

# **Renewable Energy Supply Curves:**

Practical problems and applications for policy

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# Outline

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- **Basic concept**
- **Why are they useful?**
- **Economic benefits of renewable energy (Serbia)**
- **Estimation problems: (China)**
- **Dealing with uncertainty (Croatia)**
- **Impact of power sector reform (Vietnam)**



## Basic Concepts

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Create a database of renewable energy projects: capital and operating costs, energy and capacity

Sort the projects in increasing order of production cost (using the opportunity cost of capital to annualize capital costs)

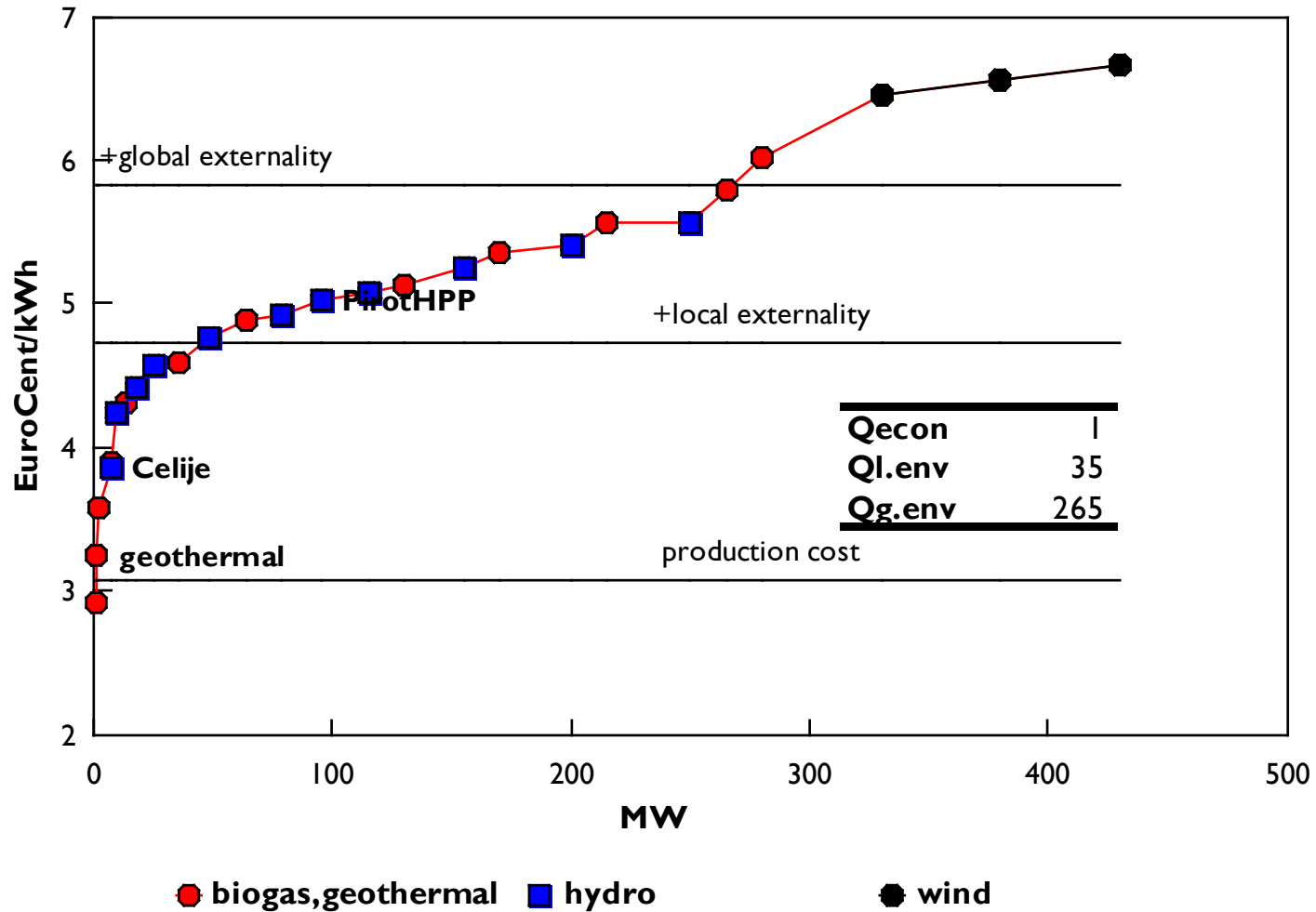
Display as a graph, plotting cumulative MW or GWh available at increasing production cost

Compare these costs with

- (avoided) thermal generation cost
- avoided social thermal generation cost (including avoided local environmental damage costs)
- avoided global thermal generation cost (including GHG damage costs)

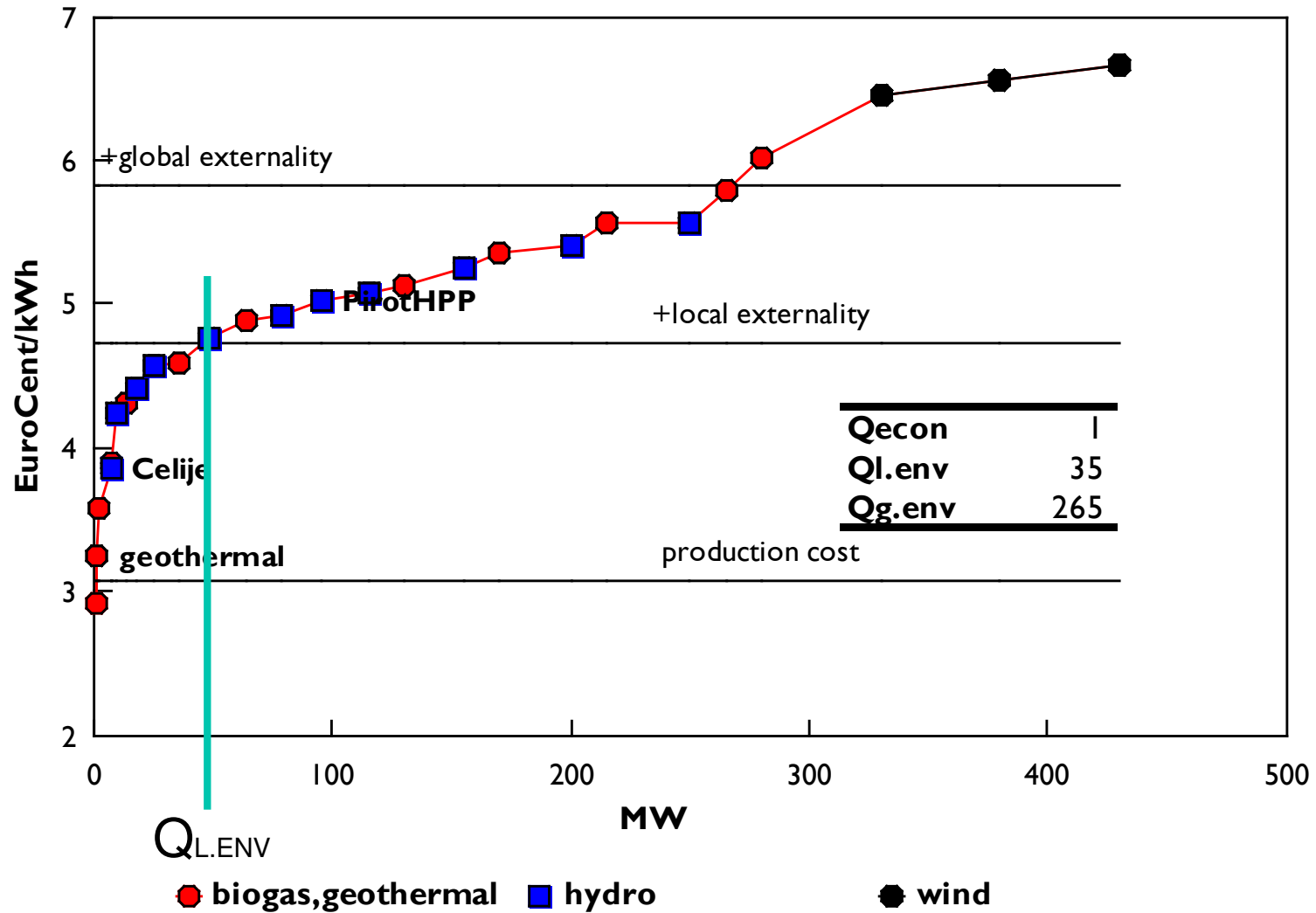


# Example: Serbia



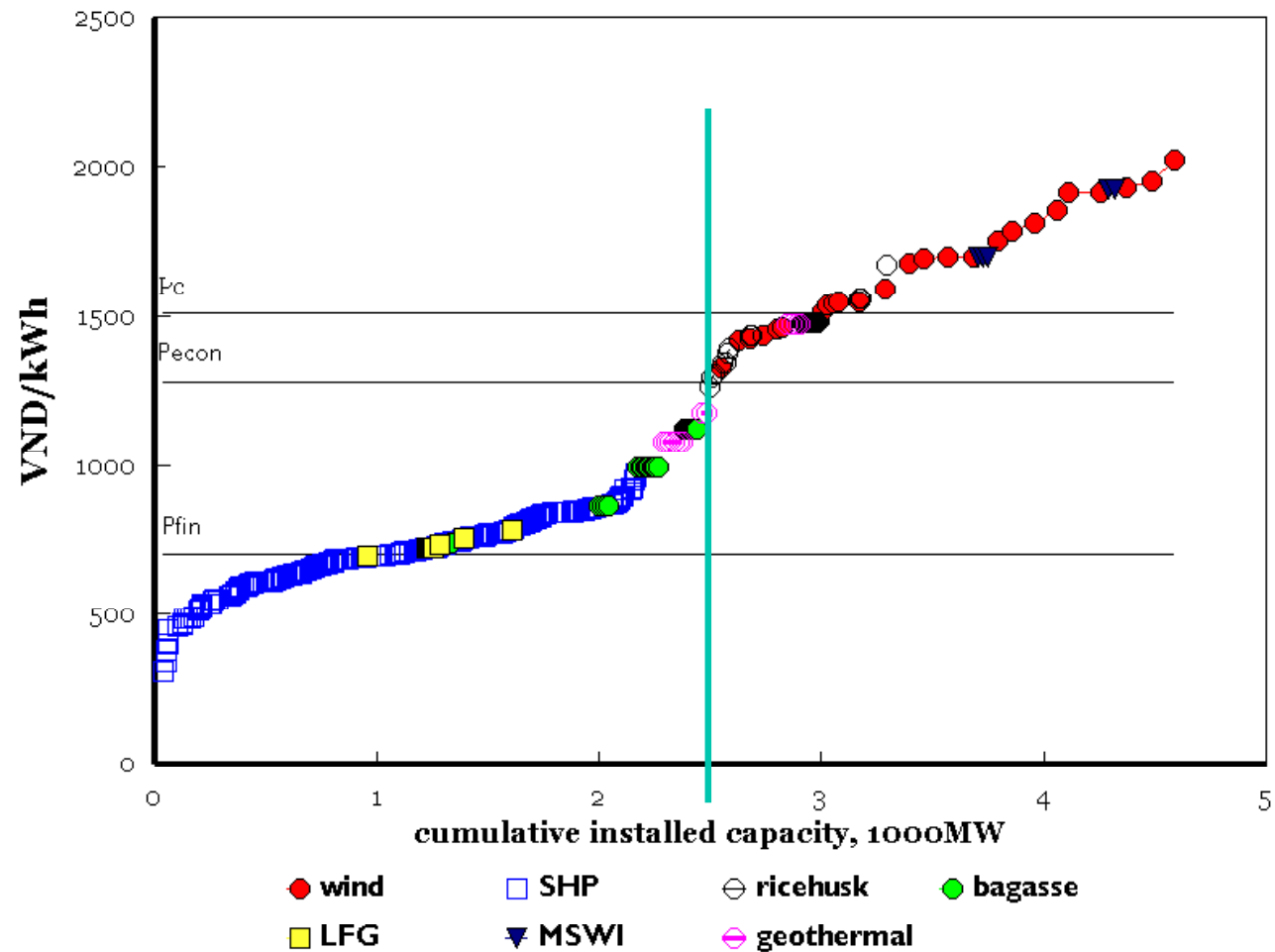
# Optimal level of renewables

Given by the intersection of the supply curve with the avoided social cost ( $Q_{l.env}$ )



