ESMAP

Renewable Energy Training

Generation and Transmission Planning for Renewables

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The World Bank

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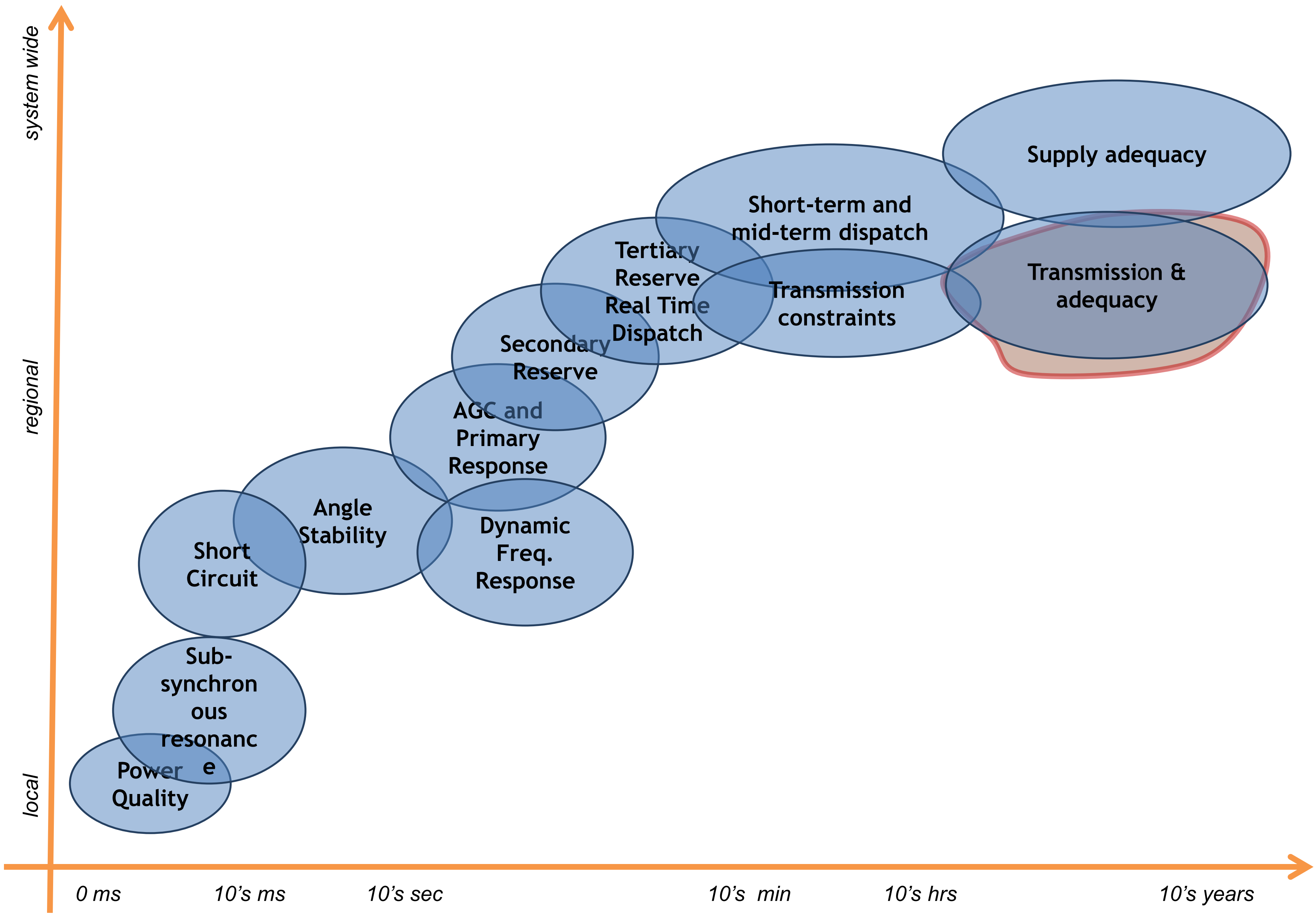
- **Variable Renewables and Transmission Planning**
- **Variable Renewables and Supply Adequacy Planning**
- **Final Remarks**

Impacts in different time/space frames and the are of focus in this presentation



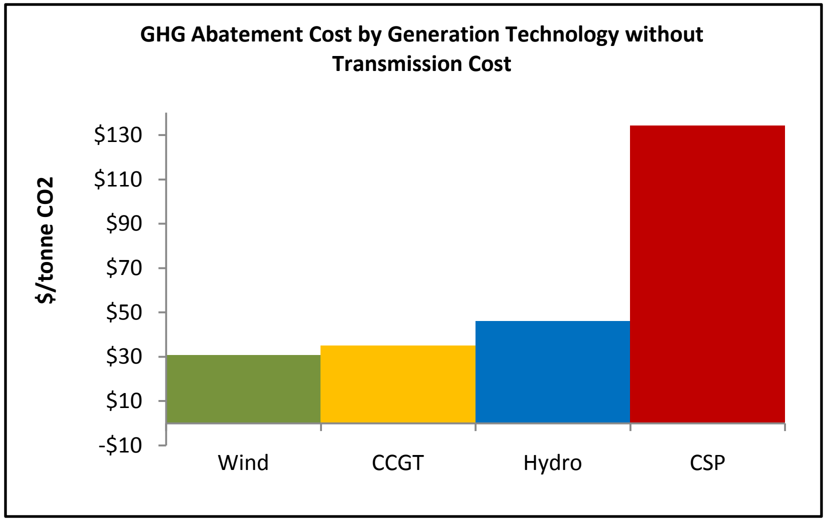
Transmission for renewable energy? Why is different

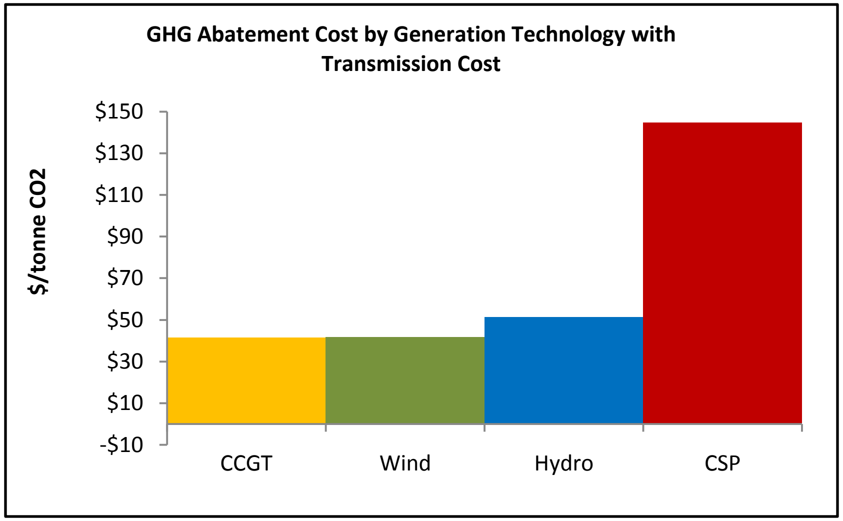
- Transmission needs to get the source, not source to the transmission.
- Resources are often "misplaced": far away from consumption or existing network
- Scaling-up requires exploiting hundreds of sites whose average size is "small" (~100 MW) even at the high voltage levels and in countries with large penetration levels
- Frequently building transmission will take more time than building, e.g., the wind power plant
- Transmission not only key to connect supply, but smooth it across the system or to manage critical condition (e.g. min load)

TRANSMISSION FOR RENEWABLE ENERGY? WHY IS DIFFERENT

- Transmission costs can change the abatement cost associated with generation technologies

- Adjusting the marginal abatement costs ($/tonne CO2) of the generation technologies for transmission swaps the economic attractiveness of the wind and CCGT technologies

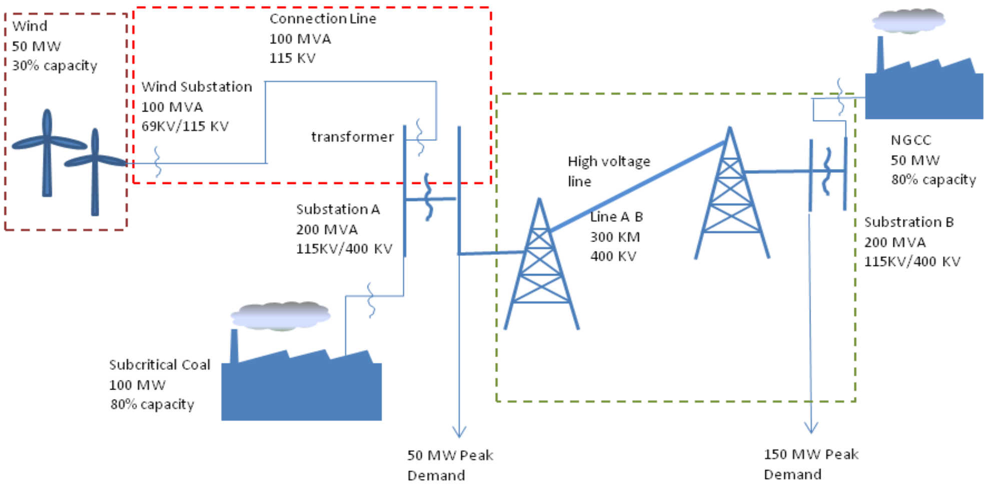




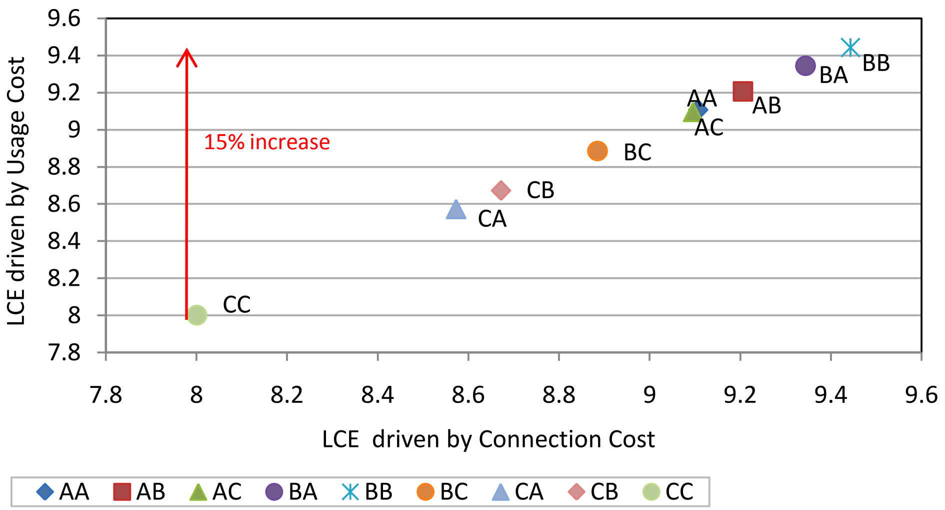
Source: World Bank
Note: Natural gas cost of 4.12 US cents/ KWh used in the analysis is based on the price of natural gas at US$ 7/ MMcf (ESMAP, 2007).
CCGT results in 62% GHG emission reductions whereas wind, hydro and CSP result in 100% GHG emission reductions.

