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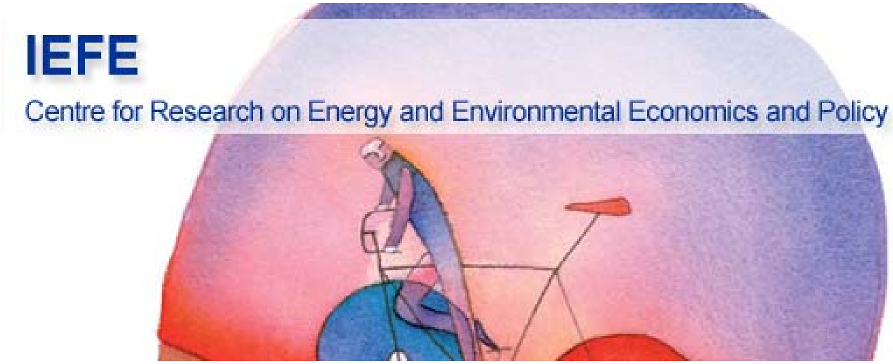

Optimal spatial pricing and its impact on renewable generation in the British market

Matteo Di Castelnuovo

IEFE-FEEM Joint Seminar Series

Milan, 22nd September 2011

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Agenda

- Introduction to spatial pricing
- The British “problem”
  - The network issue
  - The renewable issue
- Research question and methodology
- Results and conclusions
- Appendix
  - Details about the model

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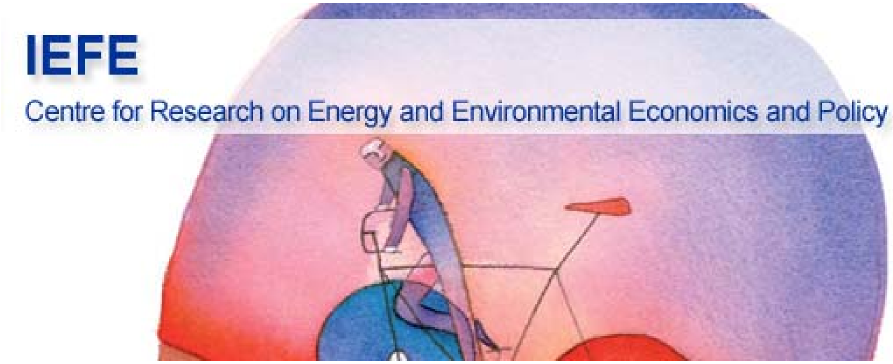
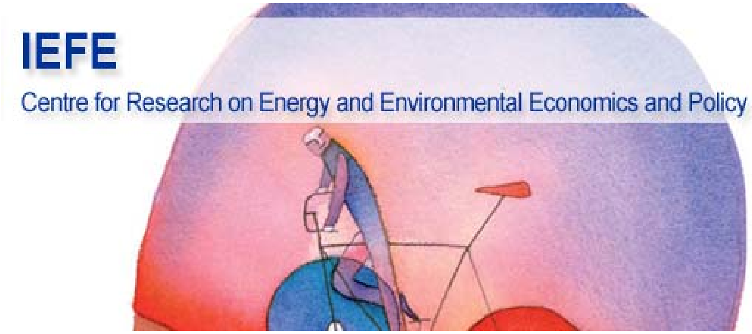


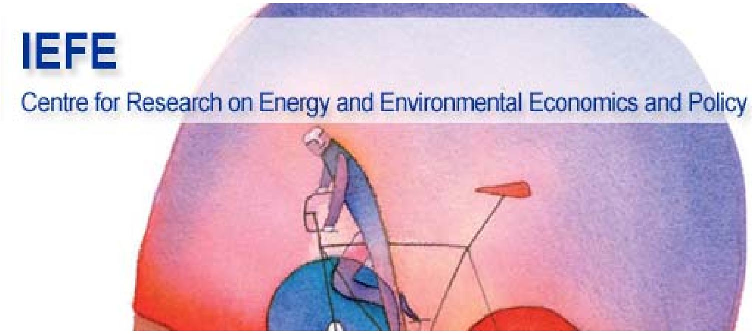
Introduction to spatial pricing



Network Economics 101

- "Electricity must be treated as a commodity which can be traded taking into account its TIME- and SPACE-varying values and costs" (Schweppe et al 1988)

- "The problem of market design is not to invent clever new prices but to design a market that will reliably discover the same prices Economics has been suggesting since Adam Smith" (Stoft 2002)



Network Economics 101

- Transporting electricity has economic consequences in terms of
  - Network losses
  - Infrastructures (investment and O&M)
  - Energy Balance between demand and supply
  - System Balance (congestion management)
- Marginal losses and opportunity cost of constraints are the two major component of MC pricing; capital costs need to be covered also.
- Vertical separation may lead to a loss of economies of scope (e.g. lack of coordination in network investments)
- Locational pricing may help recover this loss.