## Example: Vietnam

In Vietnam, local environmental damage costs are very low, but the difference between the thermal actual generation price ( $P_{fin}$ ) and the social avoided cost ( $P_{econ}$ ) is large because of fossil fuel subsidies



## Uses of supply curves

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- **set economically efficient renewable energy targets**
- **estimate economic benefits**
- **renewable energy tariff design**

**Not everybody likes supply curves, because they make transparent the relative costs and benefits of different RE technologies.**



## Uses of supply curves

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Used by the World Bank in renewable energy studies in

- China
- Sri Lanka
- Croatia
- Philippines
- Serbia
- South Africa
- Vietnam



## The main issues

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- Economic and financial supply curves may be different. But that very difference provides guidance on how government should intervene to correct market failures
- Data intensive. Reliability of information for different technologies varies widely (typically small hydro data is the best, wind data the worst).
- Supply curves change over time as information (and technology) improves, and depend upon assumed discount rates.



## Discount rates

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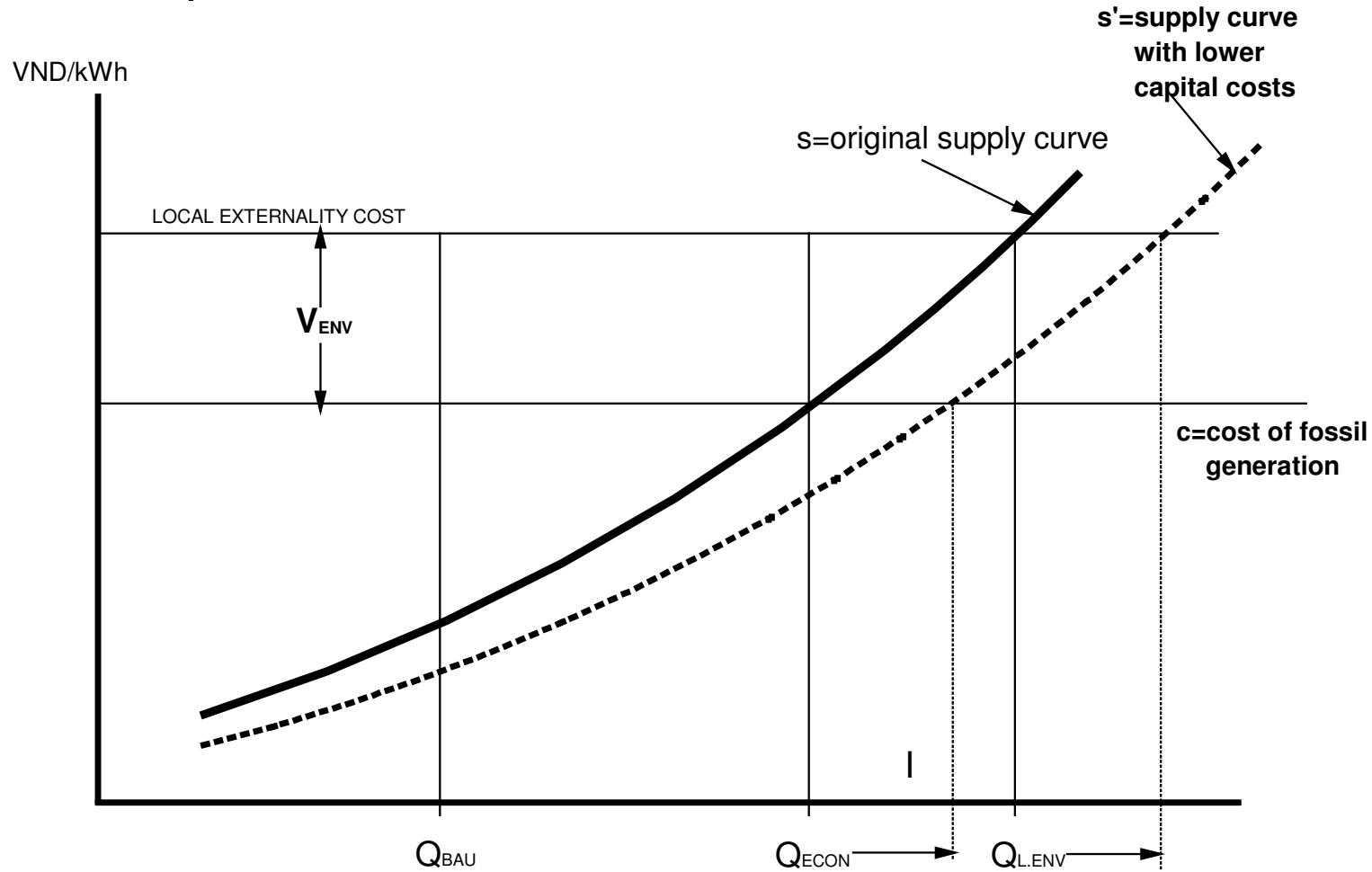
The lower the discount rate, the greater is the optimal quantity of renewables: discount rates used in World Bank renewable energy projects vary widely (set by *Governments*, not the World Bank!)

Country	Rate	Renewable energy technologies evaluated
Philippines	15%	Solar homes (PV)
Peru	14%	Small hydro, solar homes (PV) (Peru Rural Electrification Project)
India	12%	Solar homes(PV), small hydro
China	12%	Small hydro, wind, bagasse, landfill gas
Vietnam	10%	Village (micro) hydro
South Africa	10%	Landfill gas, small hydro, pulp&paper cogeneration: Renewable Energy Market Transformation project (carbon finance for renewables)
Sri Lanka	10%	Small hydro, wind, village (micro) hydro, solar homes
Cape Verde	10%	Wind
Croatia	8%	Biomass (combined heat and power), wind, small hydro

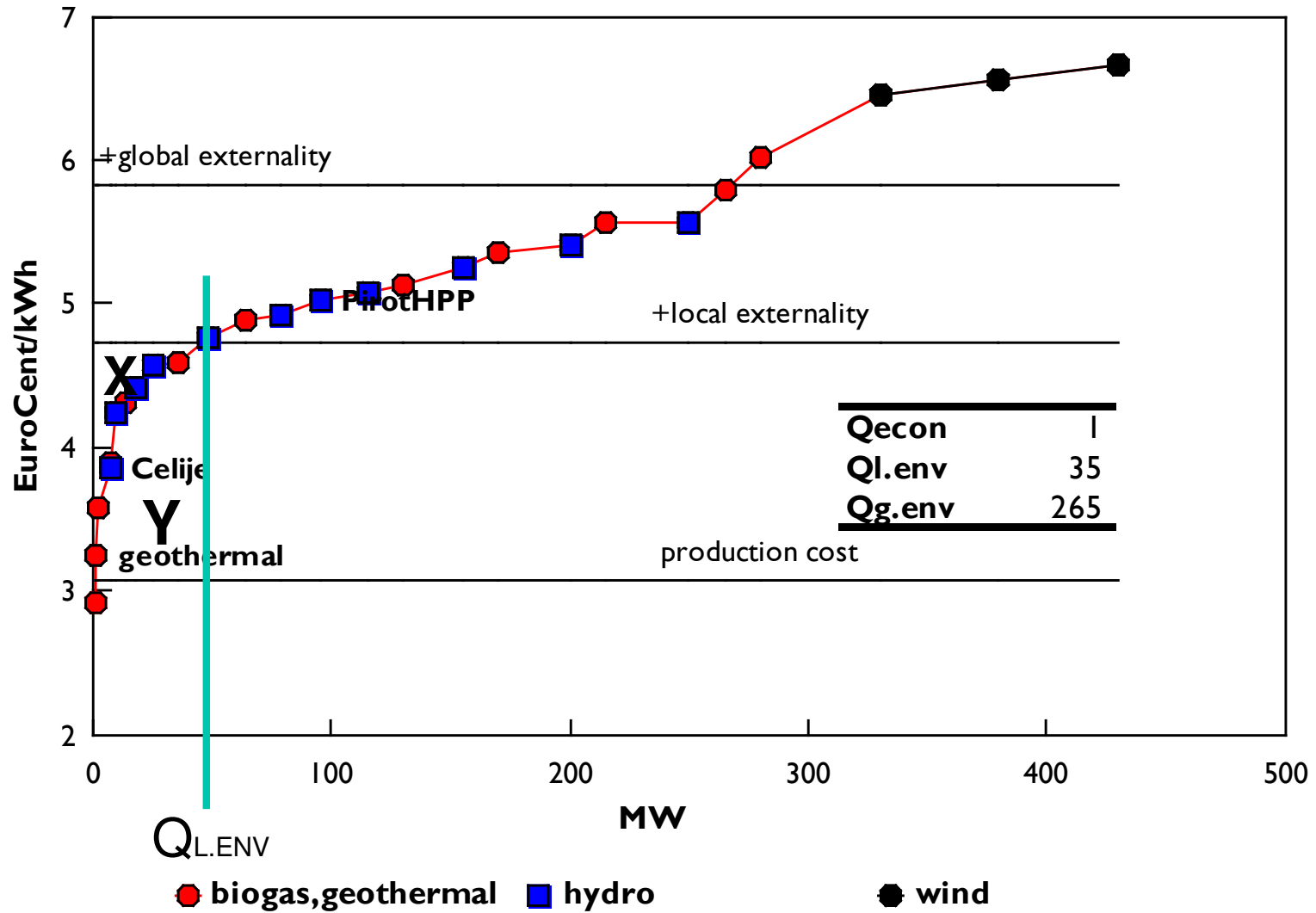


# Declining capital costs

same impact as lower discount rate



# Serbia: Supply curves used to estimate economic benefits of RE



## Economic benefits

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**Total avoided damage costs at  $Q_{LENV} = X + Y$**