- Transmission cost can impact the LCE and private returns

Options	Connection Cost	Network Cost
A	Transformer, connection line, and upgrade substation	Postage stamp-like usage
B	Transformer and connection line	Flow-based method
C	Zero cost	Zero cost

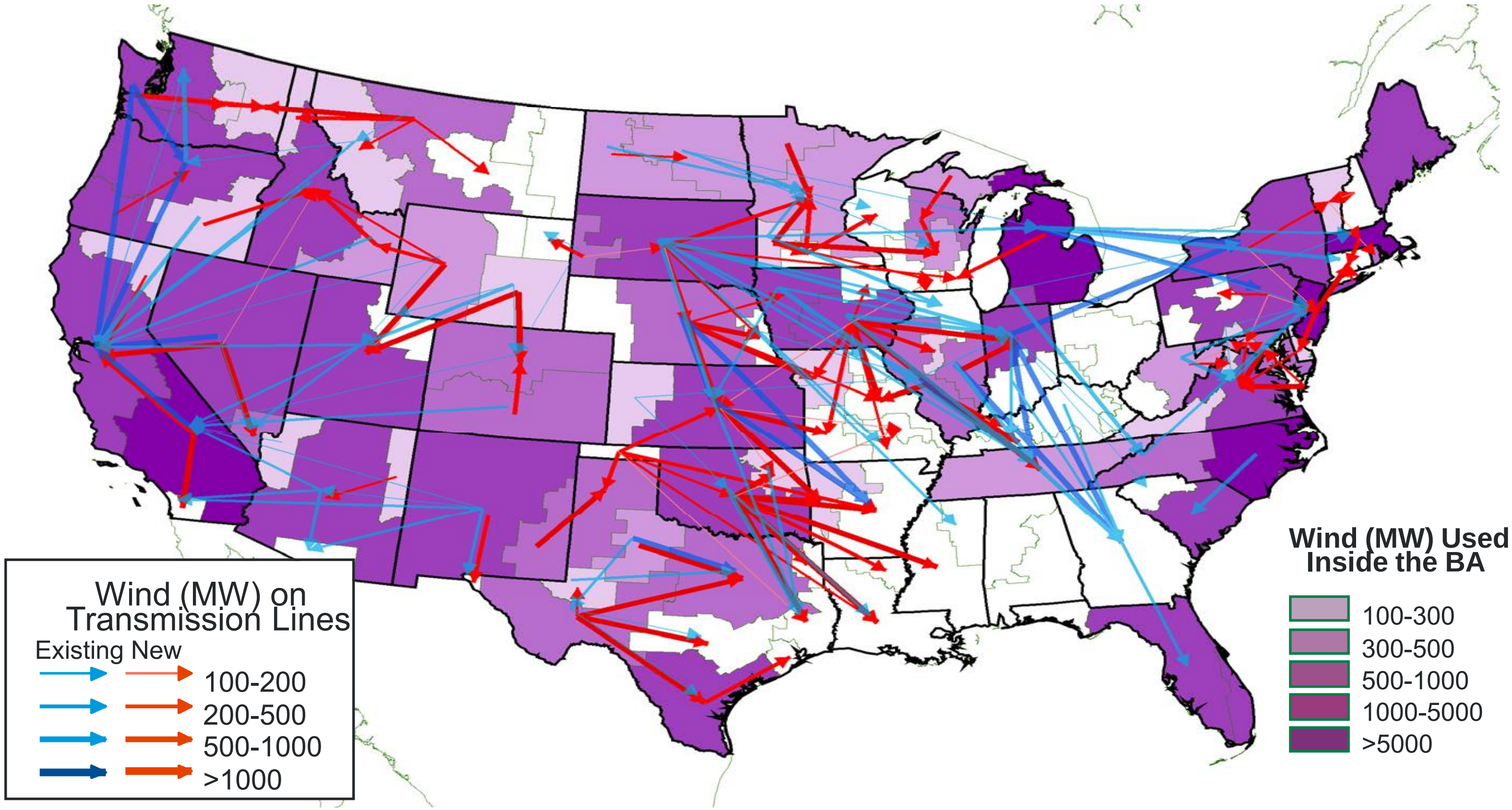


- LCE with different transmission cost rules



Note: AB means Connection Cost option A and Usage Cost option B

In the USA: achieving 20% wind energy target will required $20 billion in transmission investments



Source: US-DOE "20% Wind Energy by 2030 Increasing Wind Energy"s Contribution to U.S. Electricity Supply", July 1008

Transmission: Barrier to RE generation in several countries

In Europe: To meet target of 20% RE by 2020, € 20 billion required for 42 large transmission projects

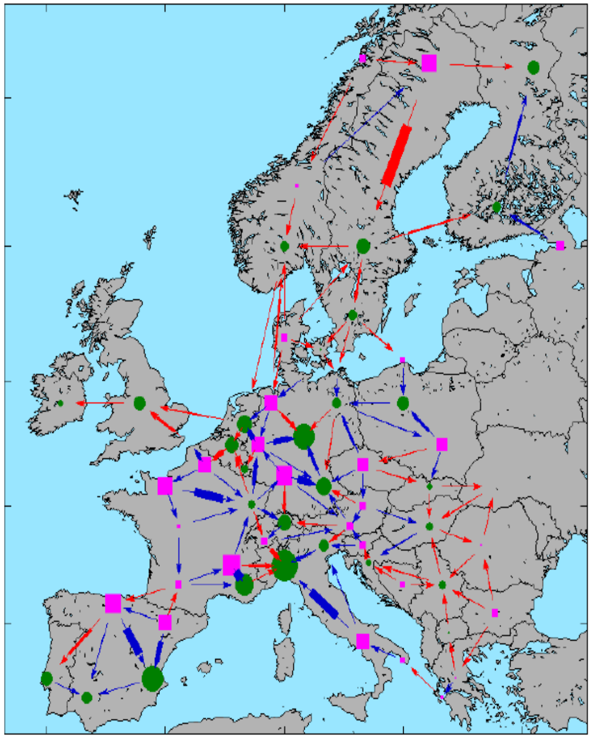


Figure 16. Annual energy flow between zones in 2020. Red: Constrained flow due to line/HVDC/NTC capacities. Blue: Non-constrained flow[2]. Green: Energy Deficit. Purple: Energy surplus.

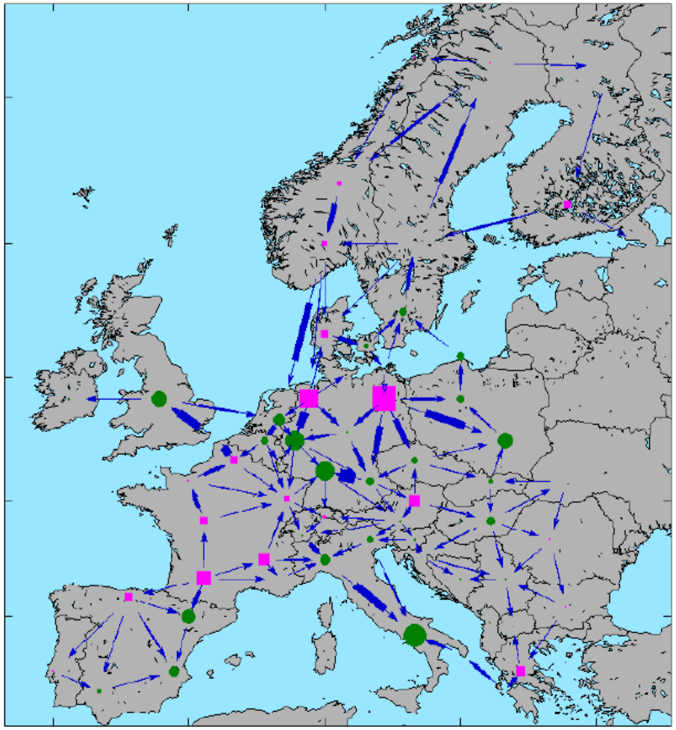


Figure 19. Change in energy flow in 2020 due to stage 2 reinforcements. Green: Reduction in production. Purple: Increase in production.

Congestion: without upgrades

with upgrades

Projects reduce congestion cost by € 1,500 million/year

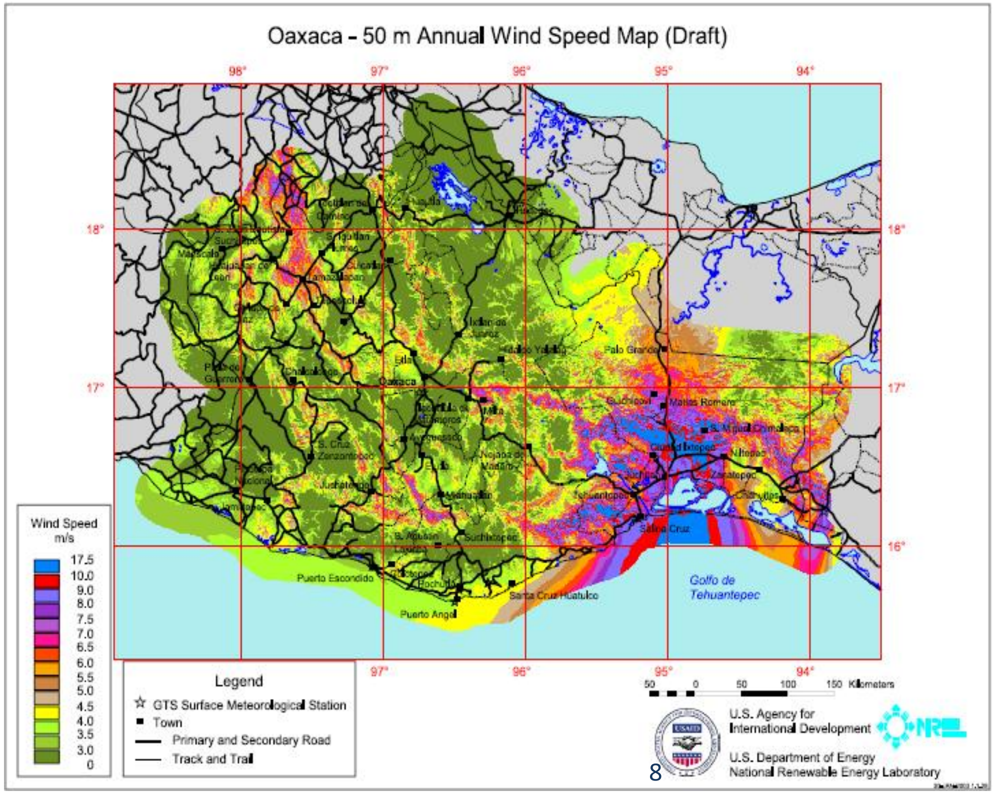
*Source: TradeWind Study. Feb 2009. http://www.trade-wind.eu/

Mexico: Wind potential in Oaxaca 10 GW

First 1,895 MW of privately-developed wind power require a new framework to expand the publicly-owned transmission system with 271 km of double circuit 400 Kv lines plus 2,125 MVA substation are needed

