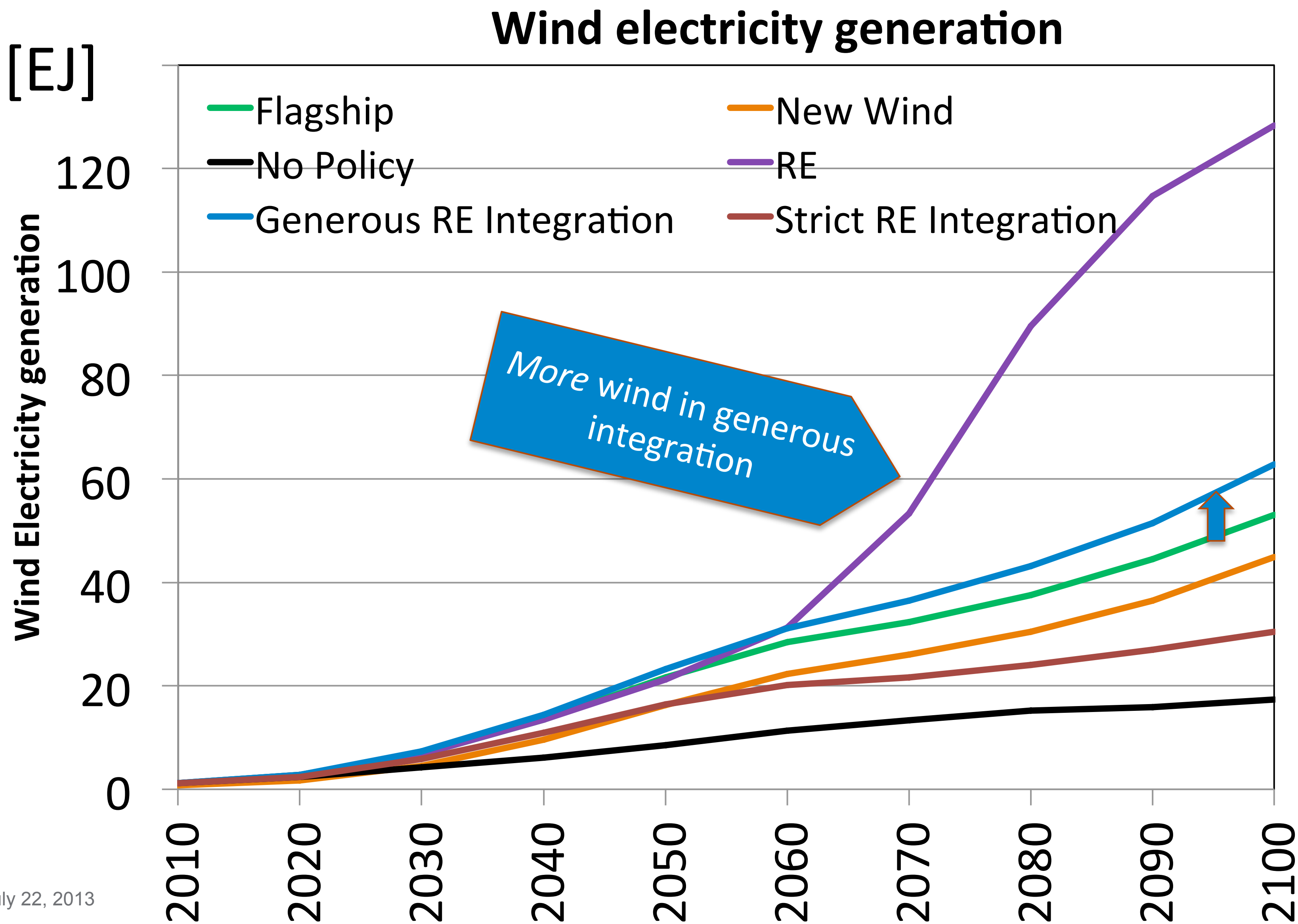


Global wind Electricity generation



Global wind Electricity generation