**Incremental production costs =  $Y$**

**Net economic benefit =  $X$**



## Estimation problems: Calculation of capacity credit

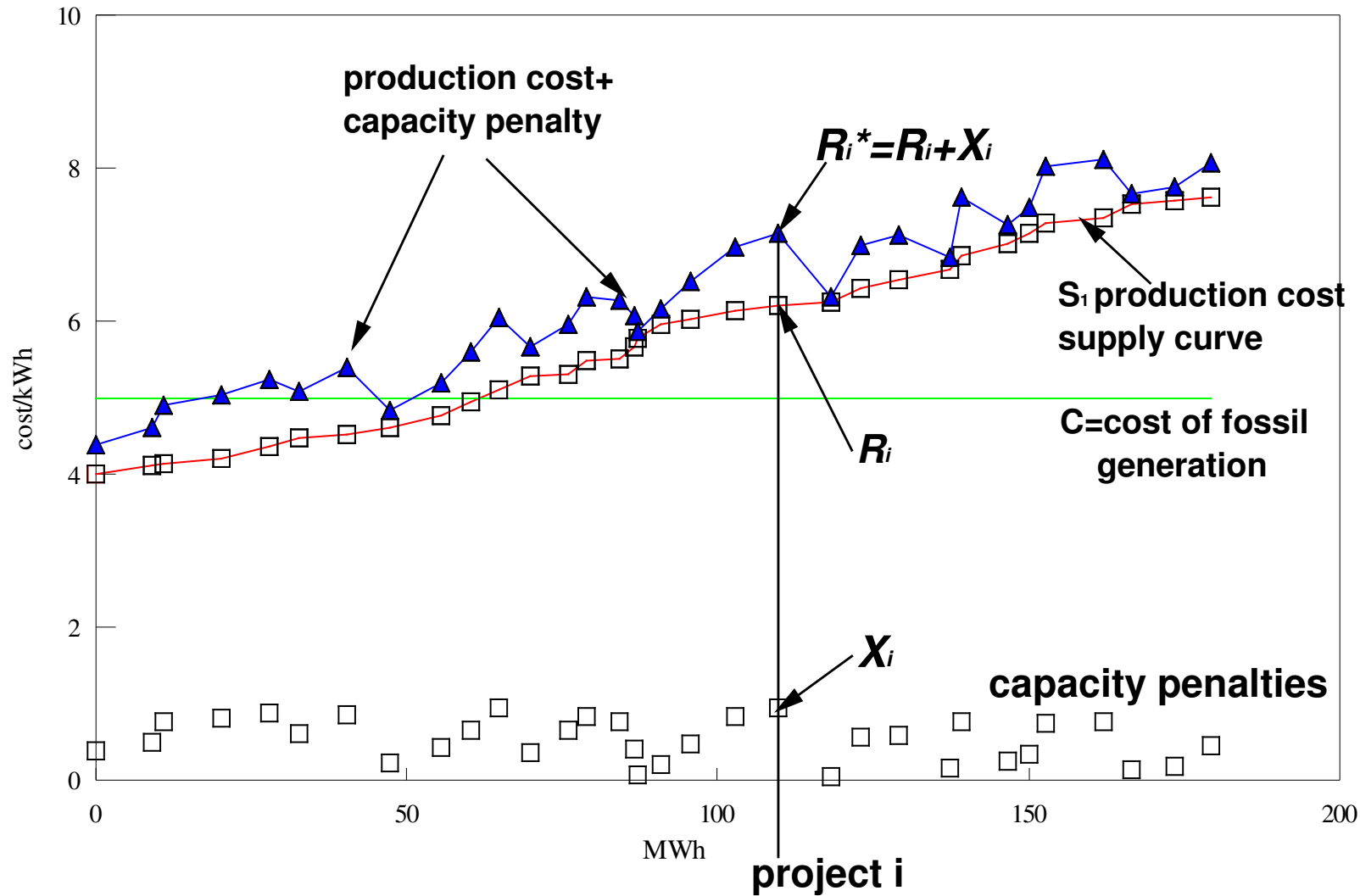
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- Calculation of the avoided cost of *energy* is straightforward.
- Avoided environmental damage costs are also *energy* related.
- But what is the cost of avoided *capacity*? The avoided cost of capacity may be a significant part of the total social avoided cost – e.g. Vietnam (based on gas CCGT as the avoided thermal project)

	VND/kWh	UScents/ kWh
Avoided energy cost	963	5.66
Avoided capacity cost	305	1.79
Avoided fixed O&M	126	0.74
Total	1394	8.20



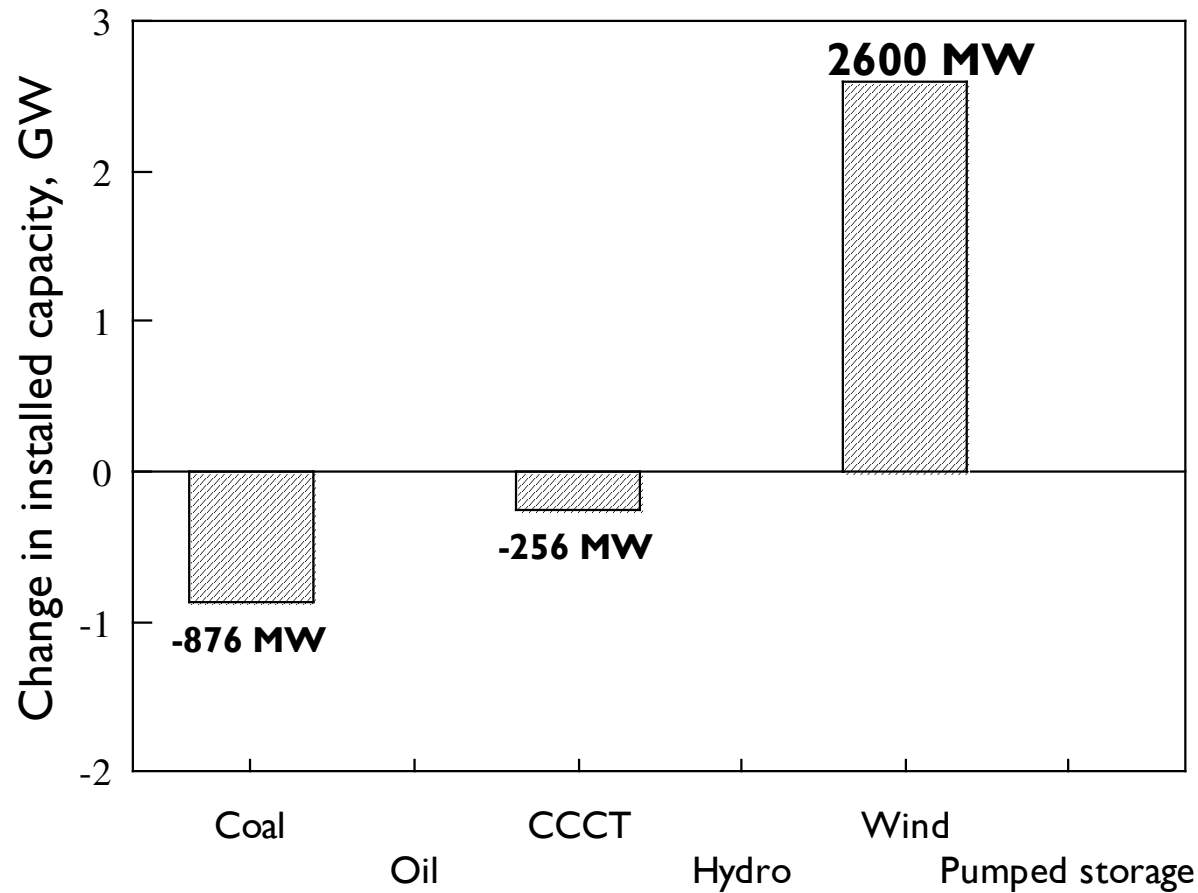
# Adjusting the supply curve for capacity credit



## China: Capacity Credits

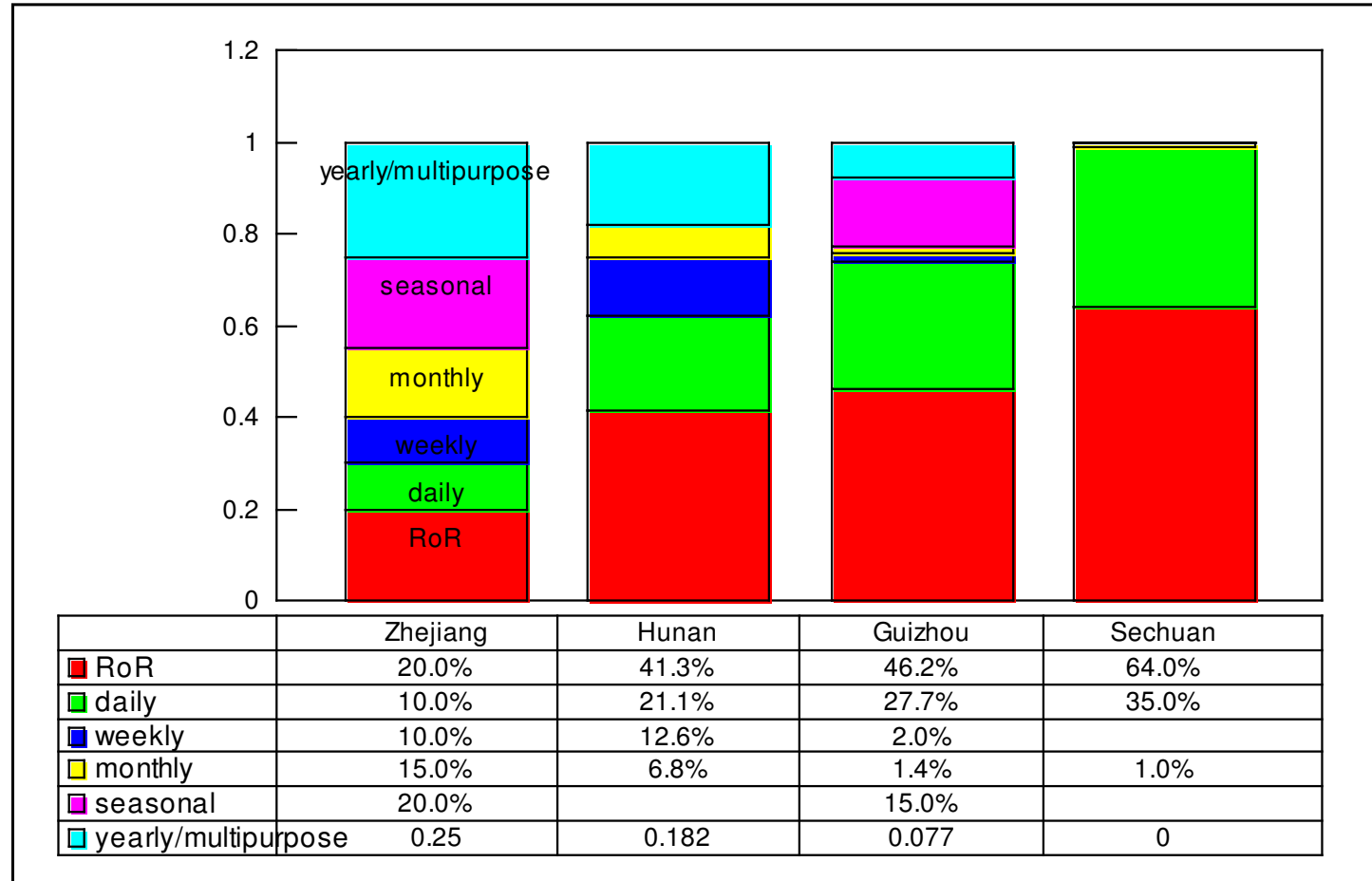
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- Capacity expansion optimization models showed 2600 MW of wind in Inner Mongolia displaced only 880 MW of coal and 250 MW of CCCT



