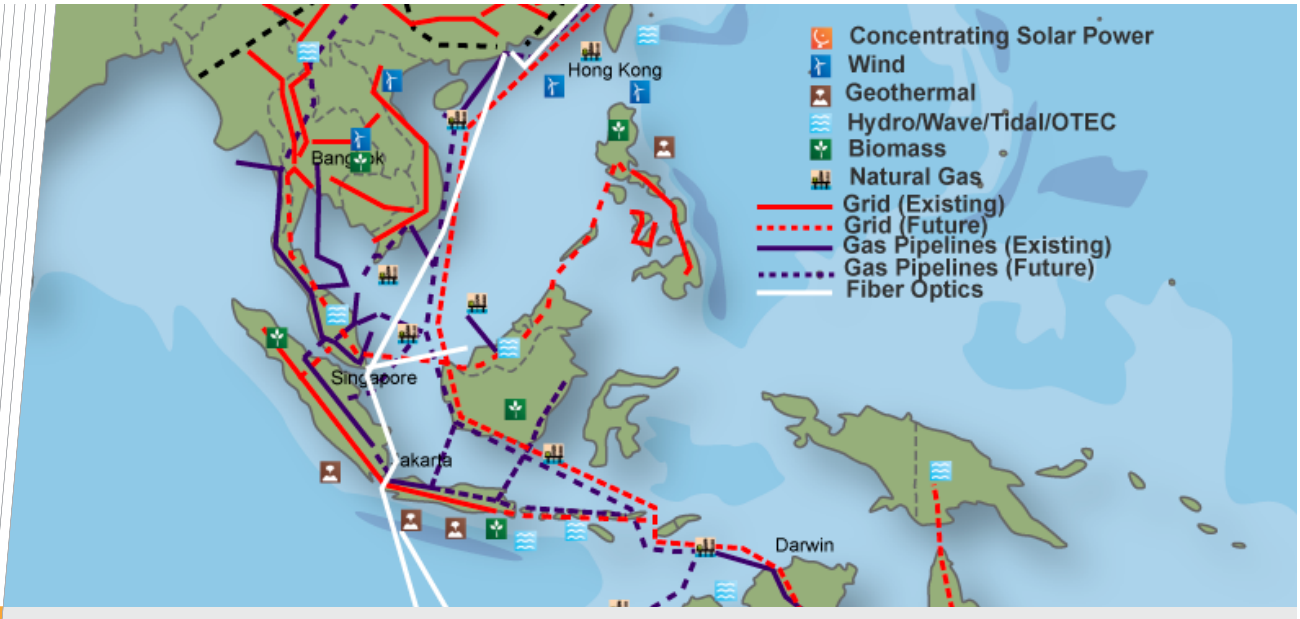

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The adequacy of intermittent renewable generation to supply electric power systems in Asia

Energy Transformed Flagship

Geoff James
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Question

- Presuming that power grids will trend towards majority renewable energy supply – much of it variable
- Allowing that the purpose of power grids of any size is to balance supply and demand continuously
- Given (historical) knowledge of the renewable energy resource over an interconnected region
- What generation capacity will be needed to ensure system adequacy for X% renewable energy supply?
  - Miminising the overall cost of investment in renewable and “conventional” generation capacity
  - With or without consideration of transmission capacity

Power system adequacy

- Adequacy = the ability to provide enough energy to satisfy user demands without violating system voltage and frequency limits under situations of planned or unplanned outage of units
- Installed capacity adequacy – longer time scales
- Operating capacity adequacy – shorter time scales
- With increased variable supply the simple solution is to increase the "conventional" spinning reserve capacity
- Entailing a sacrifice of economy and increase of emissions!

Important influences in the Asian region

- Universal access to clean energy
  - There are 800 million Asians relying on basic fuels
  - The best overall solution is likely to be a mixture of interconnected grids and minigrids
- The emergence of energy storage
  - Storage will modify demand, smooth supply, and create a new dispatchable resource for operators of clean grids
  - Whether it is best deployed in big or small units remains to be seen
- Our ability to avoid and manage contingencies
  - Long-distance interconnection by HVDC transmission creates a new dispatchable resource for grid management
  - Can improve oscillatory and transient stability

Renewable and "conventional" capacities

Type	Capacity	Variation
Variable RE	$R(x,y)$	$r(t)$
Fossil fuel	F	$f(t) \le F$
Load	L	$l(t) \le L$

$$r(t) = \iint R(x,y)\,\eta(x,y,t)\,dx\,dy$$

Generating "efficiency" of the installed capacity related to the weather

Optimisation problem

- Minimise total cost of installed capacity:

$$C = C_R \iint R(x,y)\,dx\,dy + C_F\,F$$

- Subject to balancing of supply and demand:

$$l(t) = r(t) + f(t)\ \forall t$$

- And requirements of system adequacy:

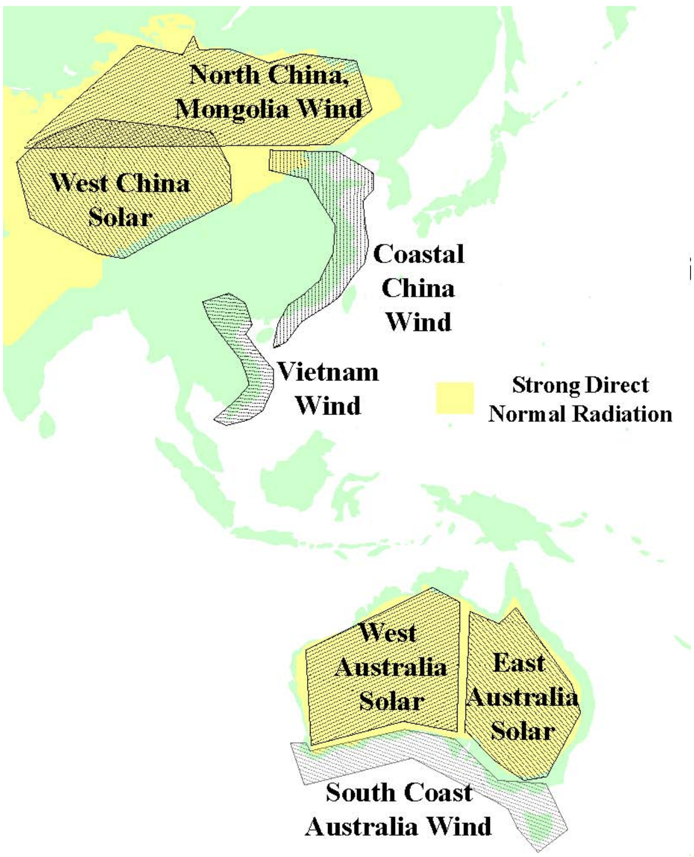
$$F \ge (1+\alpha)\left[L - \min\{r(t)\}\right]$$

Start out simply please!

Ignore transmission	With transmission
$R(x,y)$	$R(x,y)$
F	$F(x,y)$
L	$L(x,y)$

- With transmission, spatial information is needed for load and "conventional" generation
- Also separate treatment is needed for:
  - Hydro generation $h(t) \leq H$
  - Biomass generation $b(t) \leq B$
  - Geothermal generation $g(t) \leq G$

Case study: interconnected East Asia



Geoff James, Adequacy of Power Systems, 8/11/2011

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Correlation coefficients (during one year)

	EAS	SCAW	WCS	NCW	CCW	VW
WAS	0.88	0.16	0.55	0.27	0.14	0.11
EAS		0.07	0.16	0.11	0.11	0.12
SCAW			0.16	0.03	0.00	0.00
WCS				0.45	–0.03	–0.09
NCW					–0.01	–0.04
CCW						0.46

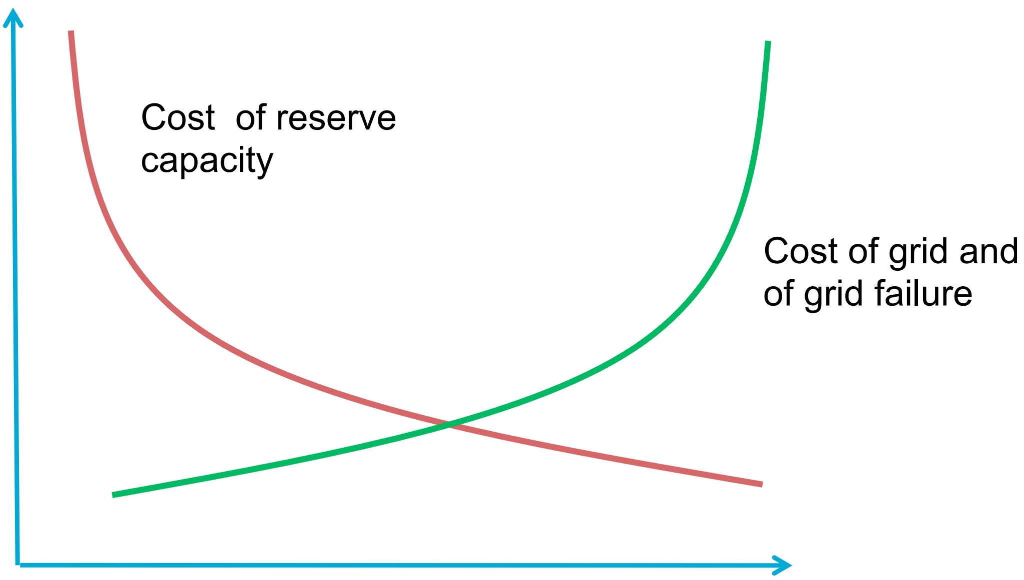
- "The Future of Renewables Linked by a Transnational Asian Grid" to appear in *Proceedings IEEE*, February 2012

Installed capacity to maximise average output

Region	Capacity
WAS	1.33
EAS	1.18
SCAW	1.16
WCS	1.05
NCW	0.45
CCW	0.80
VW	0.74

- Average output = 1.41
- Minimum output = 0.19
- Maximum output = 3.54
- Output ranges from 13% to 251% of the average output
- Very large range of variation despite massive interconnection

Is there an optimal size for an electricity grid?



- Smaller grids need proportionally more reserve capacity due to weather-related correlations in supply
- Larger grids are more expensive and consequences of failure are also more expensive

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Thank you