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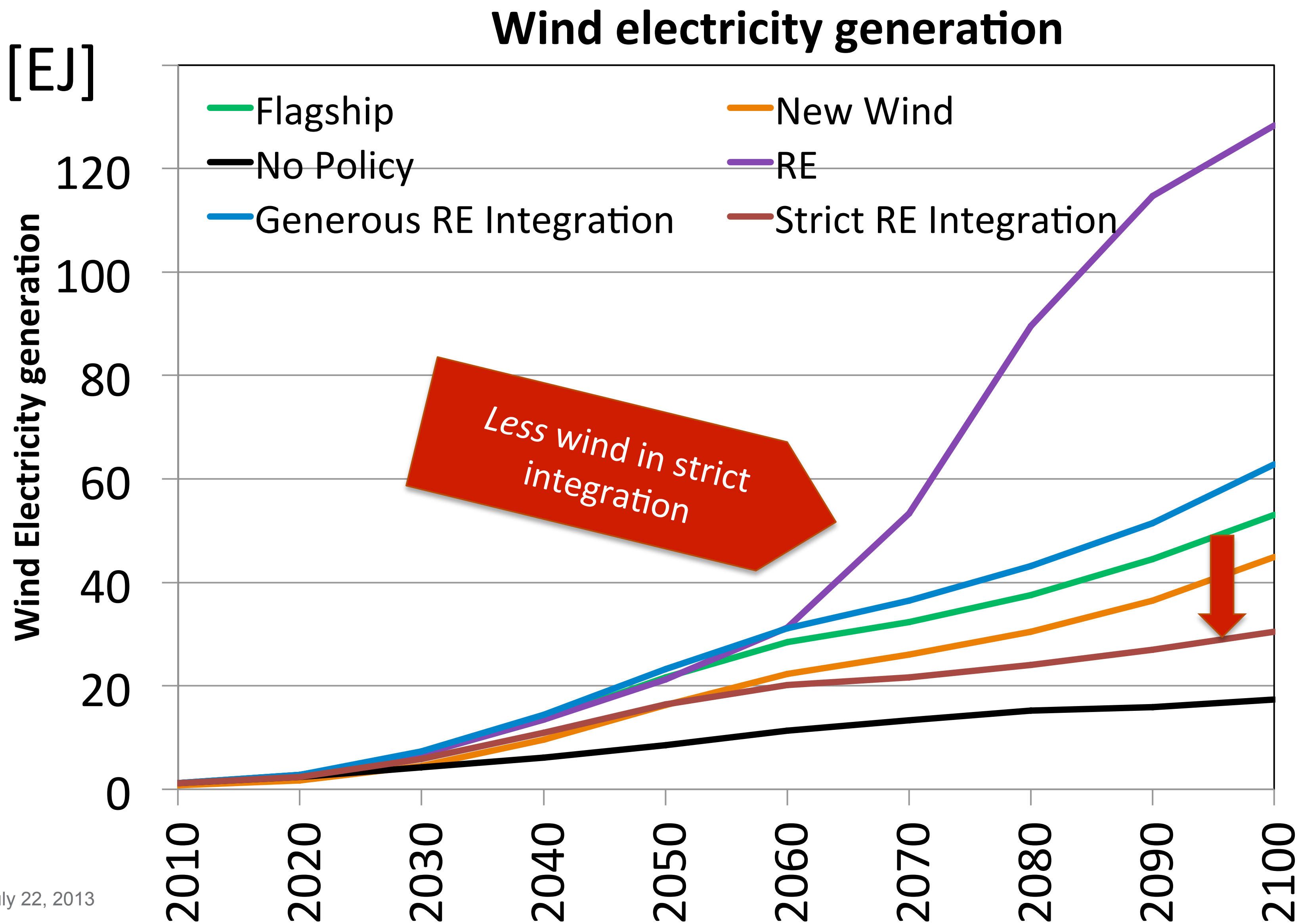
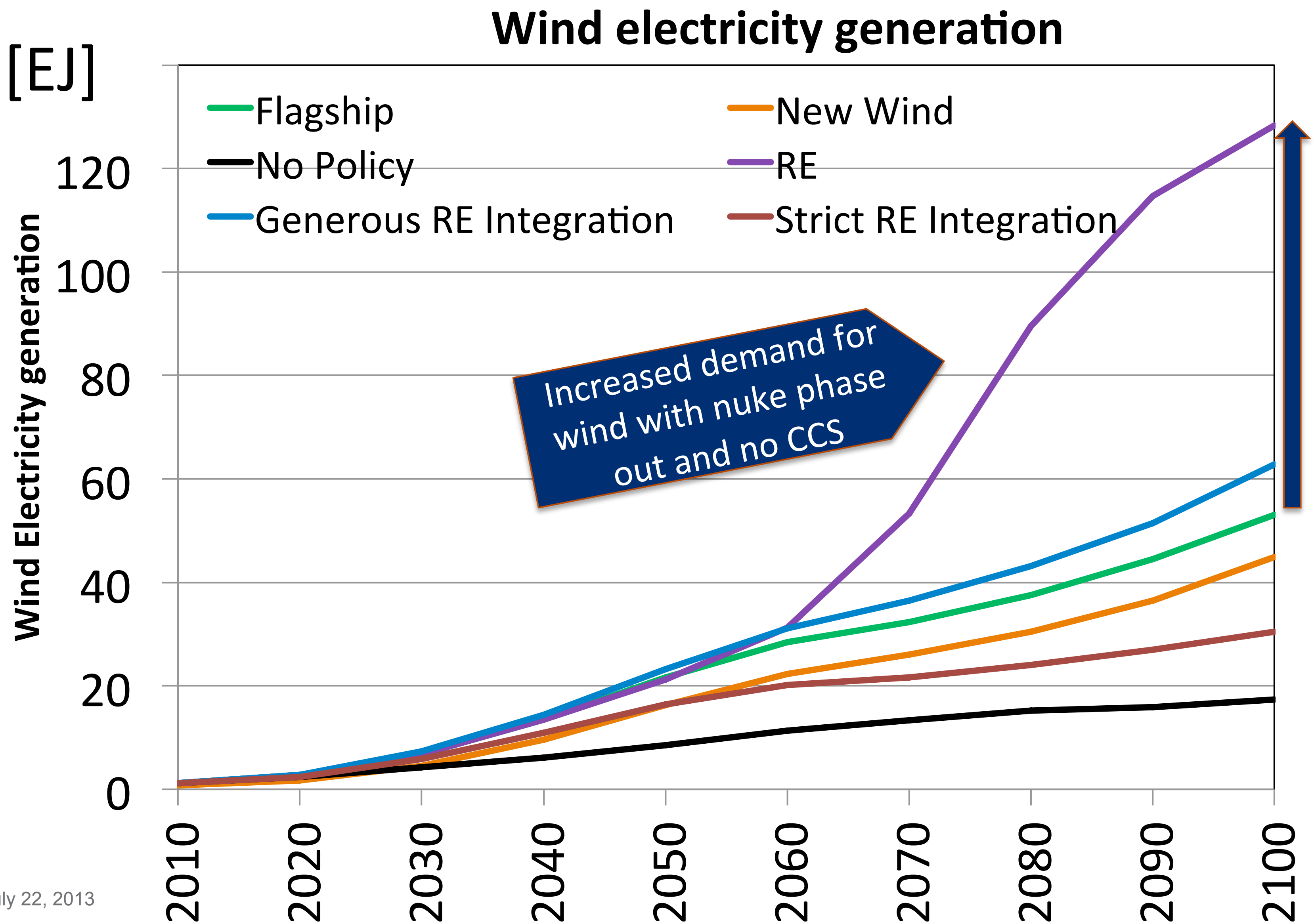