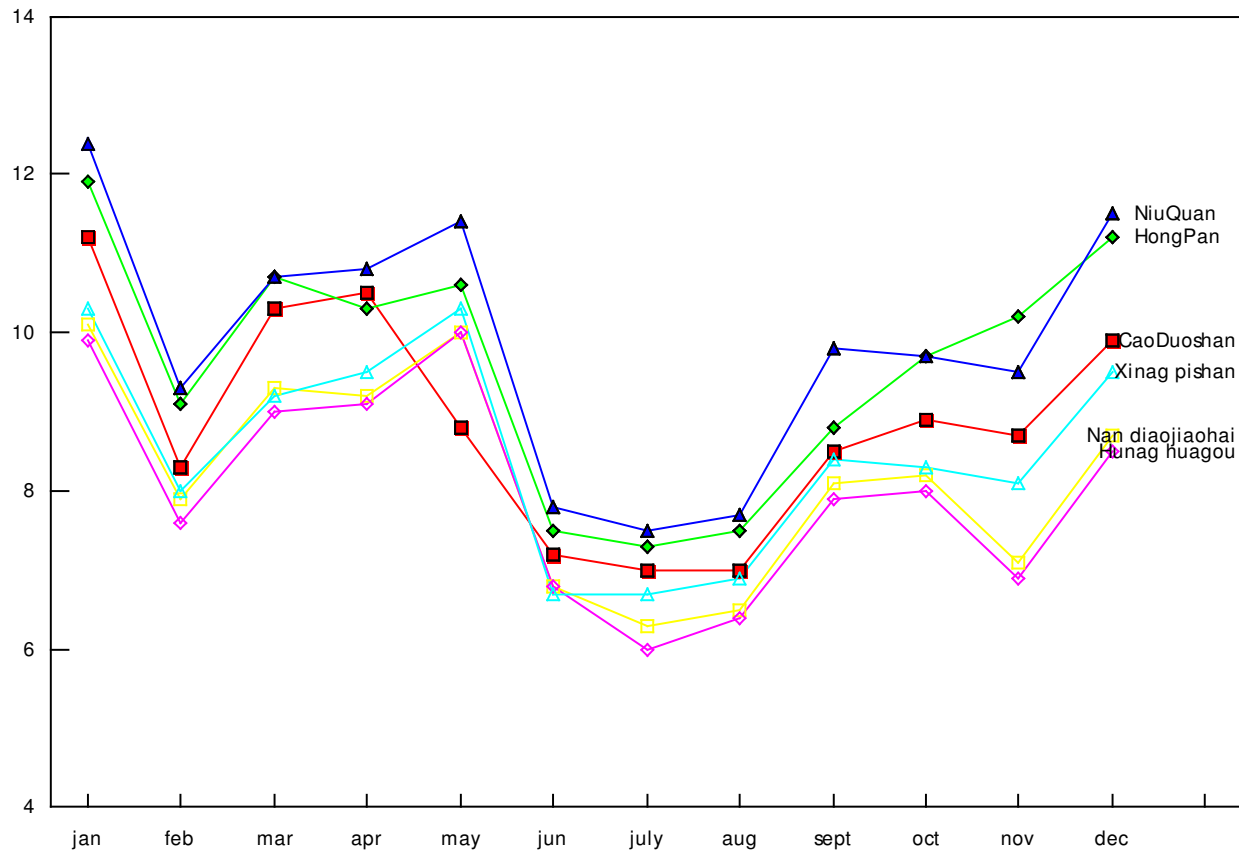
# China: small hydro storage

- Only few provinces have much storage in small hydro projects
- In most provinces, small hydro is mainly pure RoR, with insufficient pondage even for daily peaking operation



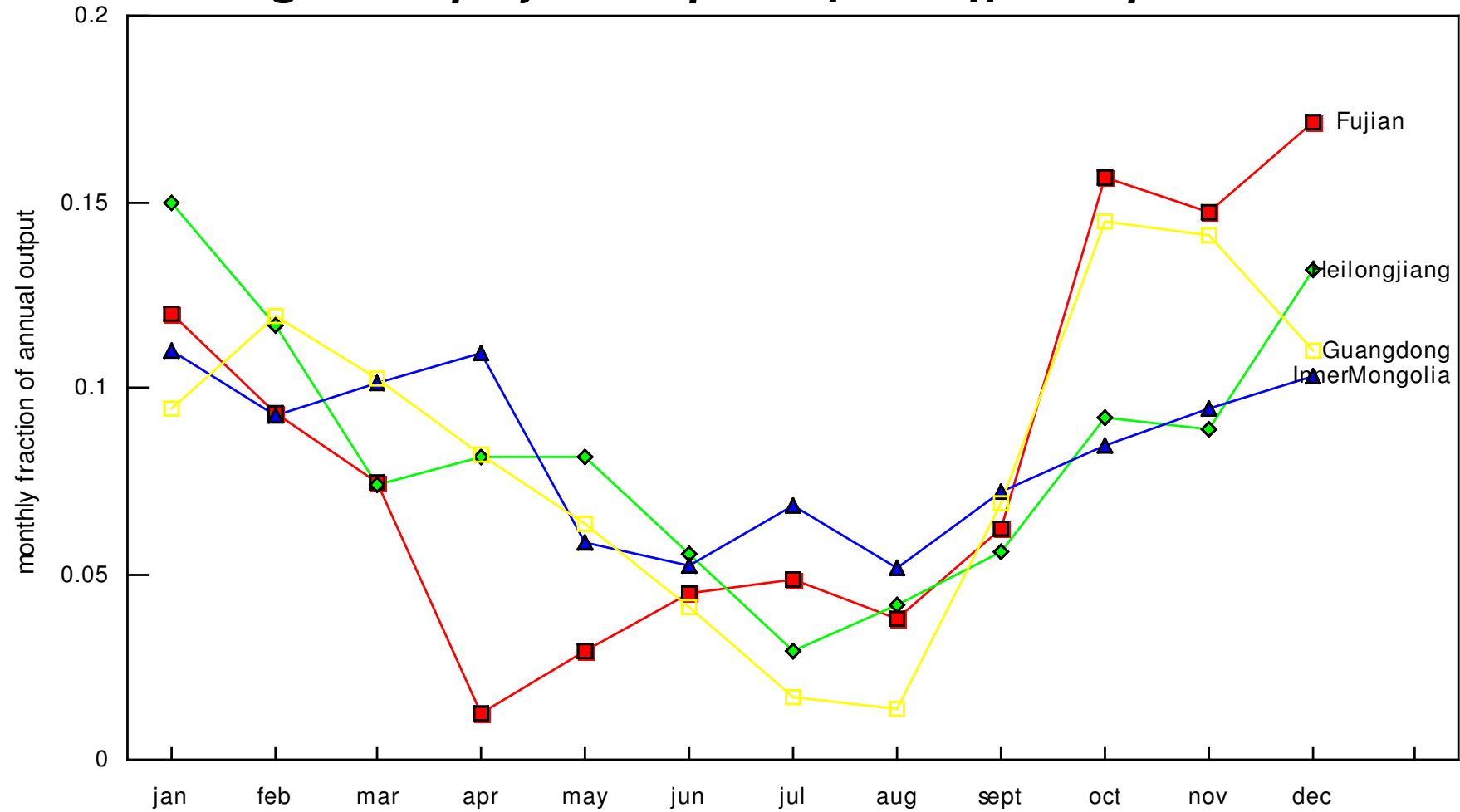
# China: Limited spatial diversity for individual renewable energy technologies

## Wind speed variations at six different sites in Inner Mongolia



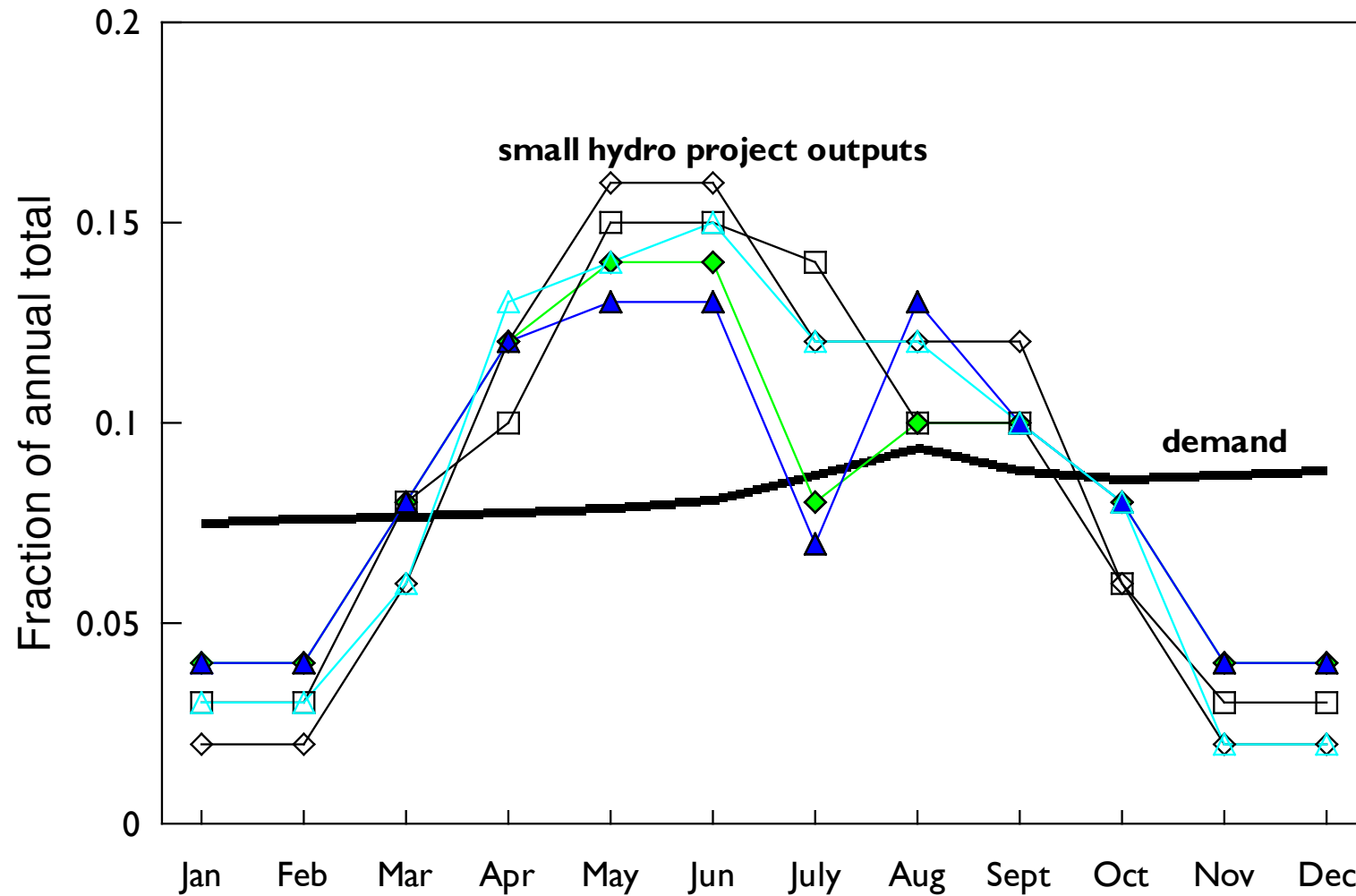
# China: Limited spatial diversity across provinces