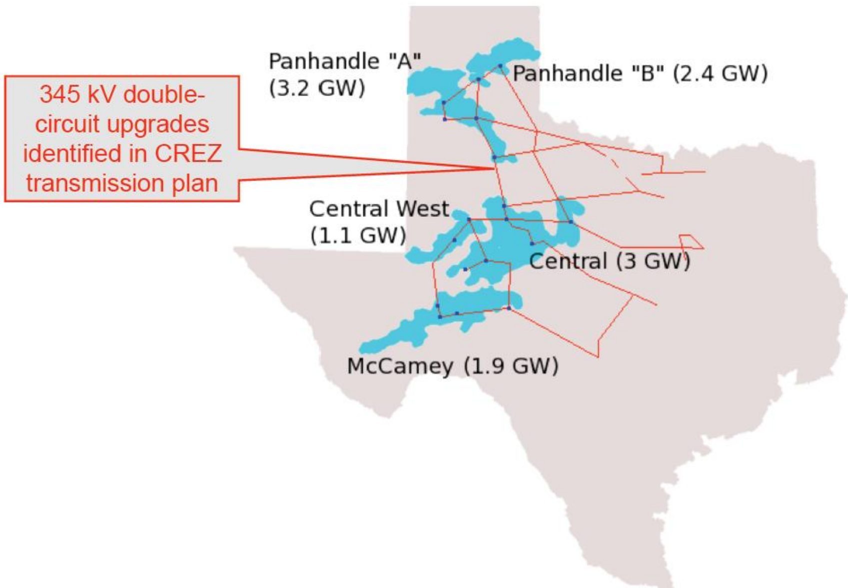
*Source: CRE (2009) and CFE (2009)

- Average wind velocity 15 m/s
- Average plant load factor > 50%
- Location: remote, far from consumption centers and the transmission system



- Renewable energy zones in Texas: Results

RE-zones approved in 2008



Source: National Renewable Energy Laboratory & US DOE

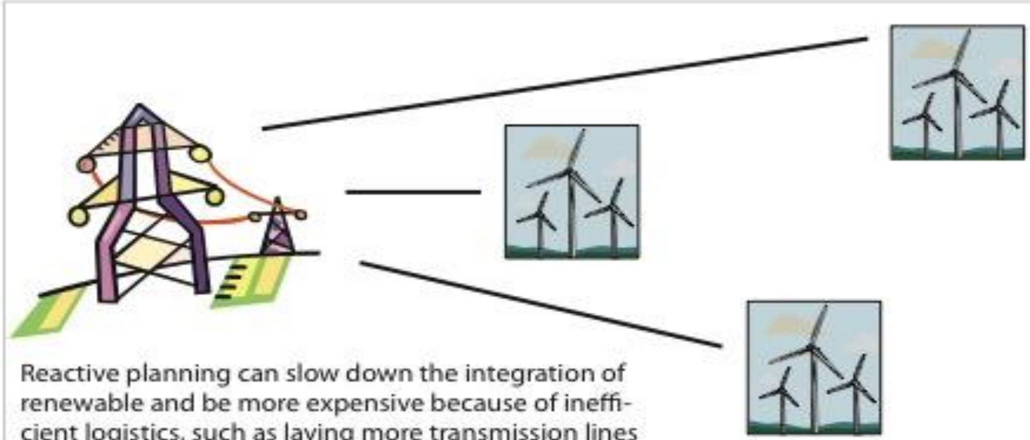
Annual Capacity (2008, MW)		Cumulative Capacity (end of 2008, MW)	
Texas	2,671	Texas	7,118
Iowa	1,600	Iowa	2,791
Minnesota	456	California	2,517
Kansas	450	Minnesota	1,753
New York	407	Washington	1,447
Wyoming	388	Colorado	1,068
North Dakota	370	Oregon	1,067
Wisconsin	342	Illinois	915
Washington	284	New York	832
West Virginia	264	Oklahoma	831
Illinois	216	Kansas	815
Oregon	185	North Dakota	714
Oklahoma	142	Wyoming	676
Indiana	131	New Mexico	497
Michigan	127	Wisconsin	395
Montana	125	Pennsylvania	361
Missouri	106	West Virginia	330
South Dakota	89	Montana	272
California	89	South Dakota	187
Pennsylvania	67	Missouri	163
Rest of U.S.	52	*Rest of U.S.*	622
TOTAL	**8,558**	**TOTAL**	**25,369**

Source: AWEA project database, EIA, Berkeley Lab estimates

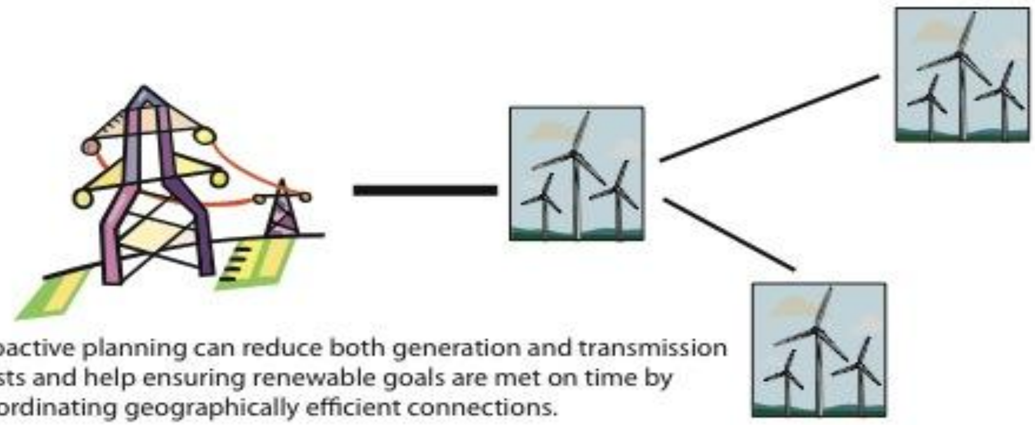
PLANNING FOR TRANSMISSION FOR RE IS KEY TO

Proactive transmission planning a key concept

- To ensure RE can be connected
- Promptly, so that RE are not waiting years to get a connection !
- And efficiently, so that the cost of transmission is minimized and to ensure that RE policy goal is met at total minimum cost. The cost can never be higher than the value given to RE.



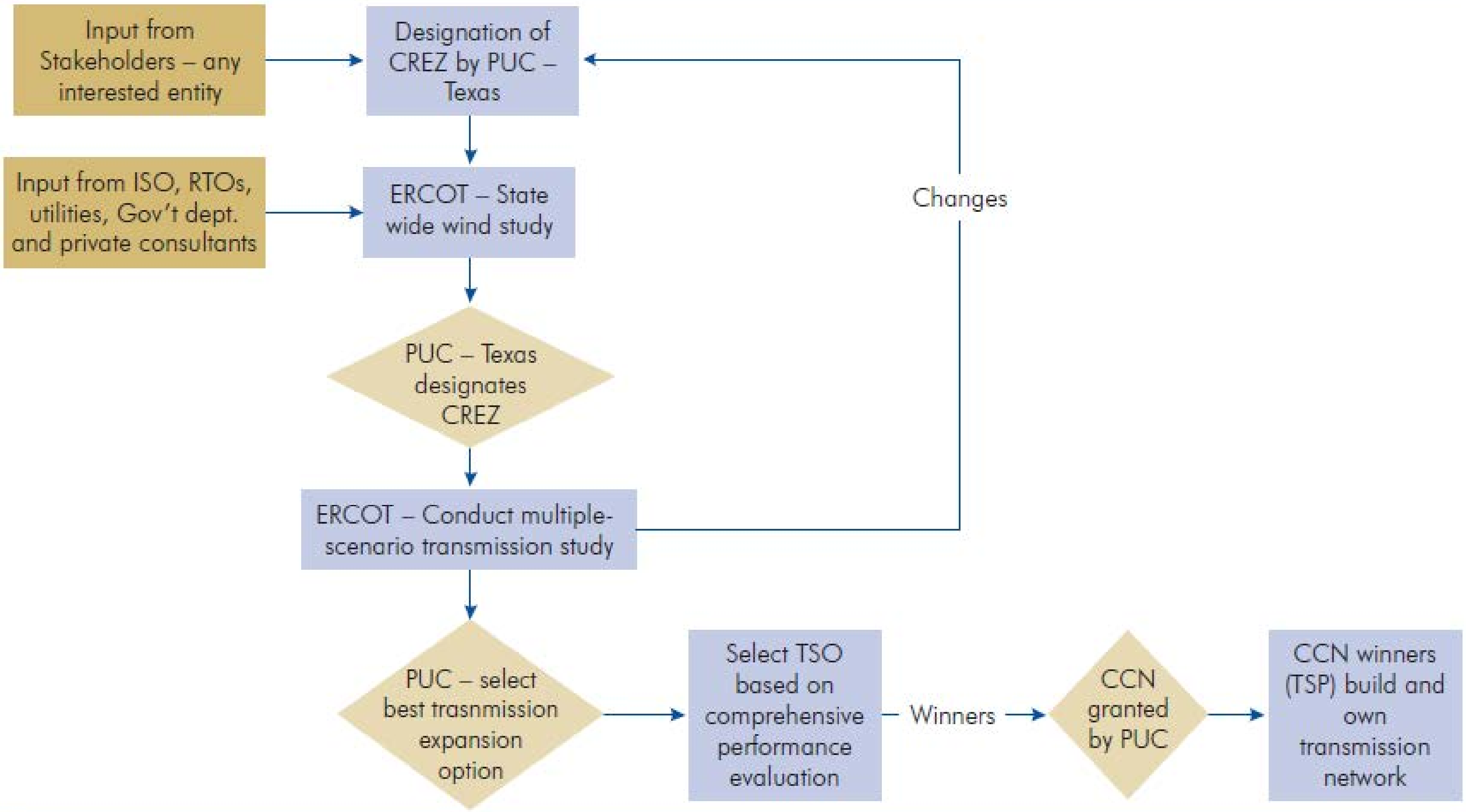
Reactive planning can slow down the integration of renewable and be more expensive because of ineffi-cient logistics, such as laying more transmission lines than necessary when new generation sites are built.



Proactive planning can reduce both generation and transmission costs and help ensuring renewable goals are met on time by coordinating geographically efficient connections.