Global wind Electricity generation



Effect of new supply curves on regional wind electricity generation

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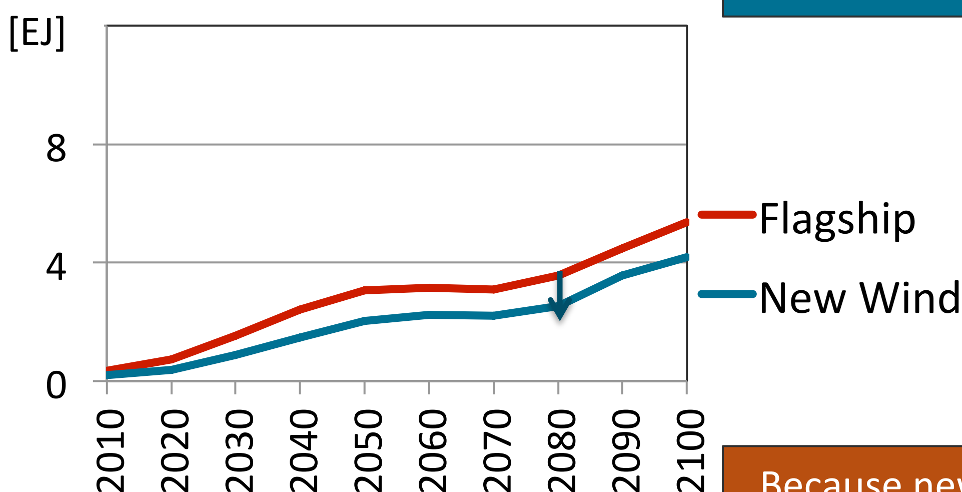
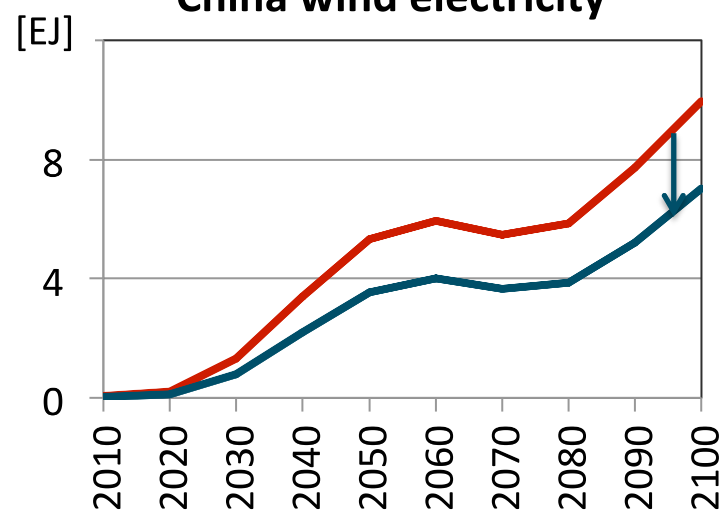
USA wind electricity