## Average wind project output in four different provinces

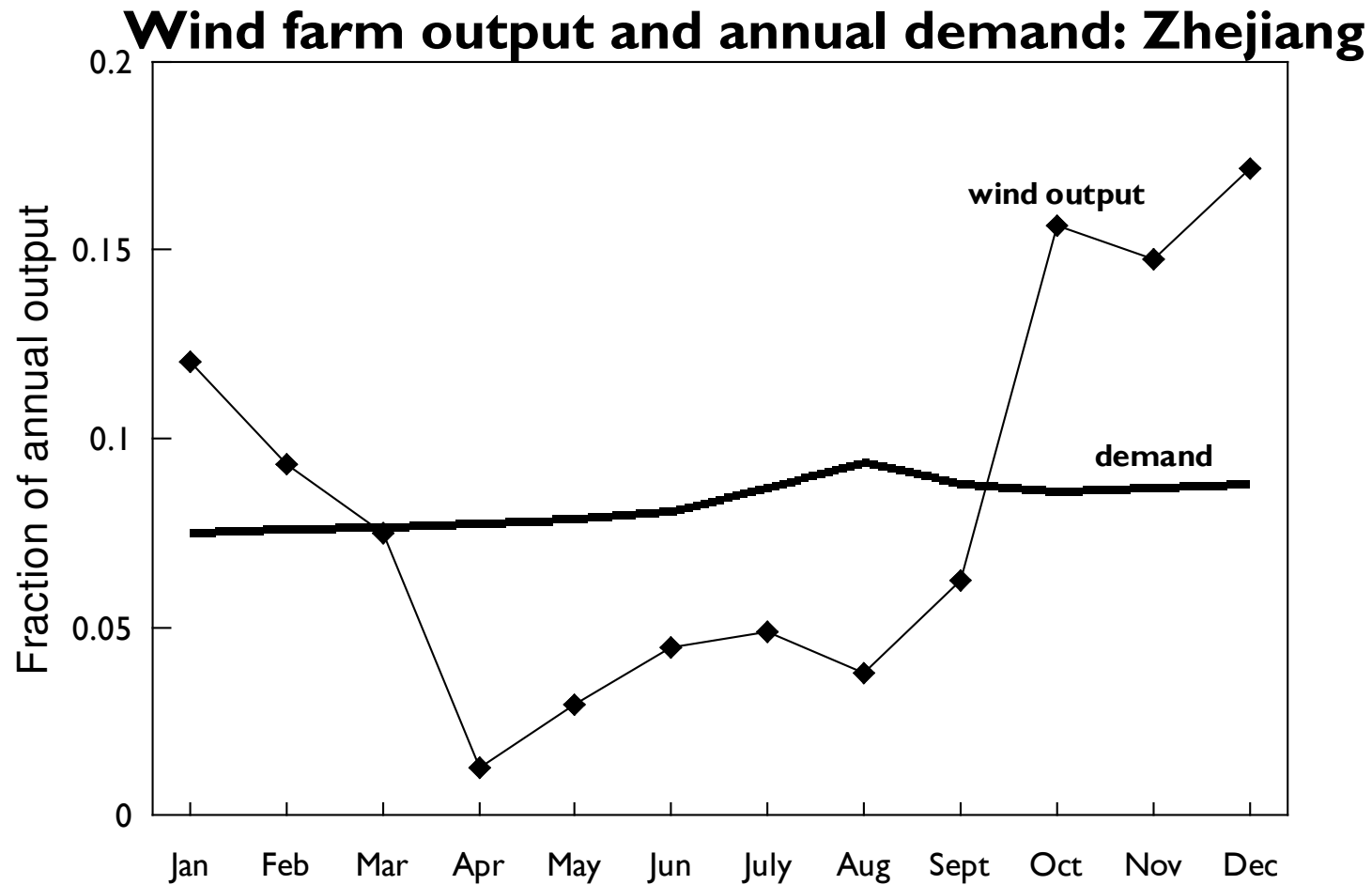


# China: SHP output poorly matched to demand curve

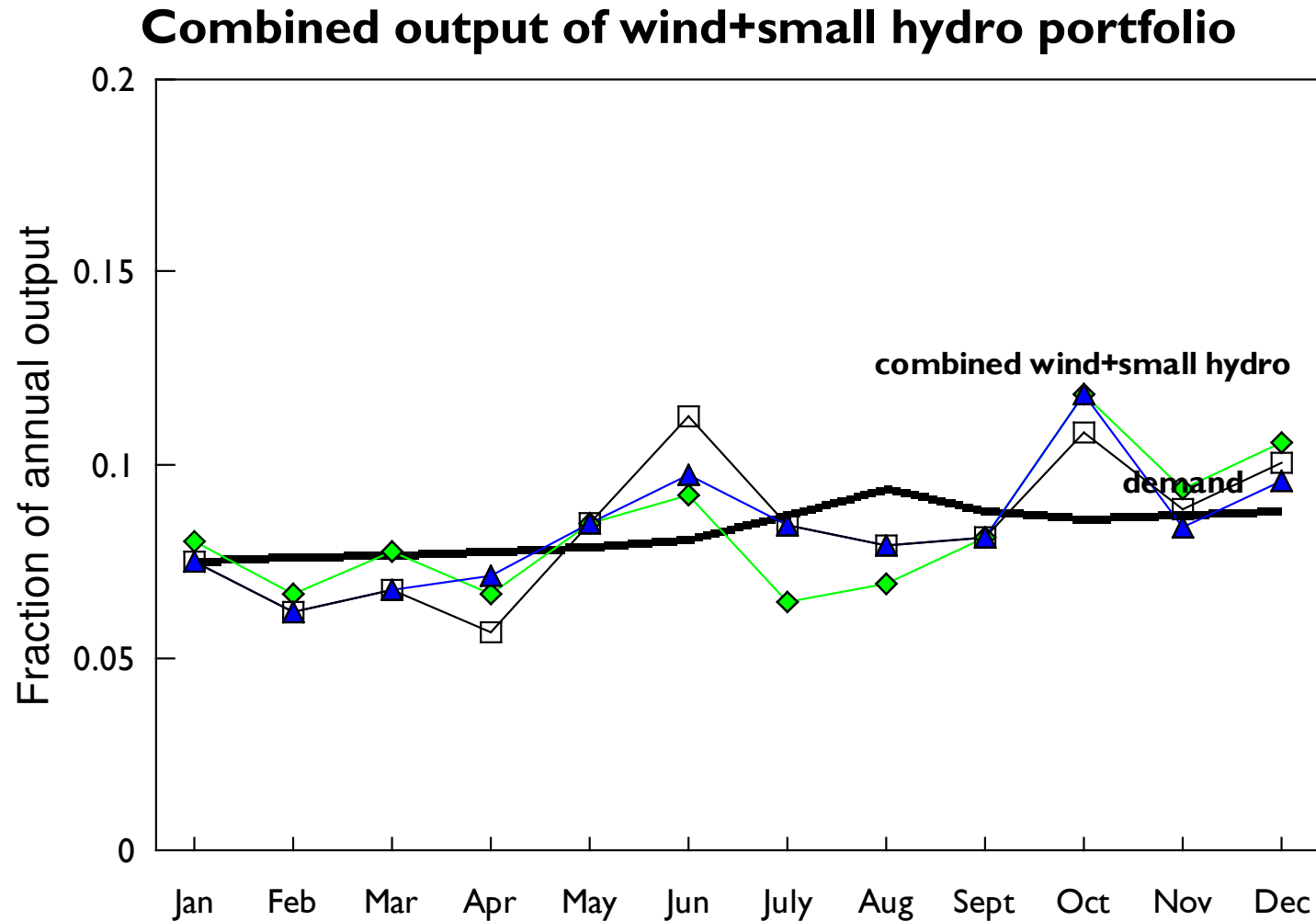
## Seasonality of small hydro production: Zhejiang Province



## China: Wind output also poorly matched to demand curve

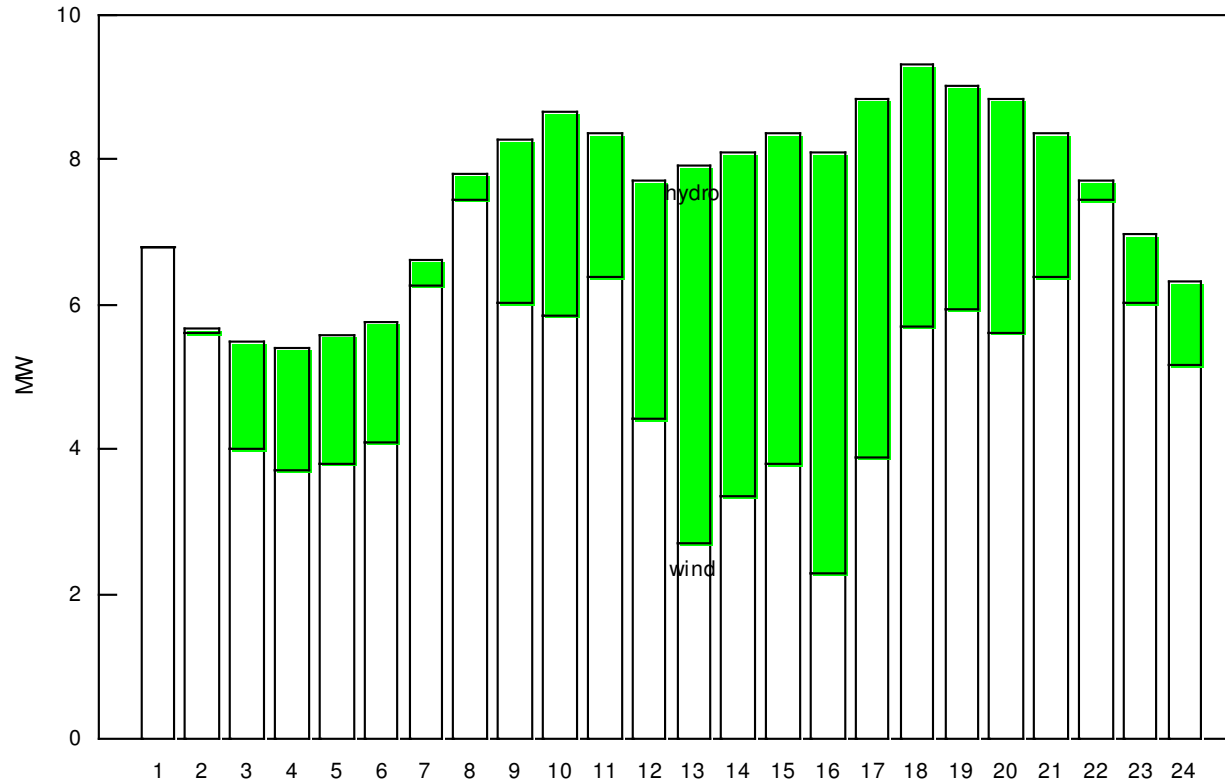


# China: combined Wind+SHP Portfolio show a good match!



## China: Combined *hourly* output wind+SHP

**Combined output of 10MW small hydro (Shaban) plus 10MW wind can match daily load curve only with daily peaking storage capacity in the SHPs**