Texas: CREZ process flow

Figure 3.7: CREZ Process, Texas



Authors

Transmission per-zone

Table 3.4: Texas Transmission Expansion Projections

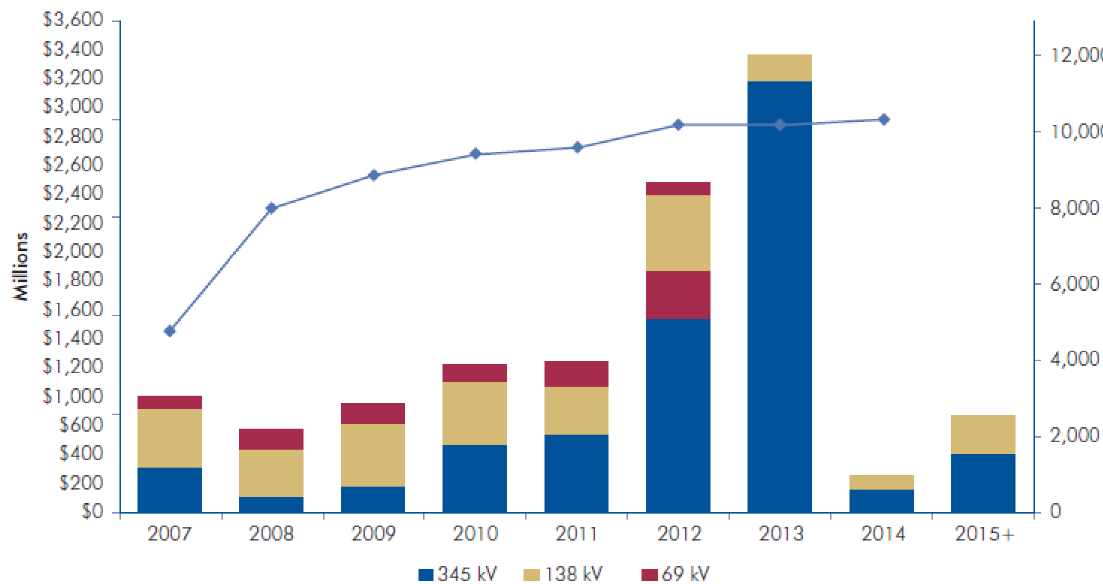
CREZ	Wind capacity (MW)	Total cost of project (US$ million)	Total CREZ miles
Panhandle A	3191	833	523
Panhandle B	2393	444	258
Central West	1859	280	186
Central	3047	1,098	704
McCamey	1063	5,188	320
Base case capabilities*	6903	n.a.	n.a.
Total	**18,456**	7,843	1,991

Source: Compiled by the authors with data obtai
n.a. Not applicable.
Note: Base case: the generation capacity was eit

Features

- *Policy target implemented by FIT*
- *Independent transmission and system operator*
- *Wind power by independent generators (private)*
- *Mandate to plan to reduce cost of T+Wind*
- *Regulator to approve final plan*
- *Transmission cost to consumer via tariffs*

2007–14 (ii)

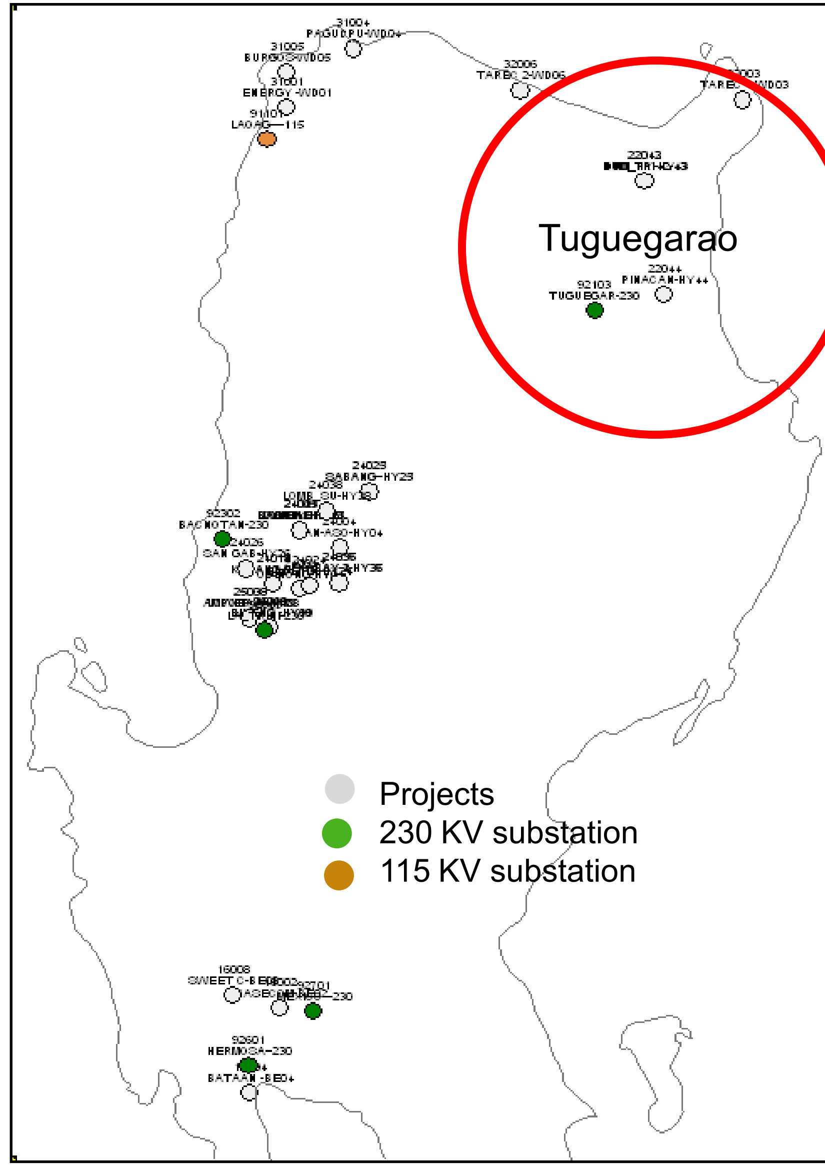


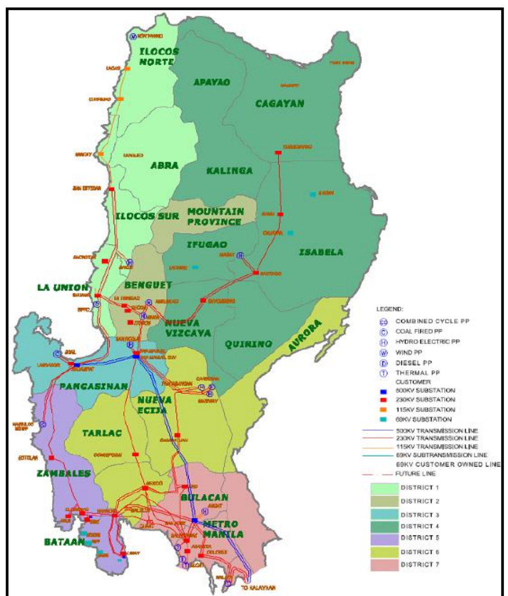
Electricity Transmission: The importance of zone planning

- Illustration of the importance to organize the transmission process (proactively connect) and bundle projects

- We focus on 21 projects in Luzon, out of more than 190 projects (wind, hydro, biomass, and others) that have already requested service contracts as of April 2010

- Transmission needs first-come first-serve vs. planned approach: **reactive vs. organized proactive approach**





Electricity Transmission: In the Philippines

- Characteristics, RE projects in Tuguegarao

Project name	Technology	Installed capacity [MW]	Bus		Geographical coordinates [ºdec]		Capacity factor [pu]
			Name	Number	Latitude	Longitude	
TAREC 2	Wind	45	TAREC 2-WD06	30006	18.4004	121.4514	0.3
TAREC 4	Wind	12	TAREC 4-WD03	30003	18.3670	122.2200	0.3
DUMMON (Main cascade)	Small hydro	2	DUM_HY-42-43	20042	18.0736	121.8790	0.5
DUMMON (Tributary)	Small hydro	2	DUM_HY-42-43	20042	18.0736	121.8790	0.5
PINACAN-HY44	Small hydro	8	PINACAN-HY44	20044	17.6627	121.9473	0.5

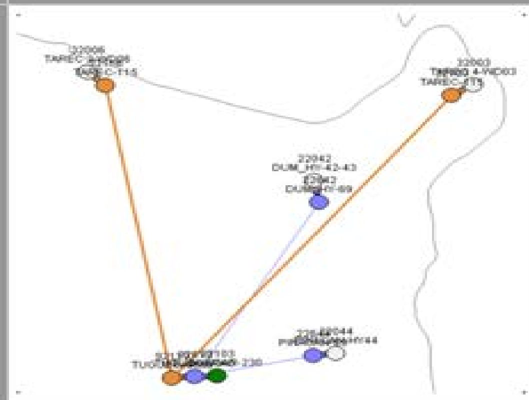
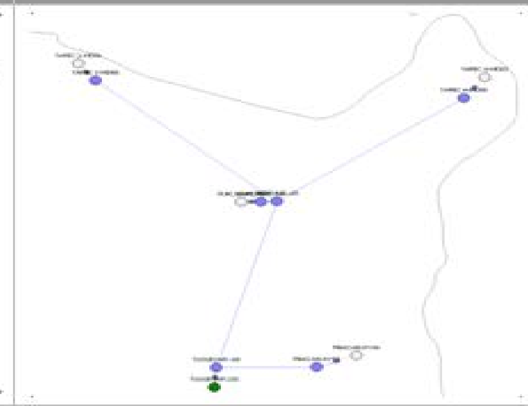
- Some of the assumptions project and transmission costs
  - All projects receive the same energy price (FIT)
  - 11% discount rate
  - 0.3 and 0.5 capacity factors, wind and hydro respectively
  - Sample of transmission costs:

Rated voltage 34.5kV			
Conductor size [AWG/MCM]	Number of conductors per bundle [-]	Resistance of conductor bundle [Ω/km]	Cost of transmission line [kU$/km]
4/0	1	0.1837	38.46
266.8	1	0.1238	41.74
336.4	1	0.0981	43.98

Rated voltage 69kV			
Conductor size [AWG/MCM]	Number of conductors per bundle [-]	Resistance of conductor bundle [Ω/km]	Cost of transmission line [kU$/km]
4/0	1	0.1837	75.59
266.8	1	0.1238	81.37
336.4	1	0.0981	84.15
397.5	1	0.0833	87.15
477	1	0.0692	92.17
556.5	1	0.0596	92.29
636	1	0.0521	97.08

Electricity Transmission: In the Philippines

- **Results:** Comparison and impact in tariffs

Item		Reactive approach	Proactive approach
Schematic network diagram			
NPV, Total (CAPEX+OPEX) [kU$]	TAREC 2	23,671	22,128
	TAREC 4	16,898	9,684
	DUMMON	7,964	1,831
	PINACAN	7,692	5,546
	ALL PROJECTS	56,225	39,189
IRR [% p.a.]	TAREC 2	6.1	6.3
	TAREC 4	2.6	5.5
	DUMMON	1.2	4.7
	PINACAN	3.4	4.1

Reactive	Proactive
23.7	20.9
66.5	36.3
56.5	12.1
27.0	19.3
33.8	22.3

Transmission price
In $/Mwh

1/2

Some General Principles to Consider: Solving the Transmission Issue

Principle 1: Extra transmission is often worth the cost. The cost of expansion transmission is often worth the incremental benefits renewable generation. Benefit should be measured considering the value attributed exclusively to renewable (P3).