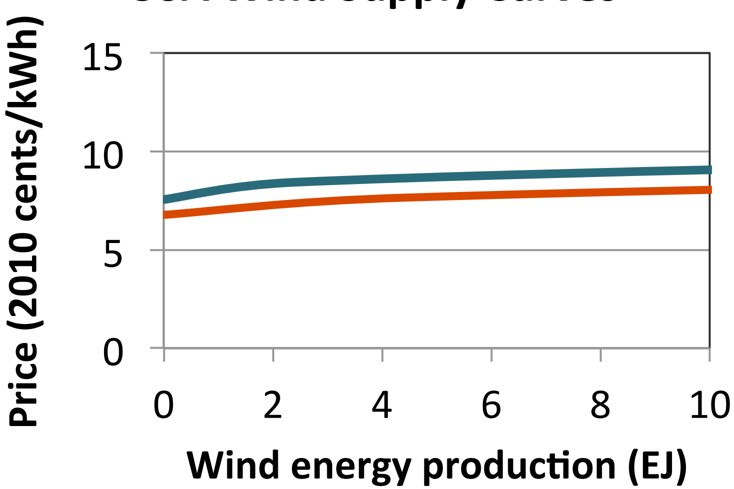


Less wind with new curve

China wind electricity

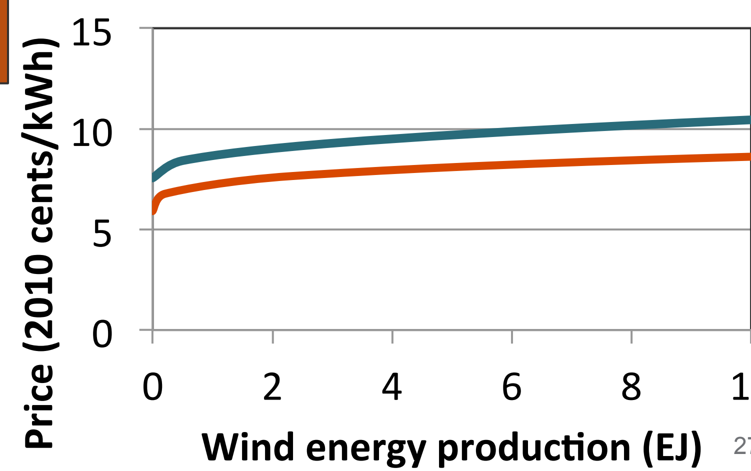


USA Wind Supply Curves



Because new curve has less resource for a given price

China Wind Supply Curves



Effect of integration limits on regional Wind electricity generation