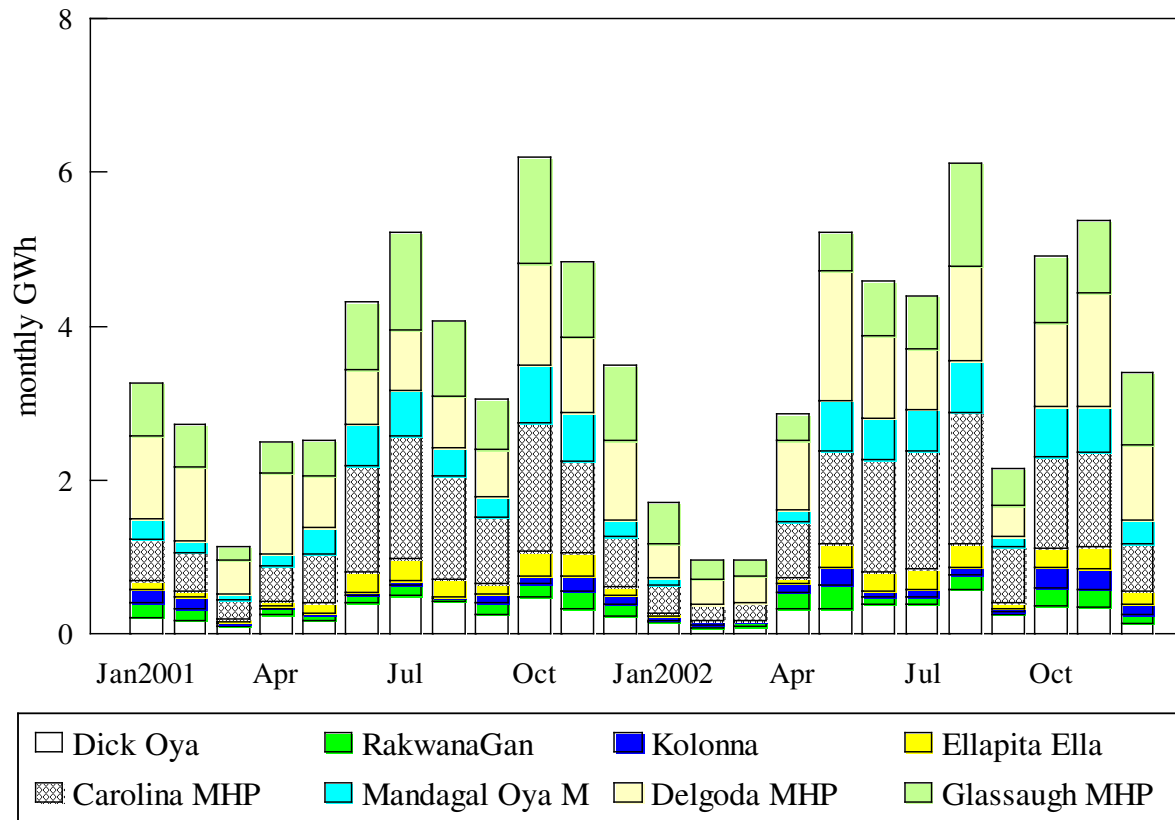


**Conclusion: Need hourly chronological production simulation model to properly assess portfolio effects.**



## Sri Lanka: Zero capacity credits!

In Sri Lanka, small hydro benefits from a tariff based on avoided marginal costs only, with no capacity credit. But dry season output is not zero!



## Sri Lanka: Highest feed-in tariffs in the world!?

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	FeedinTariff	
	LKR/kWh	UScents/kWh
Minihydro	14.58	12.44
<b>Wind</b>	<b>23.07</b>	<b>19.68</b>
Biomass	18.56	15.84
agricultural waste	13.88	11.84
municipal waste	15.31	13.06
waste heat recovery	9.31	7.94

Avoided cost tariff from 1998-2007; so successful (40+ ) small hydro projects, that developers association became very powerful, and successfully lobbied the Government for a higher tariff!



## Dealing with uncertainty: Croatia (2003)

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- Croatia wants to join the EU, requiring harmonisation of energy policies
- EU is encouraging Croatia to set ambitious renewable energy targets
- Ultimately, Croatia *will* join the EU, but the timing was considered highly uncertain: might be 5 years from now, might be 10 years from now, might be 15 years from now?
- Renewable energy development is also uncertain: we can draw supply curves, but depending on assumptions, the optimal quantity has high variance



## Croatia analysis

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Step I: calculate the supply curve, net benefits and the target under three sets of assumptions

### Assumptions (in 2002)

	Pessimistic assumptions (for renewables)	Expected (most likely assumptions)	Optimistic assumptions (for renewables)
Local externality value, ECents/kWh	0.35	1	1.6
Wind capital costs	675 E/kW	600 /kW	525/kW
Avoided costs: based on	Gas CCCT	Gas CCCT+coal	coal
Carbon externality	US\$5/ton	US\$15/ton	US\$20/ton



# Croatia analysis

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## Results

	Pessimistic assumptions (for renewables)	Expected (most likely assumptions)	Optimistic assumptions (for renewables)
Net benefits, 2010, EuroMillion (NPV)	4.5	13.5	63
Target, $Q_{ENV}$ (GWh in 2010)	175	1070	3340
Target, $Q_{ENV}$ (MW, 2010)	37	317	1335

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**Targets vary widely. What to do?!**

**Answer: model the problem as a formal decision analysis**



## Croatia analysis

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This analysis asks the following questions:

- Suppose that we make a decision based on “*expected* assumptions”, but that the future brings, say, *optimistic* conditions. What are the consequences in lost benefits?
- On the other hand, suppose we make a decision based on *optimistic* assumptions, but that the future actually brings values of input variables corresponding to *pessimistic* assumptions?

And so on, for all nine combinations of assumptions and futures. In other words, **what are the consequences of having made a decision based on incorrect assumptions?**



## Croatia analysis: calculate the 3 x 3 payoff matrix

### Net economic benefits, NPV million Euros

		Actual outcome				
		<i>Pessimistic</i>	<i>Expected</i>	<i>Optimistic</i>	<i>Risk Neutral [expected value]</i>	<i>Risk averse [minimax]</i>
Probability of outcome>		33.3%	33.3%	33.3%		
Target (MW)	Assumption					
37	Pessimistic	4.5	6.7	10	7	4.5
<b>317</b>	<b>Expected</b>	<b>-4.1</b>	<b>13.5</b>	<b>29.9</b>	<b>13.1</b>	<b>-4.1</b>
1334	Optimistic	-7.4	13.1	63.1	22.9	-7.4

## Croatia Recommendation

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Until EU accession is imminent, stay with 317MW target! Always easier to increase a target than to decrease it.

With the benefit of hindsight,

- actual carbon price six years later is higher than the 20\$/ton assumed under optimistic scenario;
- actual price (2008) of wind is 1300-1700/kW, so much more pessimistic than assumed in 2003.
- The timing of Croatia's accession to the EU is still unclear (linked to problems with Lisbon treaty, land dispute with Slovenia)



## Policy reform: Vietnam

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**Question: what are the environmental impacts of energy sector policy reforms?**

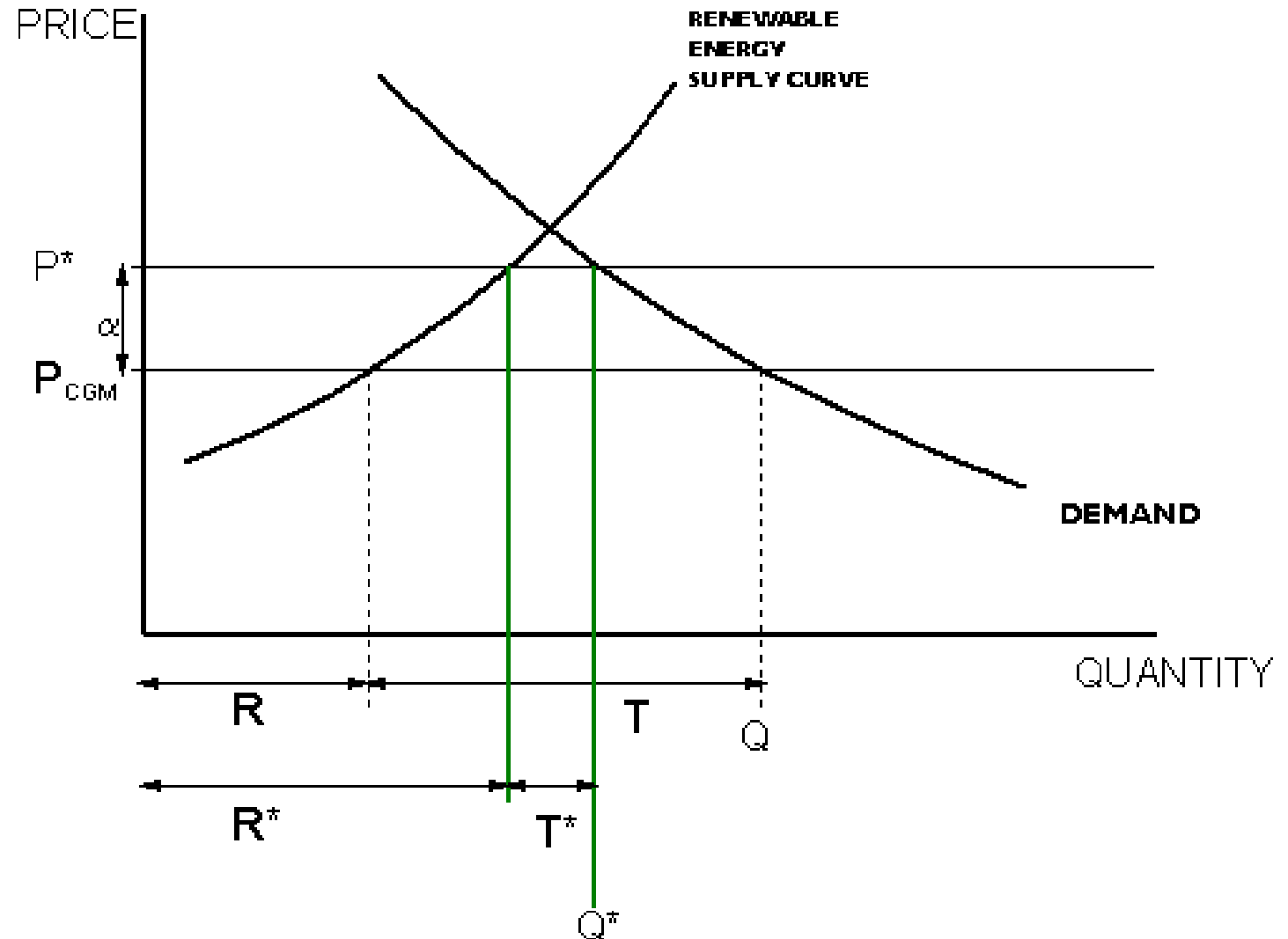
- Domestic gas and coal is highly subsidized, so the (financial) avoided cost tariff is low
- If the fuel subsidies were removed, what is the increased penetration of renewable energy?