Principle 2: Develop transmission proactively. Sparsely and granular renewable resources require proactive and organized planning to reduce cost and connection times

Principle 3: Maximize the net benefit of renewable transmission. Transmission should be planned as to maximize the befits of renewable minus the cost of generation. Along with proper pricing, this ensure that the most valuable sources are developed first

Principle 4: Transmission should use efficient pricing. Suppliers need to pay their share of transmission costs, to help ensure best combined transmission and renewable generation resources are developed first and reduce excess profits

Principle 5: Broadly allocate uncovered transmission costs. Given the befits of renewable are externalities reduced, uncovered transmission charges should be applied as broadly as possible

For more details

ENERGY AND MINING SECTOR BOARD DISCUSSION PAPER

PAPER NO.26

JUNE 2011

Transmission Expansion for Renewable Energy Scale-Up

Emerging Lessons and Recommendations

Marcelino Madrigal
Steven Stoft

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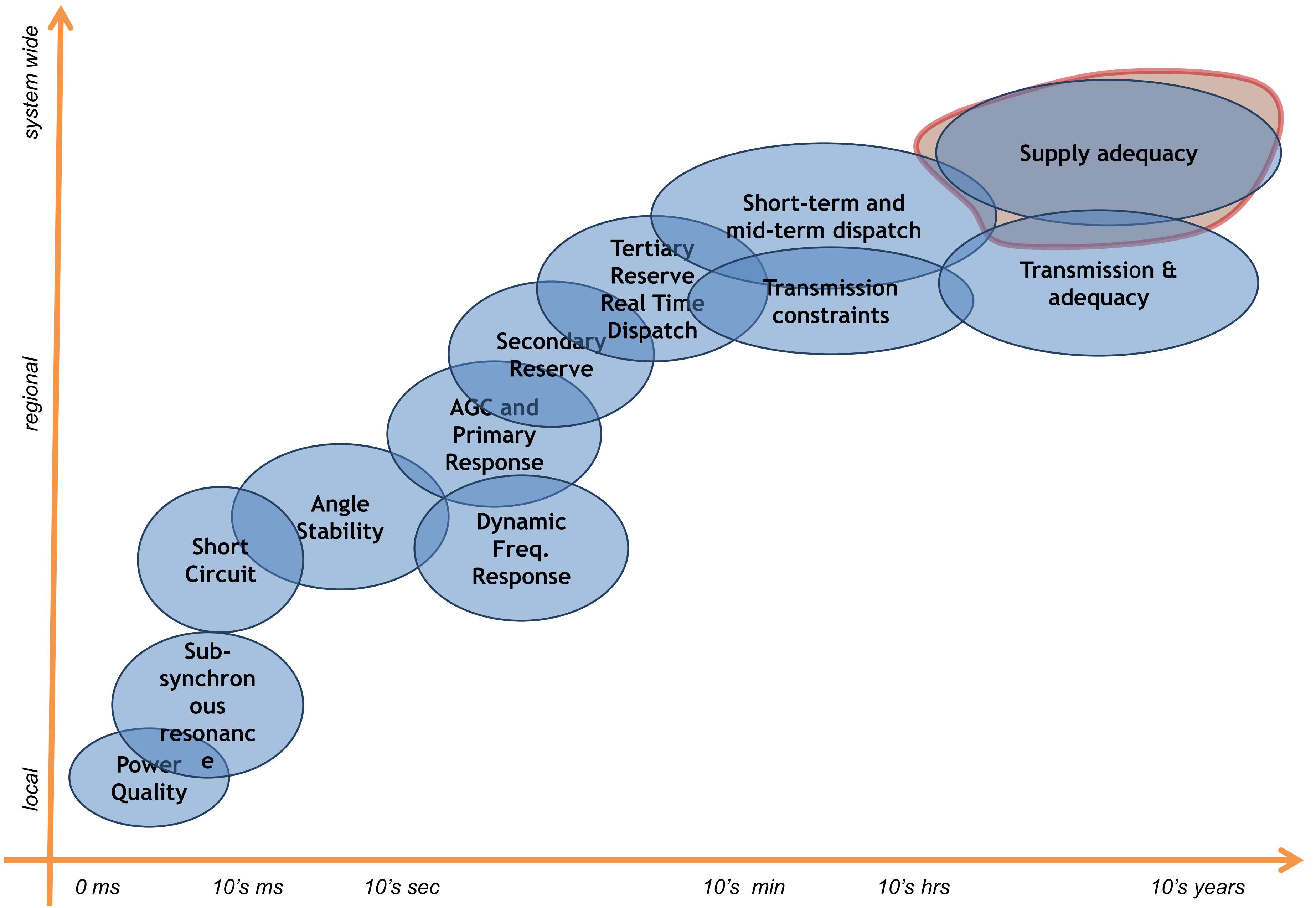
IMPACTS IN DIFFERENT TIME/SPACE FRAMES AND THE ARE OF FOCUS IN THIS PRESENTATION



VARIABLE RENEWABLE ENERGY TECHNOLOGIES AND PLANNING

- Do variable renewable contribute to long-run adequacy and security ? (e.g firm and peak energy when needed)
- How to estimate the combination of supplies that still meets planning reserve requirements ?
- While variable renewables contribute to long-term system adequacy, there are still mainly an incremental energy resource
- They can serve any amount of firm or peak energy needed, the main implication will be the cost
- If that is case, how to consider the impacts in long-term planning ? To preserve long-run reliability criteria.

VARIABLE RENEWABLE ENERGY TECHNOLOGIES AND PLANNING

- Variable power sources are still mainly and energy resource, their contribution to supply adequacy will be limited if compared to a conventional power source

- While the levelyzed cost of energy of good (e.g. wind) resources could be comparable to some conventional sources (e.g. gas in an expensive gas region), the cost to meet a given adequacy standard can be considerable different. Specially if

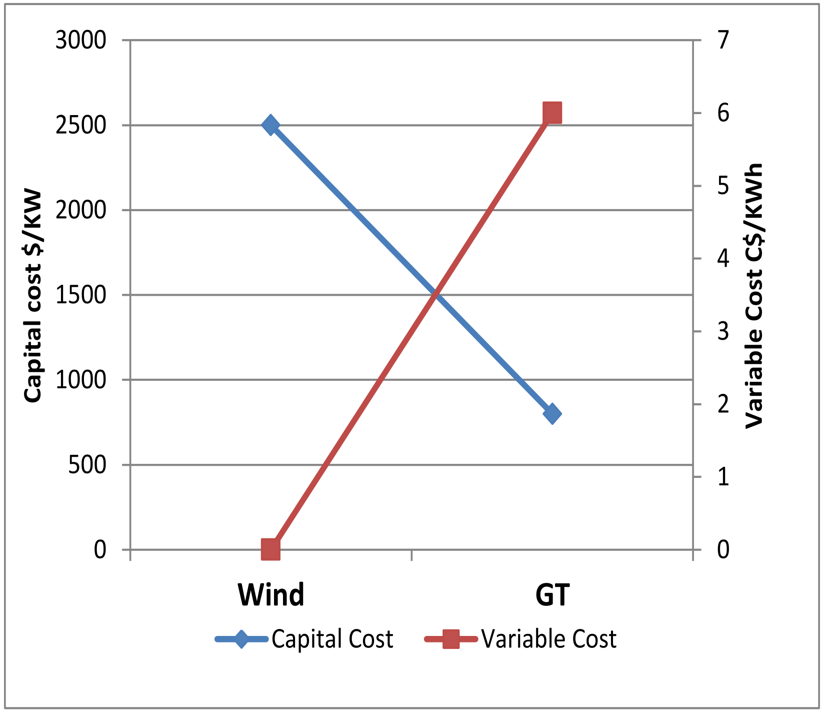
    - Variable sources does not coincides with critical periods (peak demand)

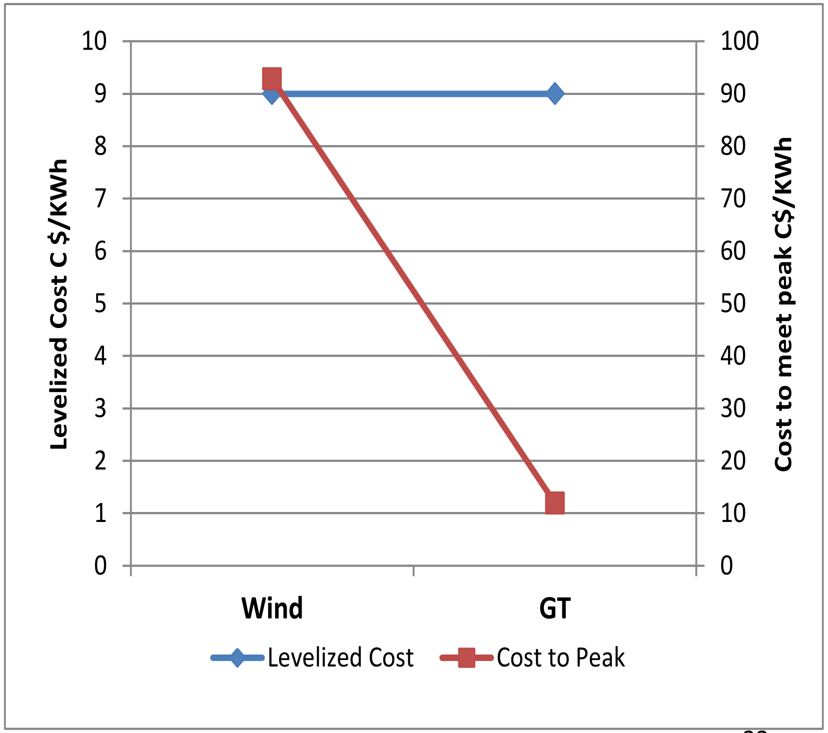
    - No diversity of resources

    - The existing system is already adequate

Example: Levelyzed cost vs. Cost to meet peak

- A wind and a gas power plant could have similar levelized cost energy, say 9 c$US/KWh. However, the cost to meet peak can be drastically different (9 vs 90 US$/KWh), if wind power does not coincided with peak





- **Capacity value** of variable power sources. There are several approaches, selecting will depend on the characteristics of demand and supply options. Deterministic or probabilistic approaches

  - The capacity equivalent to the average generation production

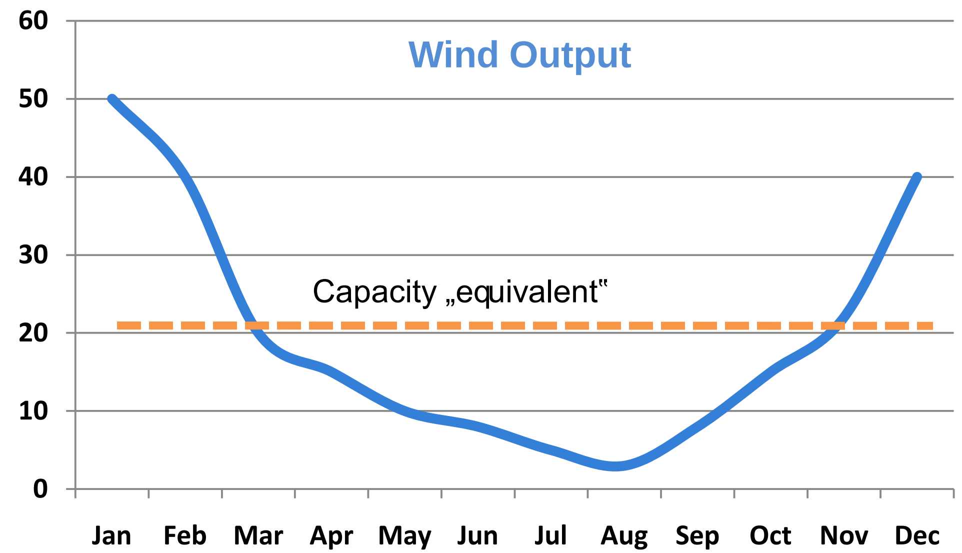
  - The amount of firm energy that unit can supply with a given probability (e.g. say 95%)