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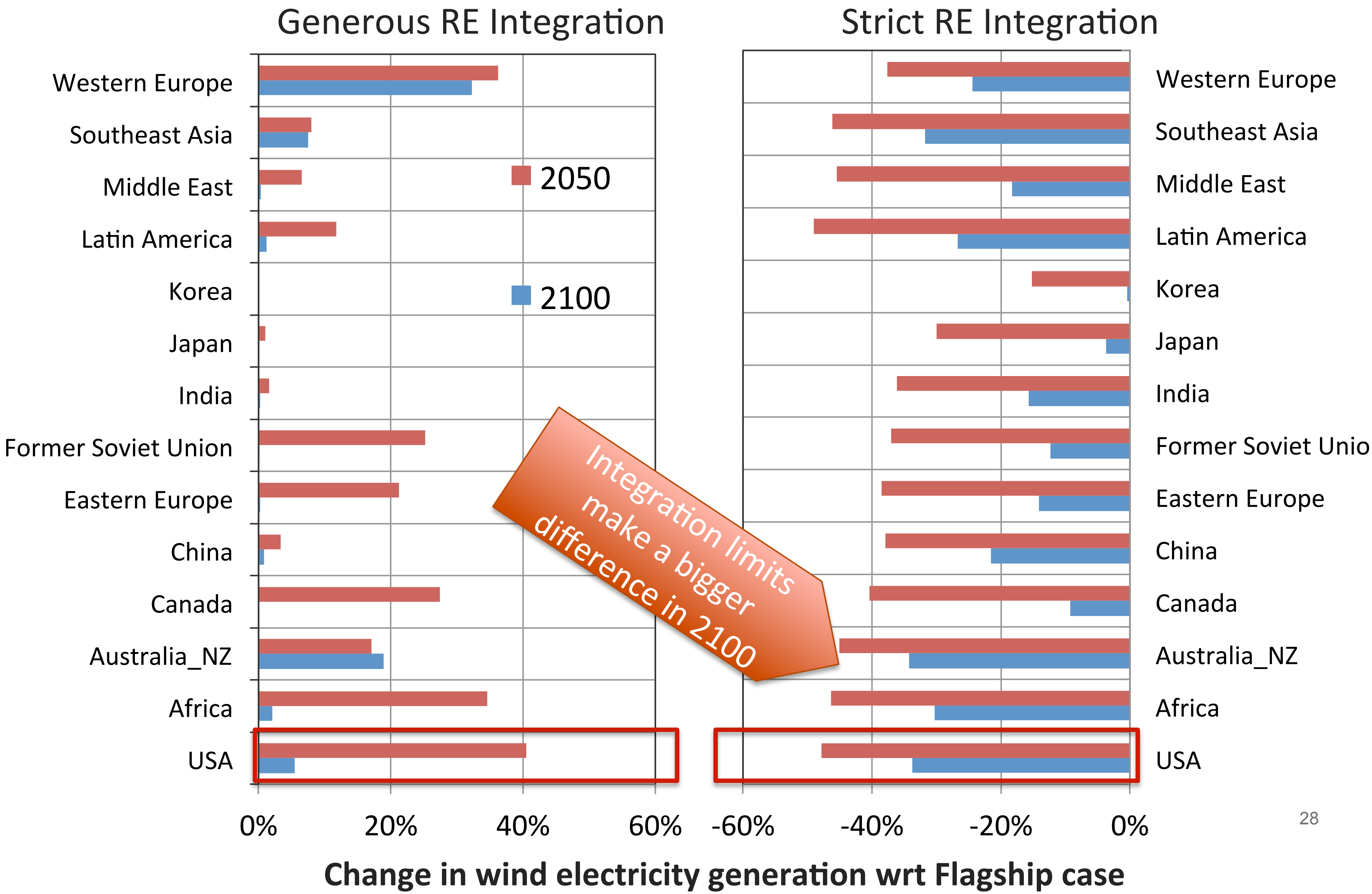

Effect of integration limits on regional Wind electricity generation

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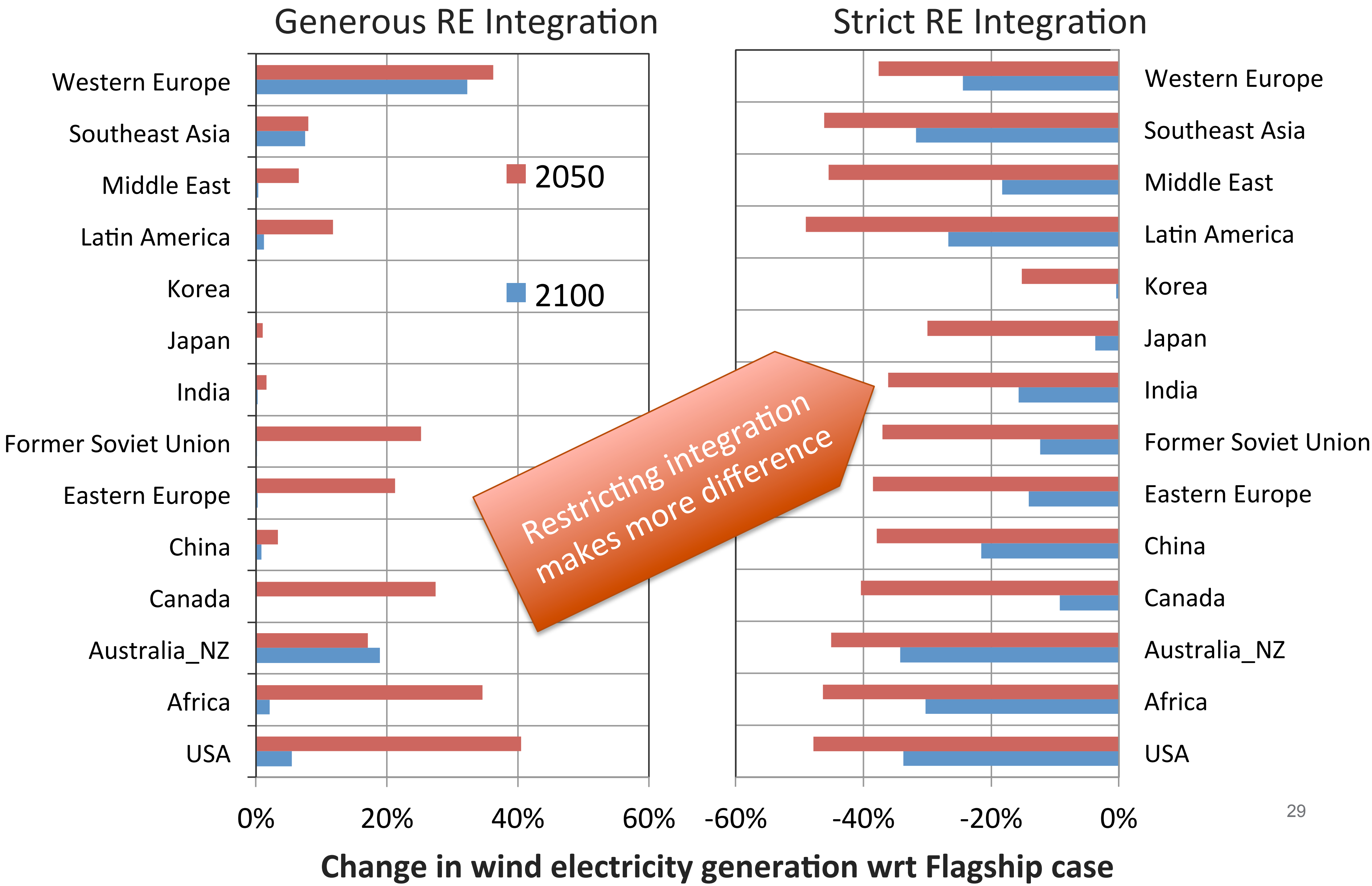