# Vietnam analysis: impact of subsidy removal

The figure shows

- the price of thermal energy in a competitive generation market,  $P_{CGM}$ , assuming that the coal price is subsidized in the amount  $\sigma$ .
- The quantity consumed at this price,  $Q$ , is given by the intersection of the demand curve with  $P_{CGM}$ .
- The amount of renewables will be  $R$  (namely that quantity whose production cost is less than  $P_{CGM}$ ), and the balance will be fossil generation,  $T$  ( $T=Q - R$ ).



## Vietnam analysis: impact of subsidy removal

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If the subsidy on domestic coal is removed:

- The CGM price increases to  $P^*$ .
- At this higher price, the demand curve intersects at the lower level of consumption  $Q^*$ . More renewable energy will be economic at the higher price  $P^*$ , and the quantity of fossil energy reduces to  $T^*$  ( $R^*+T^*=Q^*$ ).

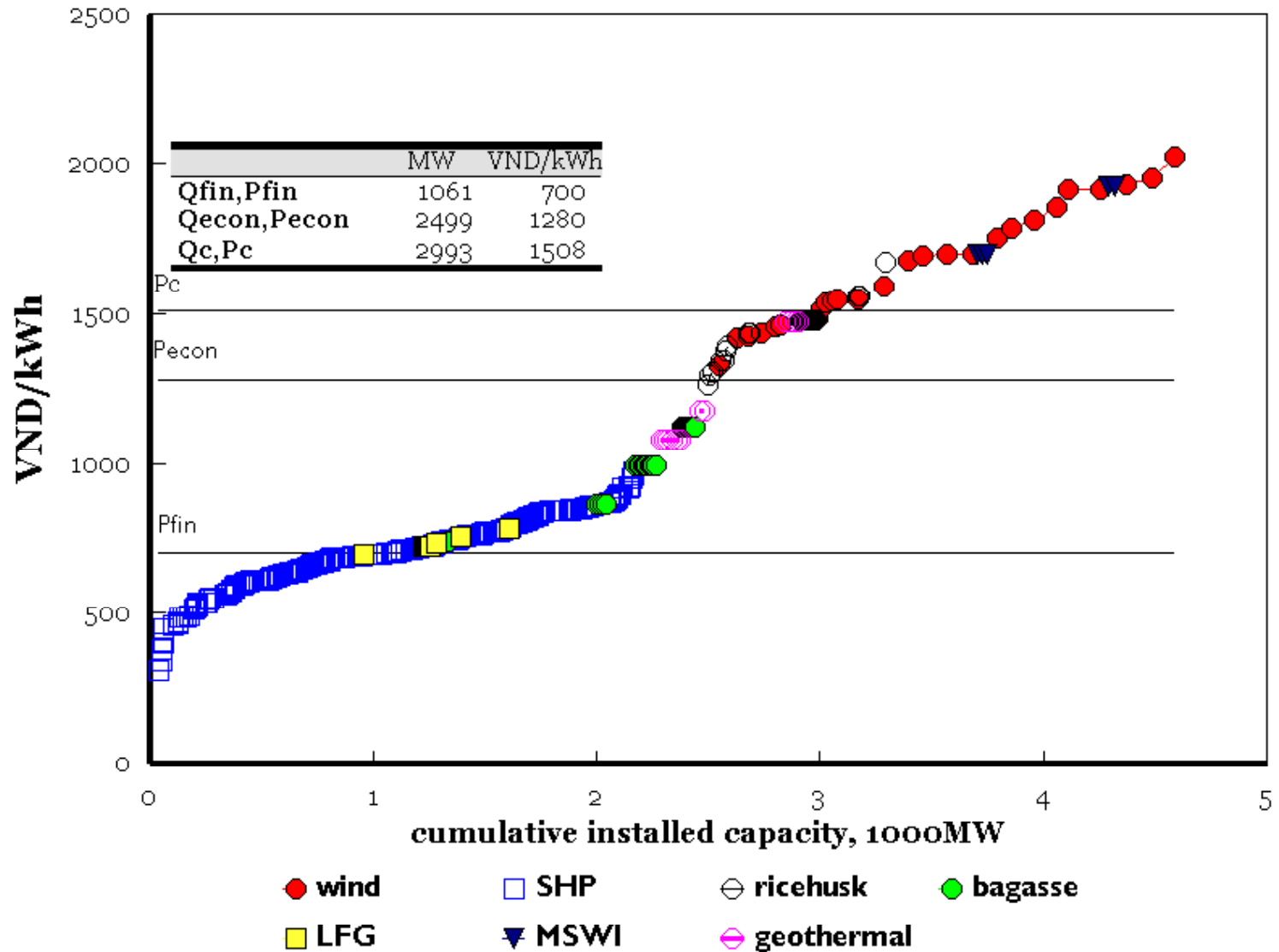
Thus there are three important consequences of reducing the subsidy on coal:

- less electricity is consumed
- the amount of fossil energy, and hence GHG emissions, is reduced, and
- the amount of renewable energy is increased.

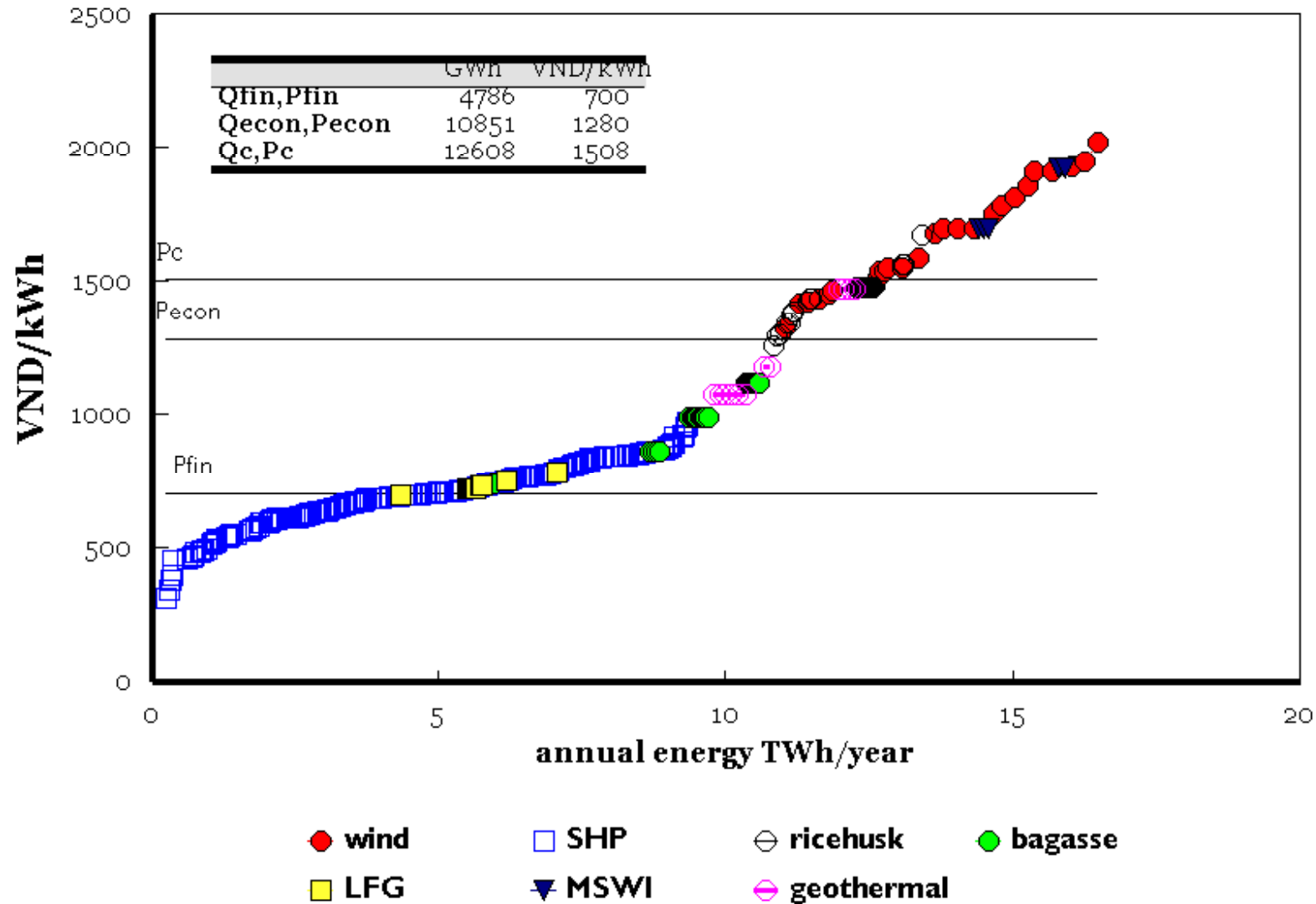


# Vietnam analysis: the RE supply curve (MW)

LFG=landfill gas;  
 SHP=small  
 hydro;  
 MSWI  
 =municipal solid  
 waste  
 incineration  
 $P_{fin}$ =average  
 tariff yield at the  
 avoid cost tariff  
 $P_{econ}$ =average  
 avoided social  
 cost of thermal  
 energy  
 $P_c = P_{econ} + CER$   
 revenue at  
 15\$/tonCO<sub>2</sub>