  - The contribution of the unit to meet peak demand

  - The contribution of the source to Loss of Load Probability (LOLP) or Loss of Load Expectation (LOLE)

- **Deterministic (1)**: capacity equivalent to the average generation production. Example Wind Power Pant

Wind		
Cap	MW	100
	Month	Pout
1	Jan	50
2	Feb	40
3	Mar	20
4	Apr	15
5	May	10
6	Jun	8
7	Jul	5
8	Aug	3
9	Sep	8
10	Oct	15
11	Nov	22
12	Dec	40
Max		50
Min		3
C.F		0.196667



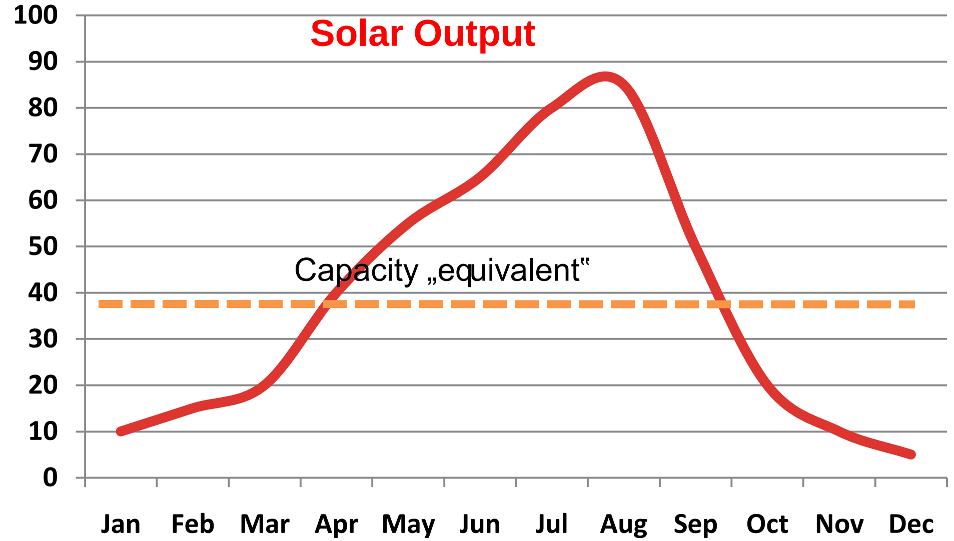
Capacity contribution:

Plate capacity (MW) X Capacity Factor (c.f.)

= 100 X 0.196667 = **20 MW**

- **Deterministic (1)**: capacity equivalent to the average generation production. Example Solar Power Pant

Solar		
Cap	MW	100
	Month	Pout
1	Jan	10
2	Feb	15
3	Mar	20
4	Apr	40
5	May	55
6	Jun	65
7	Jul	80
8	Aug	85
9	Sep	50
10	Oct	20
11	Nov	10
12	Dec	5
Max		85
Min		5
C.F		0.379167

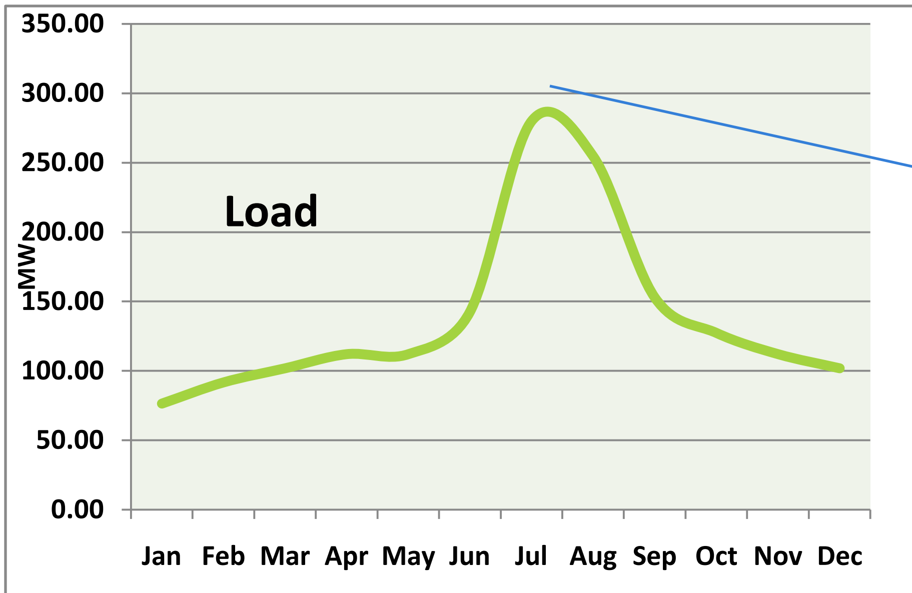


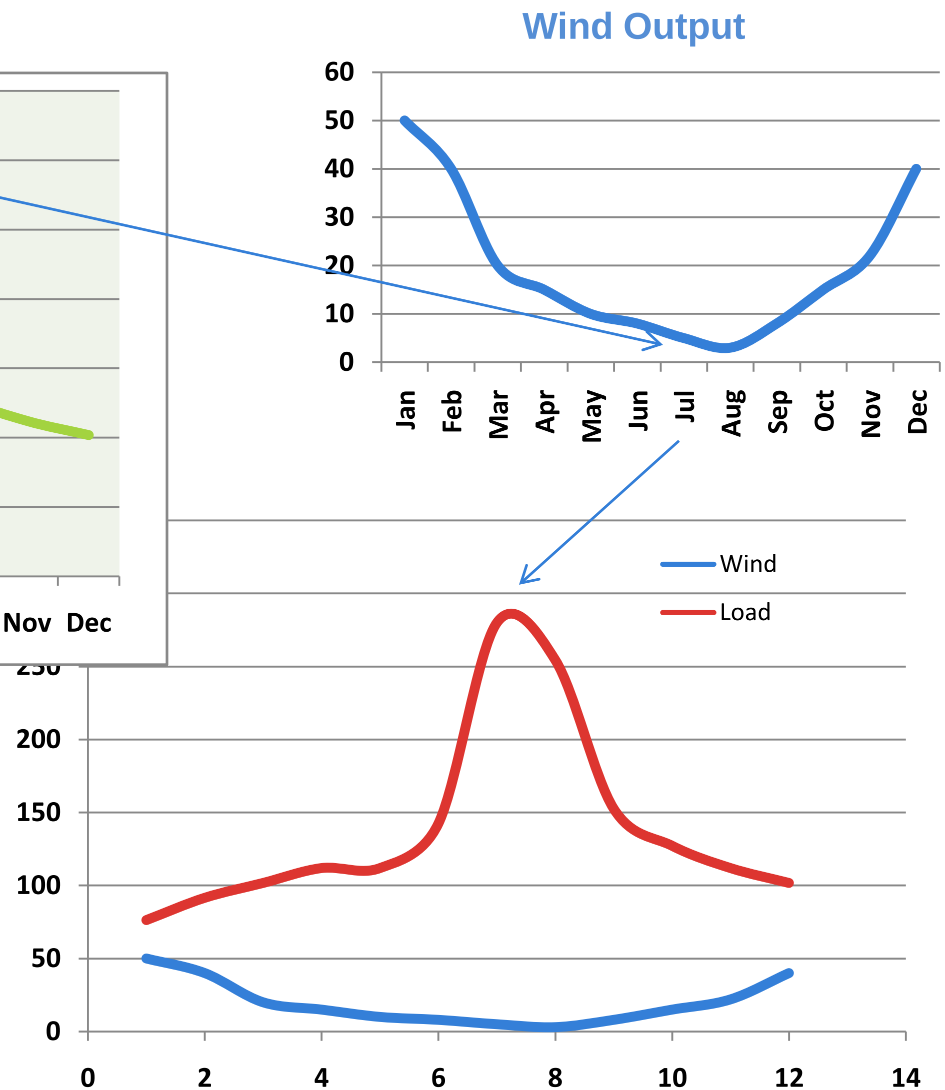
Capacity contribution:

Plate capacity (MW) X Capacity Factor (c.f.)

= 100 X 0.379167 = **38 MW**

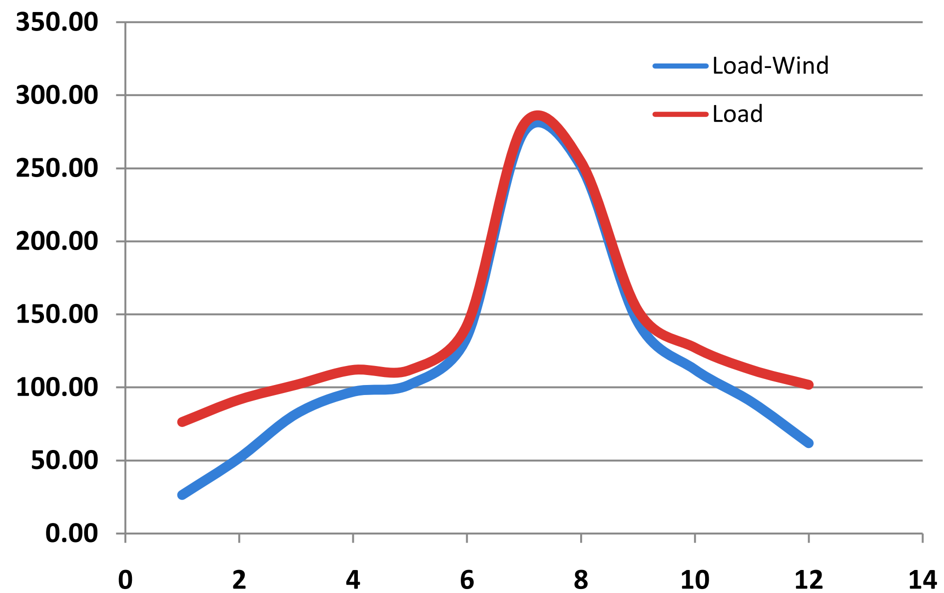
- **Deterministic (2)**: capacity equivalent = contribution to peak demand. Wind