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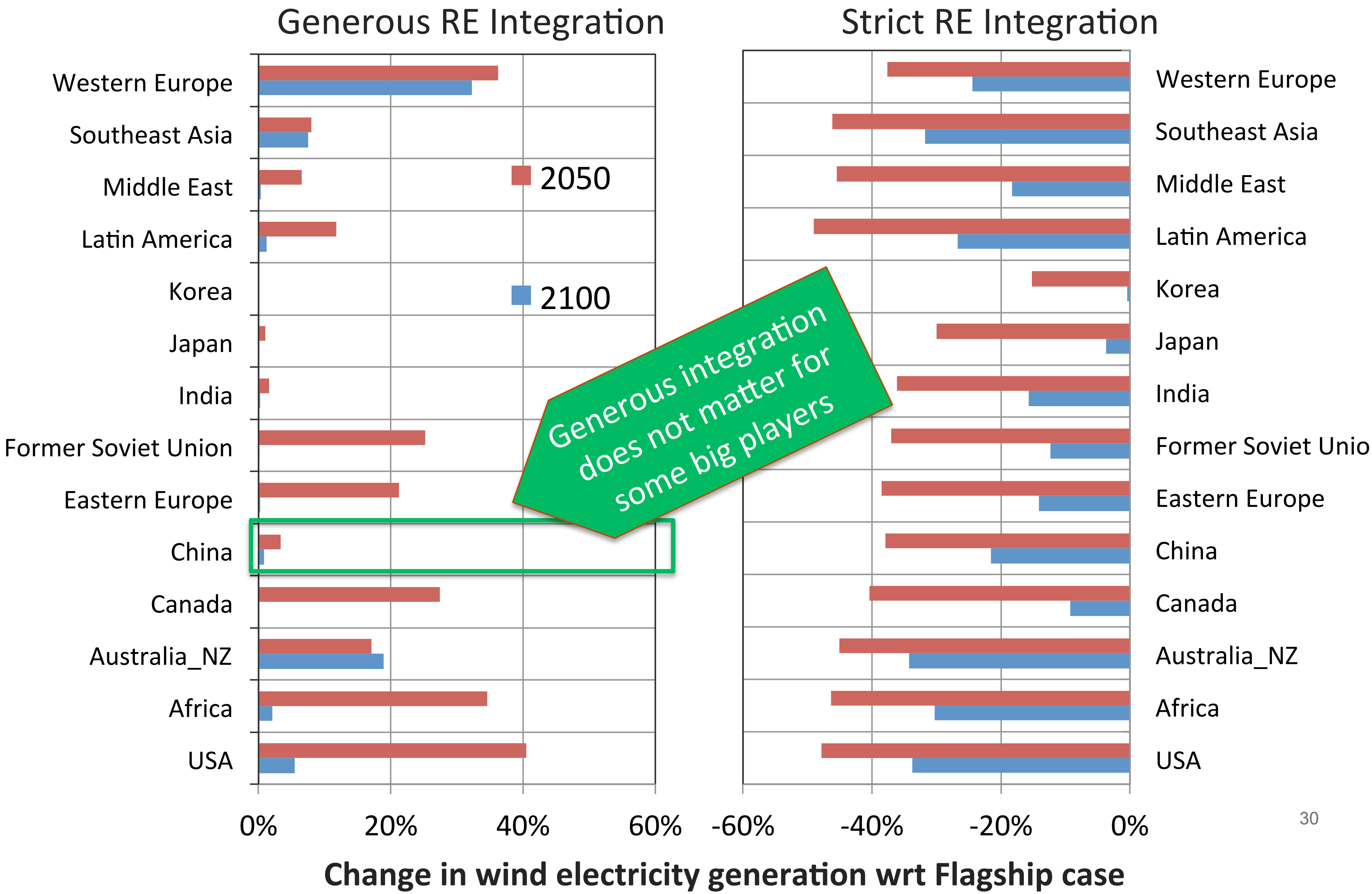