# Vietnam: Energy supply curve (TWh)



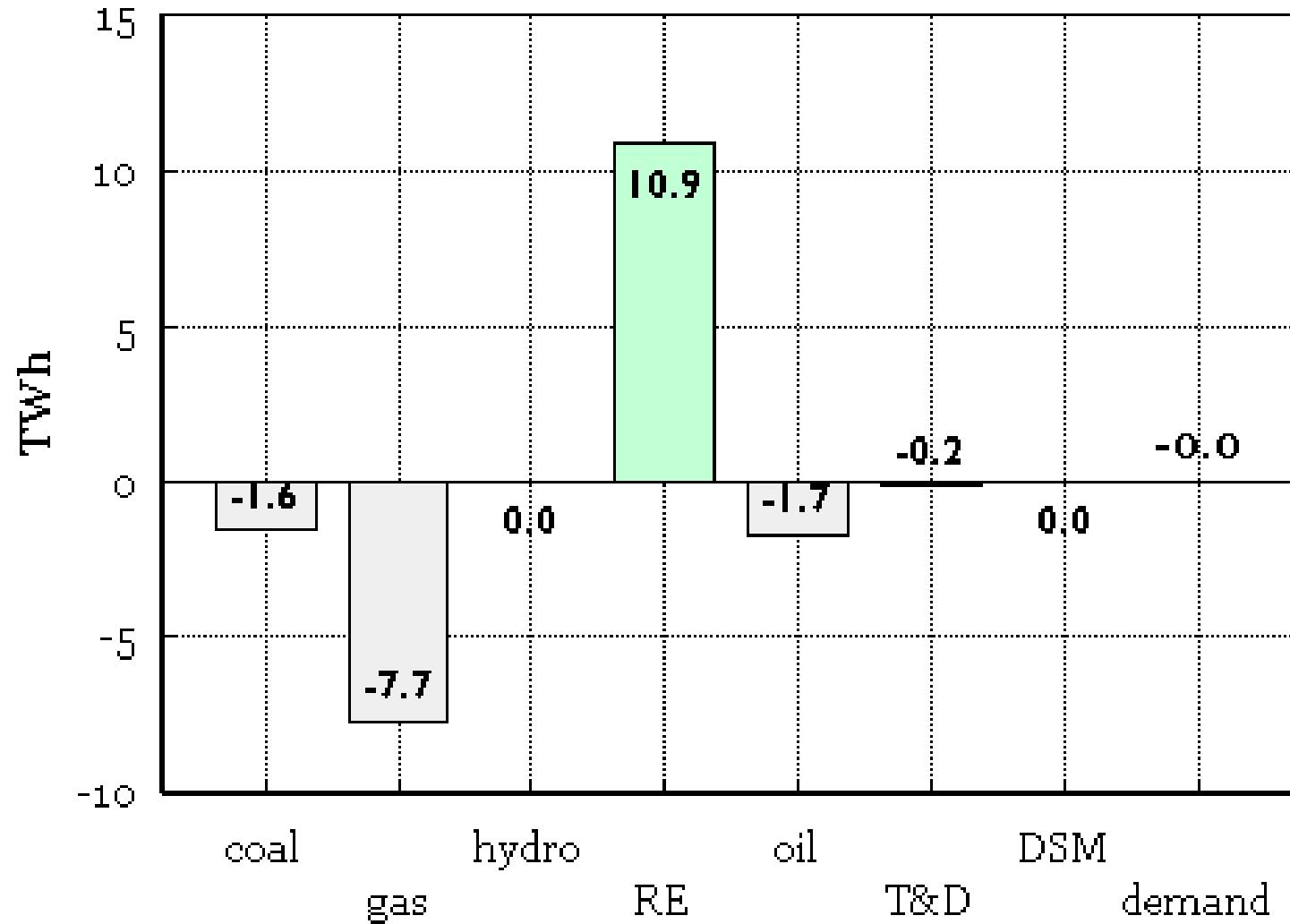
## Vietnam: totals by Technology

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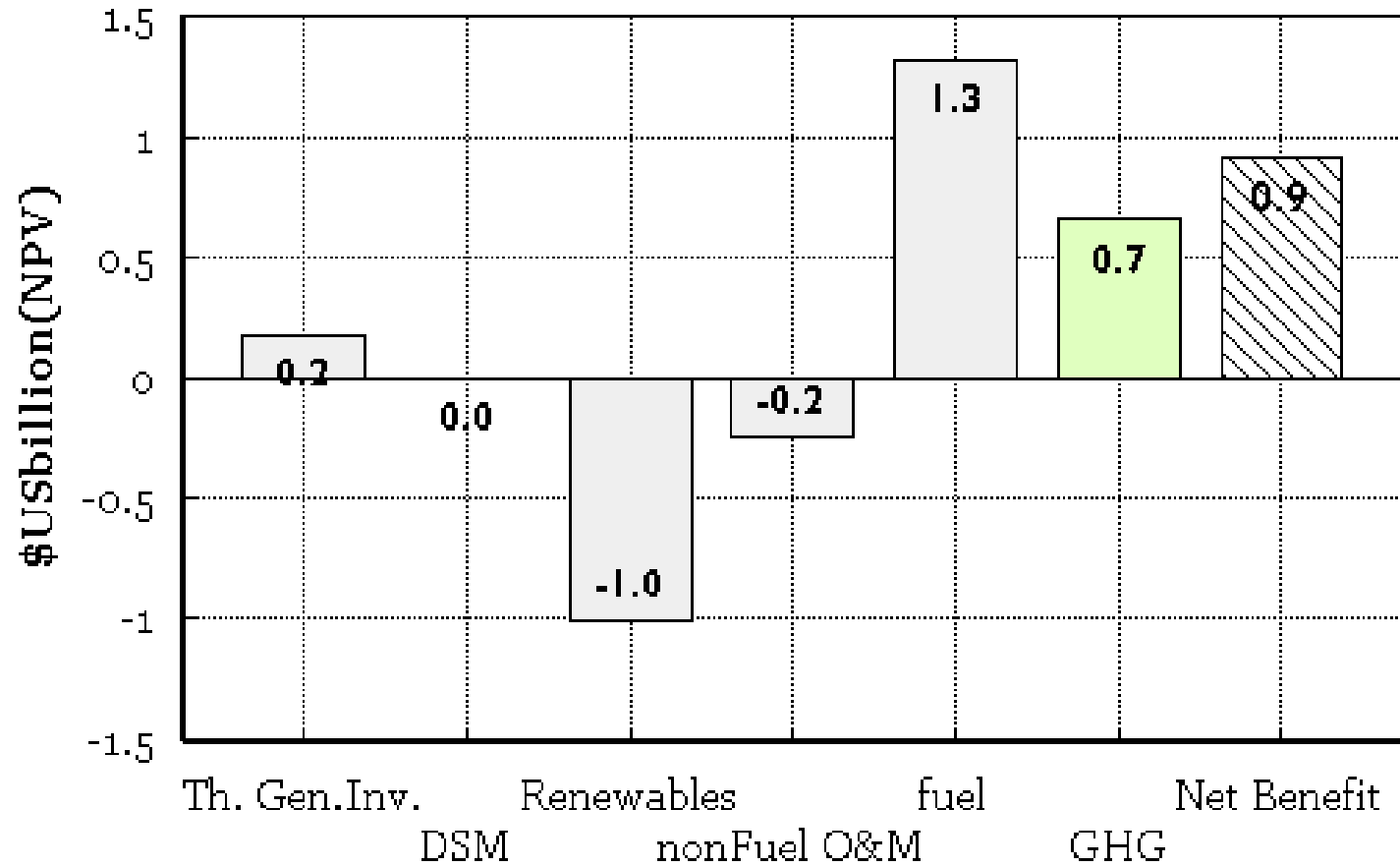
	Installed capacity, MW				Energy, GWh			
	Pfin	Pecon	Pg	total	Pfin	Pecon	Pg	total
SHP	1054	976	0	2030	4757	8814	8814	22385
ricehusk	0	15	139	154	0	66	658	724
bagasse	0	250	0	250	0	896	896	1791
LFG	7	45	0	52	29	214	214	456
MSWI	0	0	0	0	0	0	0	0
geothermal	0	152	79	231	0	862	1249	2110
wind	0	0	276	276	0	0	778	778
total	1061	1439	494	2993	4786	10851	12608	28244



## Vietnam: Generation substitutions



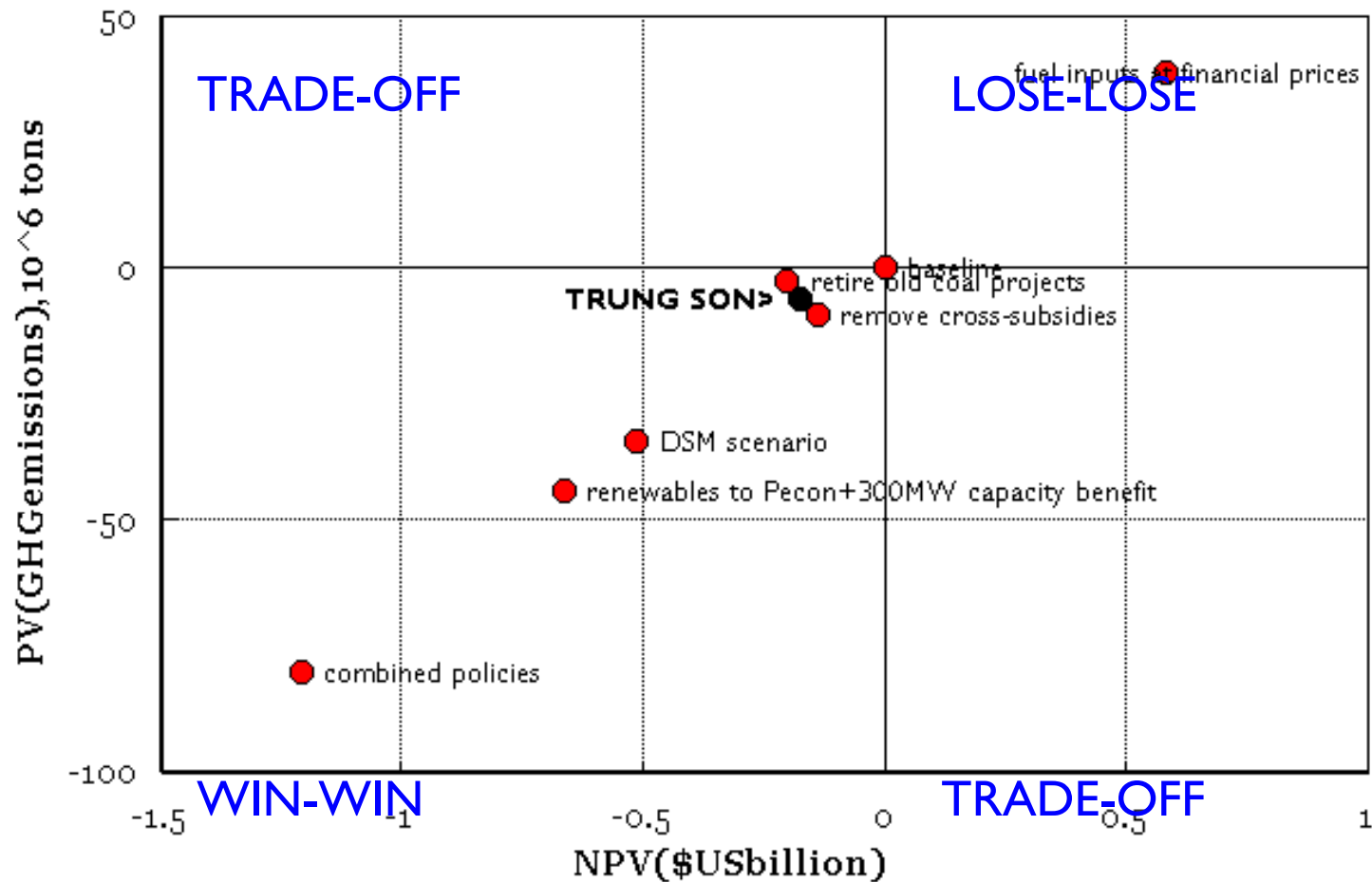
## Vietnam: Cost structure changes



(GHG benefits at 30\$/tonCO<sub>2</sub>)



## Vietnam: comparison of policies



- Values relative to baseline
- Trung Son is a 260MW hydro project!