- **Deterministic (2)**: capacity equivalent = contribution to peak demand. Wind

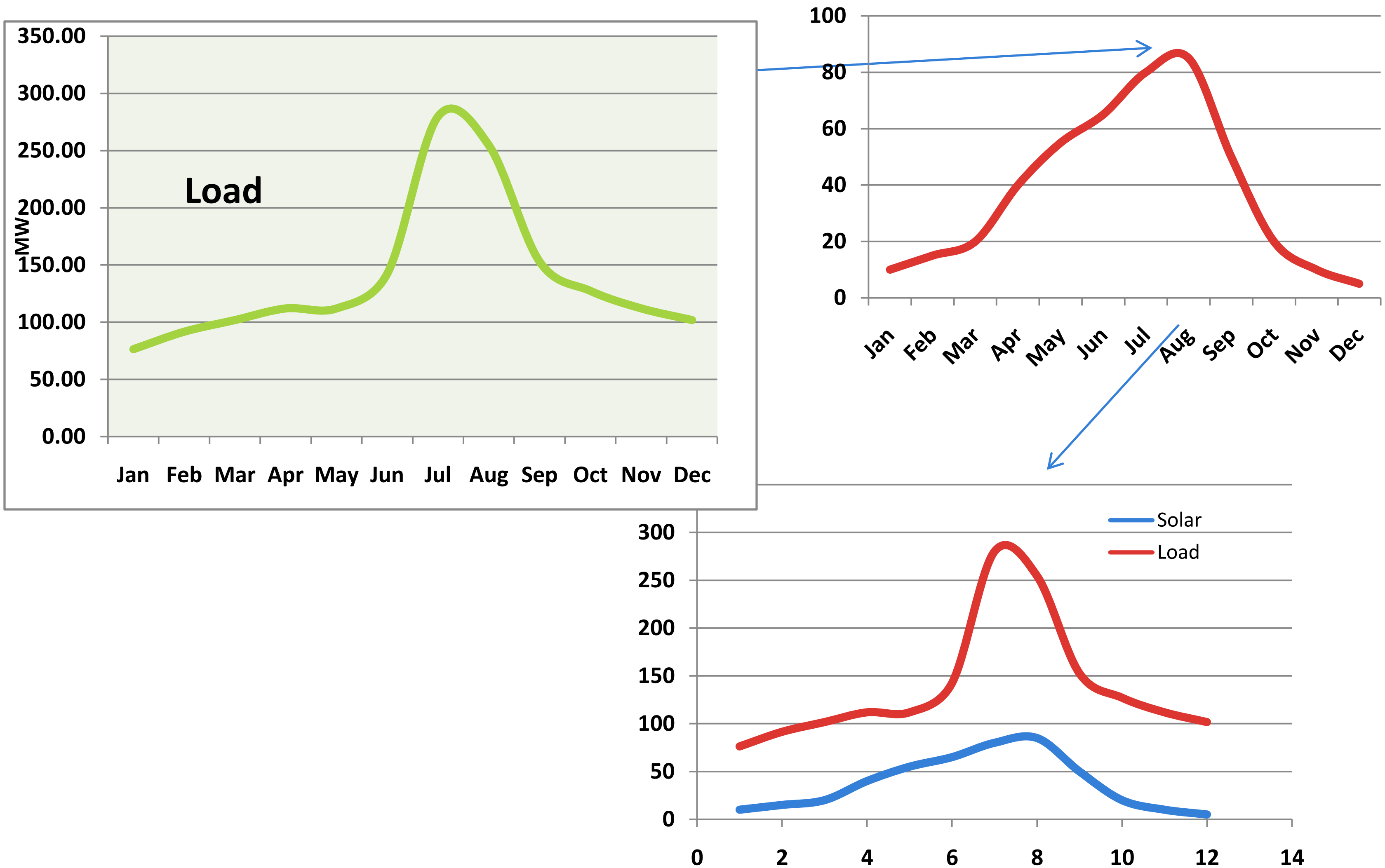
Wind				
Cap	MW	100		
	Month	Pout	L	L-W
1	Jan	50	76.36	26.36
2	Feb	40	91.64	51.64
3	Mar	20	101.82	81.82
4	Apr	15	112.00	97.00
5	May	10	112.00	102.00
6	Jun	8	142.55	134.55
7	Jul	5	280.00	275.00
8	Aug	3	254.55	251.55
9	Sep	8	152.73	144.73
10	Oct	15	127.27	112.27
11	Nov	22	112.00	90.00
12	Dec	40	101.82	61.82
Max		50.00	280.00	275.00
Min		3.00	76.36	26.36



Capacity contribution:

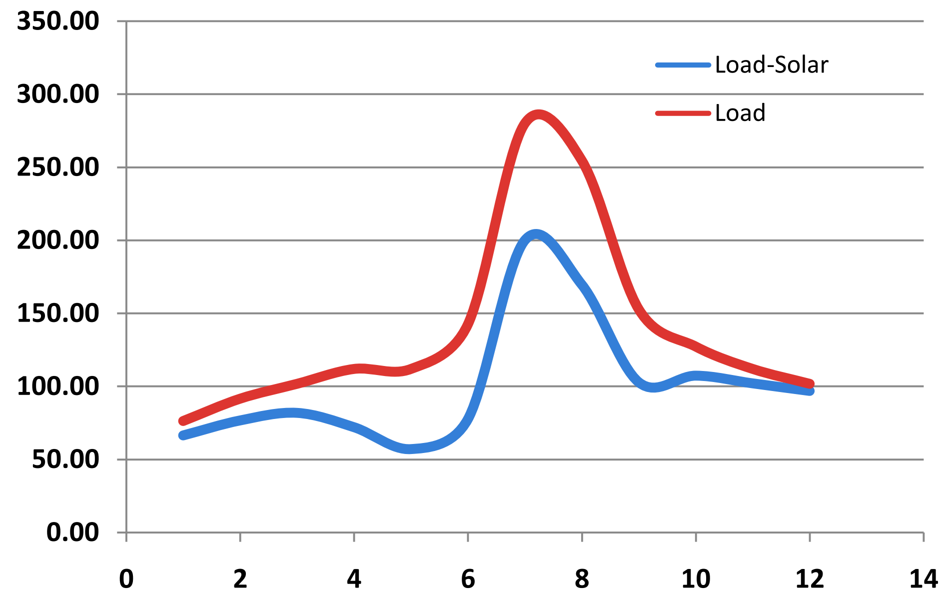
280 – 275 = **5 MW**

- **Deterministic (2)**: capacity equivalent = contribution to peak demand. Solar



- **Deterministic (2)**: capacity equivalent = contribution to peak demand. Solar

Solar				
Cap	MW	100		
	Month	Pout	L	L-S
1	Jan	10	76.36	66.36
2	Feb	15	91.64	76.64
3	Mar	20	101.82	81.82
4	Apr	40	112.00	72.00
5	May	55	112.00	57.00
6	Jun	65	142.55	77.55
7	Jul	80	280.00	200.00
8	Aug	85	254.55	169.55
9	Sep	50	152.73	102.73
10	Oct	20	127.27	107.27
11	Nov	10	112.00	102.00
12	Dec	5	101.82	96.82
Max		85.00	280.00	200.00
Min		5.00	76.36	57.00



Capacity contribution:

280 – 200 = **80 MW**

- **Capacity Contribution of Renewable Energy Using LOLE Probabilistic Approach**: capacity contribution = incremental demand that can be met at the same value of LOLE after the renewable source is added to the system

  - **Step 1.** Determine original LOLEo, e.g. without the renewable energy source, using system LDCo and COPT
  - **Step 2.** Forecast renewable production and reduce such production from total load forecast, compute new LDC -> LDCn
  - **Step 3.** Determine after renewable energy resource addition LOLEn
  - **Step 4.** Increase demand across all hours until LOLEn=LOLEo
  - **Step 5.** Capacity contribution of the renewable source is

Capacity Contribution = Dn-Do

Dn - maximum demand corresponding to LOLEo

Do - maximum demand corresponding to LOLEn

***Source**: "Capacity Value of Wind Power" by the IEEE Task Force on Capacity Value: Keane, A. Milligan, M. Dent, C. J. Hasche, B. D'Annunzio, C. Dragoon, K. Holttinen, H. Samaan, N. Soder, L. O'Malley, M. IEEE Transactions on Power Systems: Vol. 26, No 2, May 2010.*

Example/Probabilistic: 3 generation units 350 MW total

Adding 100 MW of **Wind**

- **LOLEn** – At peak demand (e.g. time frame only summer)

LOLE n= 8.15 days/year

State	Total Capacity Out	U1 0.02	U2 0.03	U3 0.05	COPT Calculation	Prob	Total Cap In	% Time L>C	LOLEi Probi
1	0	1	1	1	=0.98 X 0.97 X 0.95	0.903070	350	0	0
2	50	0	1	1	=0.02 X 0.97 X 0.95	0.018430	300	0	0
3	100	1	0	1	=0.98 X 0.03 X 0.95	0.027930	250	13.14316	0.367089
4	200	1	1	0	=0.98 X 0.97 X 0.05	0.047530	150	35.85739	1.704302
5	150	0	0	1	=0.02 X 0.03 X 0.95	0.000570	200	23.0654	0.013147
6	250	0	1	0	=0.02 X 0.97 X 0.05	0.000970	100	53.88668	0.05227
7	300	1	0	0	=0.98 X 0.03 X 0.05	0.001470	50	84.70796	0.124521
8	350	0	0	0	=0.02 X 0.03 X 0.05	0.000030	0	100	0.003
Total						1.000000			
LOLE (%)									2.264328
LOLE (d/y)									8.151581

LOLE decreases from LOLEo=9.37 to LOLEn= 8.15 days/year

Wind has a positive capacity contribution

Example/Probabilistic: 3 generation units 350 MW total

Adding 100 MW of **Solar**

- **LOLEn** – At peak demand (e.g. time frame only summer)