Effect of integration limits on regional Wind electricity generation

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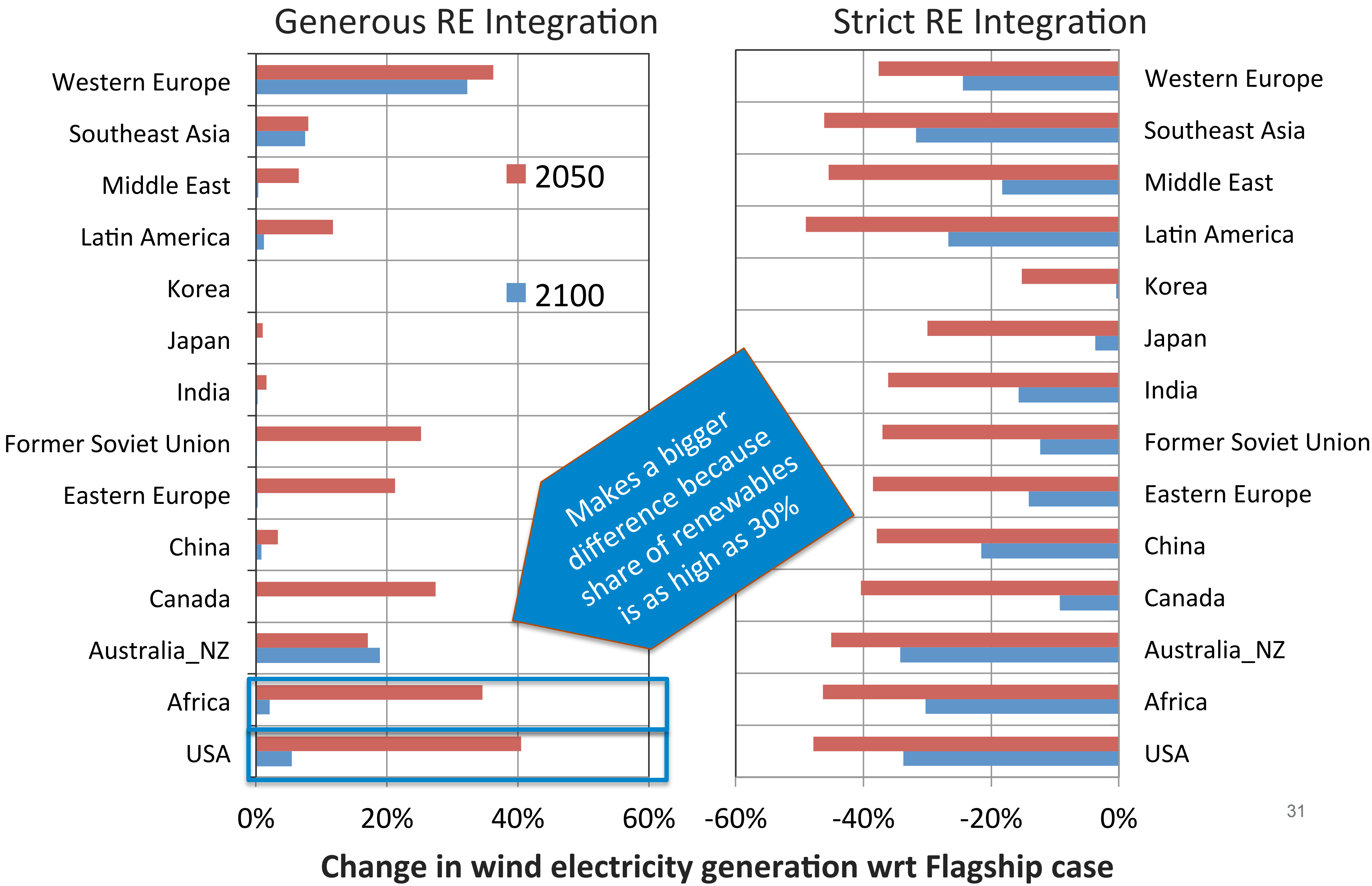
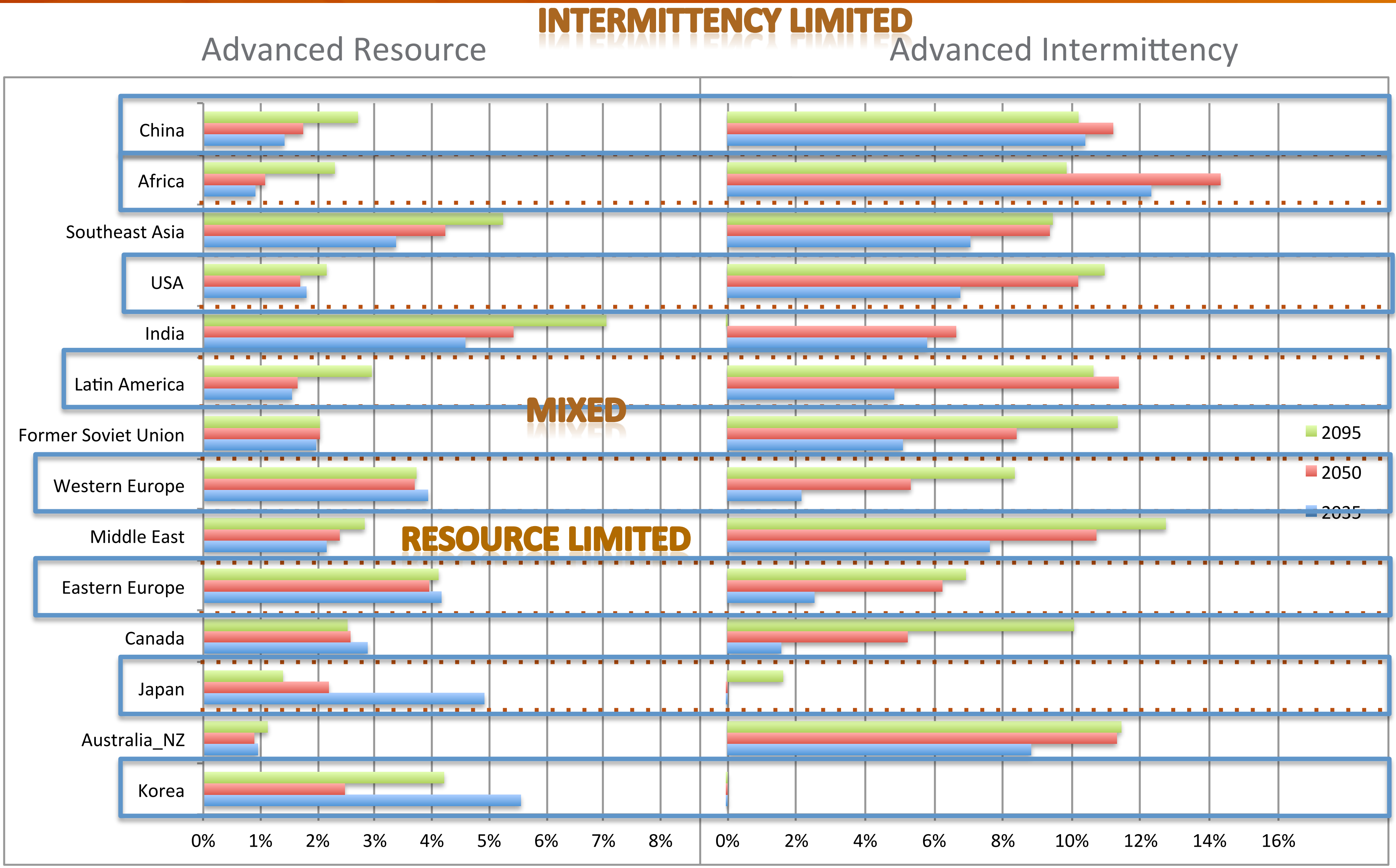


Regional Change in Wind Production



Summary

- The new supply curve shifts to the left (but we need to check this out more thoroughly)
  - Increased wind generation cost
  - Reduced wind generation

- The influence of integration constraints interacts critically with supplies. Expanded integration is generally more important later in the century when production is higher and for regions with higher low-cost supplies.

- In GCAM, you'll use it if you need it. With phase out of nuclear and no CCS, development of wind energy increases significantly.

The End