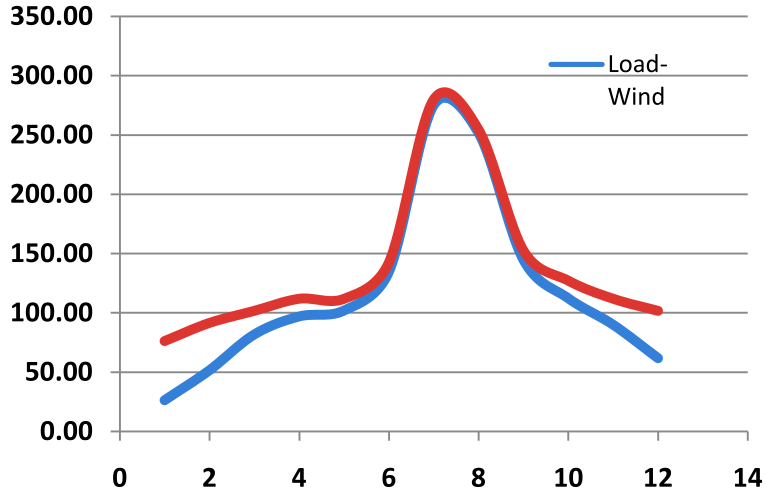
LOLE n= 3.87 days/year

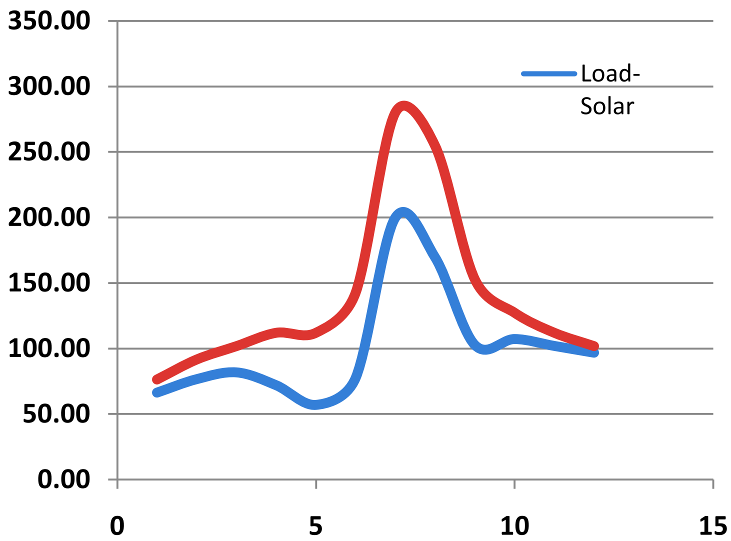
State	Total Capacity Out	U1 0.02	U2 0.03	U3 0.05	COPT Calculation	Prob	Total Cap In	% Time L>C	LOLEi Probi
1	0	1	1	1	=0.98 X 0.97 X 0.95	0.903070	350	0	0
2	50	0	1	1	=0.02 X 0.97 X 0.95	0.018430	300	0	0
3	100	1	0	1	=0.98 X 0.03 X 0.95	0.027930	250	0	0
4	200	1	1	0	=0.98 X 0.97 X 0.05	0.047530	150	18.43318	0.876129
5	150	0	0	1	=0.02 X 0.03 X 0.95	0.000570	200	3.667671	0.002091
6	250	0	1	0	=0.02 X 0.97 X 0.05	0.000970	100	49.58257	0.048095
7	300	1	0	0	=0.98 X 0.03 X 0.05	0.001470	50	100	0.147
8	350	0	0	0	=0.02 X 0.03 X 0.05	0.000030	0	100	0.003
Total						1.000000			
LOLE (%)									1.076315
LOLE (d/y)									3.874733

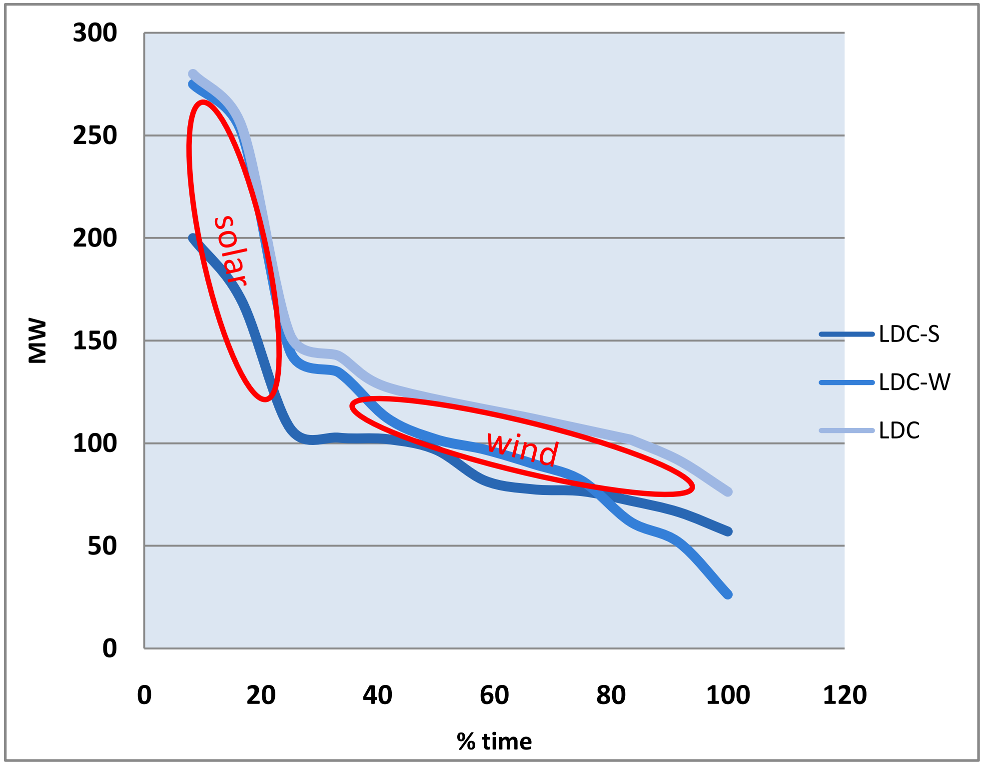
LOLE decreases from LOLEo=9.37 to LOLEn= 3.87 days/year

Solar has also a positive capacity contribution

Load duration curves, with and without RE sources







Analysis

- The combination of load shape and reliability of existing units is such that
  - Probabilities of losing load at mid-load levels are high
  - The Solar plan in the example contributes ‘more’ at peak and also mid levels
  - The Wind plan in the example contributes ‘more’ at mid-load and low load levels
  - This makes for a higher capacity contribution of solar
  - The same wind power output in a different system could contribute more or less
  - The same solar power output in a different system could contribute even more or less
  - It all depends on the correlation of load with wind and solar and the reliability of existing system

Capacity value of wind and solar: results after iterative process to increase demand unit LOLEo=LOLEn

Method	Same LOLE		
	d/y LOLE	Incr. Dem	Cap-Contrib (MW)
Original	9.37	0.00	
Wind	9.23	24.75	**25**
Solar	9.53	88.00	**88**

Summary: Capacity Contribution: Comparison of Methods

Method	Average/Capacity Factor		
			Average
	MW-instl.	c.f.	Cap-Contrib (MW)
Wind	100.00	0.20	**20**
Solar	100.00	0.38	**38**
Method	Contribution to Peak		
	Peak	Peak	Peak
	Reserve %	Demand	Cap-Contrib (MW)
Original	25	280.00	
Wind	17	275.00	**5**
Solar	21.527778	200.00	**80**
Method	Same LOLE		
	d/y		
	LOLE	Incr. Dem	Cap-Contrib (MW)
Original	9.37	0.00	
Wind	9.23	24.75	**25**
Solar	9.53	88.00	**88**
Method	Other: Garver/ Effective Load CC		
			ELCC
			Cap-Contrib (MW)
Wind			**12**
Solar			**39**

Example: Ireland, resource adequacy assessment

- The share of wind energy to energy demand has greatly increased from 1.6% in 2002 to 7.1% in 2007

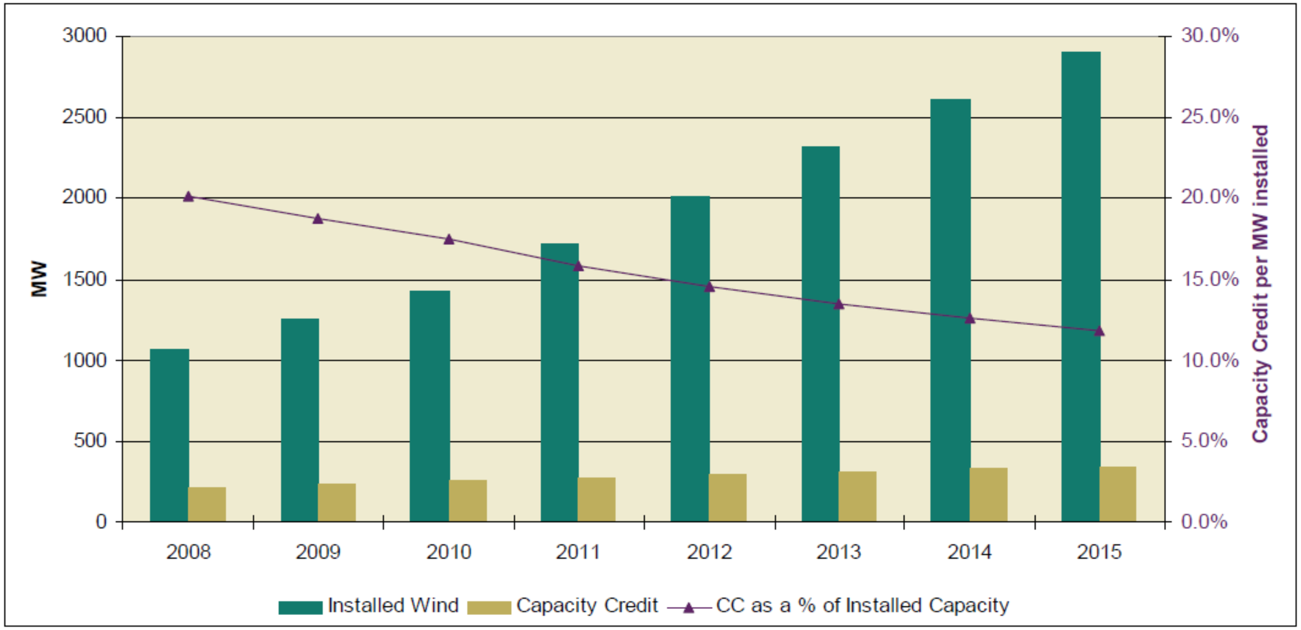
- Going forward, the capacity of installed wind power generation is expected to increase since it will be mandated to meet the government goal of supplying 40% energy from renewables by 2020

- In 2008 peak demand 5086 MW, wind power 1067 MW, conventional 6213 MW, other renewables 185 MW. EIRGRID reported that the contribution of wind power to the peak demand (that happens during winter in the evenings of a weekday) was zero.

- However, the contribution of wind power to system adequacy, which is assessed using LOLE methodology, is expected to continue decreasing, following recent trends.

Example: Ireland, resource adequacy assessment

- The capacity contribution of wind power has fallen from 34% in 2002 to 23% in 2007. The capacity contribution of wind power is expected to go down further to just above 10% in terms of total installed capacity by 2015.



Source: Eirgrid. Adequacy Report for the Period 2009-2015
[*www.eirgrid.com*](http://www.eirgrid.com)

Contents

- **Variable Renewables and Transmission Planning**
- **Variable Renewables and Supply Adequacy Planning**
- **Final Remarks**

FINAL REMARKS

- Operational impacts of variable power sources can be managed without major challenges at lower penetration levels (<10%) and the cost implications will be low

- At higher penetration levels (>10 to 30%) operational cost will increase, operations need be adapted: forecasting, and flexibly resources will be required, operational costs can increase

- Transmission will be required, need to plan transmission proactively to reduce costs and connect promptly

- Variable power sources are mainly energy resources. They can contribute to “firm”, “peak”, or “base-load” power; however, their contribution will be often limited and at higher costs

- The extra cost will highly depend on each system existing resources cost, type, complementarity of variable power sources and their diversity, current adequacy conditions of the system, and valuation of externality cost