Optimal spatial pricing = Locational marginal pricing (LMP), also known as nodal pricing

$$p_n = \mu_e \left(1 + \frac{\partial l}{\partial d_n} \right) + \sum_i \mu_i \frac{\partial z_i}{\partial d_n} \qquad \text{(market clearing price)}$$

μ_e = shadow price of the energy balance constraint = marginal cost of generation at the reference bus

μ_i = shadow price of the flow constraint for line *i*

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Why does spatial pricing matter?

EU transmission pricing

	Sharing of network operator charges		Price signal		Are losses included in the tariffs charged by TSO?	Are system services included in the tariffs charged by TSO?
	Generation	Load	Seasonal / time-of-day (1)	Location		
Austria	15%	85%	-	-	Yes	Through a specific component to generators
Belgium	0%	100%	xxx	-	Not included for grid >=150 kV	Tariff for ancillary services
Bosnia and Herzegovina	0%	100%	-	-	No	No
Bulgaria	0%	100%	-	-	Yes	Yes
Croatia	0%	100%	x	-	Yes	Yes
Czech Republic	0%	100%	-	-	Yes	Yes
Denmark	4%	96%	-	-	Yes	Yes
Estonia	0%	100%	x	-	Yes	Yes
Finland	11%	89%	x	-	Yes	Yes
France	2%	98%	-	-	Yes	Yes
Germany	0%	100%	-	-	Yes	Yes
Great Britain	27% TNUoS Tariff (2) 50% BSUoS Tariff (2)	73% TNUoS Tariff 50% BSUoS Tariff	xx	TNUoS - locational; BSUoS - non-locational	No, recovered in the energy market	Included in BSUoS Tariff
Greece	0 % Use of system 0 % Uplift charges	100 % Use of system 100 % Uplift charges	x	-	No, recovered in the energy market	Included in Uplift charges
Hungary	0%	100%	-	-	Yes	Tariff for ancillary services
Ireland	25%	75%	-	Generation only	No, recovered in the energy market	Yes
Italy	0%	100%	-	-	No, recovered in the energy market	Yes
Latvia	0%	100%			Yes	Yes
Lithuania	0%	100%	-	-	Yes	Yes
Luxembourg	0%	100%	-	-	Yes	Yes
FYROM	0%	100%	-	-	Yes	Yes
Netherlands	0%	100%	-	-	Yes	Tariff for ancillary services
Northern Ireland	25%	75%	xxx	-	No	Tariff for ancillary services
Norway	35%	65%	xxx (via losses)	Location	Yes	Yes
Poland	0,60%	99.4%	-	-	Yes	Yes
Portugal	0%	100%	xx	-	No, included in energy price	No, included in energy price
Romania	20,69% use of system	79,31% use of system	-	6 G zones =6 G tariffs values 8 L zones =8 L	Yes	Tariff for ancillary services
	0% system services	100% systems services				
Serbia	0%	100%	x	-	Yes	Yes
Slovak Rep.	0%	100%	-	-	Through a specific fee	Through a specific fee
Slovenia	0%	100%	xx	-	Yes	Tariff for ancillary services
Spain	6%	94%	xxx	-	No, included in energy price	No, included in energy price
Sweden	25%	75%	-	Location	Yes	Yes
Switzerland	0%	100%	-	-	By a separate tariff for losses	By separate tariffs for ancillary services

Remarks:

(1) The "X" indicates time differentiation. With one "X", there is only one time differentiation ("day-night", "summer-winter" or another one). With two "X" (or more), there are two (or more) time differentiations.

(2) TNUoS: Transmission Network Use of System; BSUoS=Balancing Services Use of System

Source: ENTSO-E 2011

The British “problem”

The network issue

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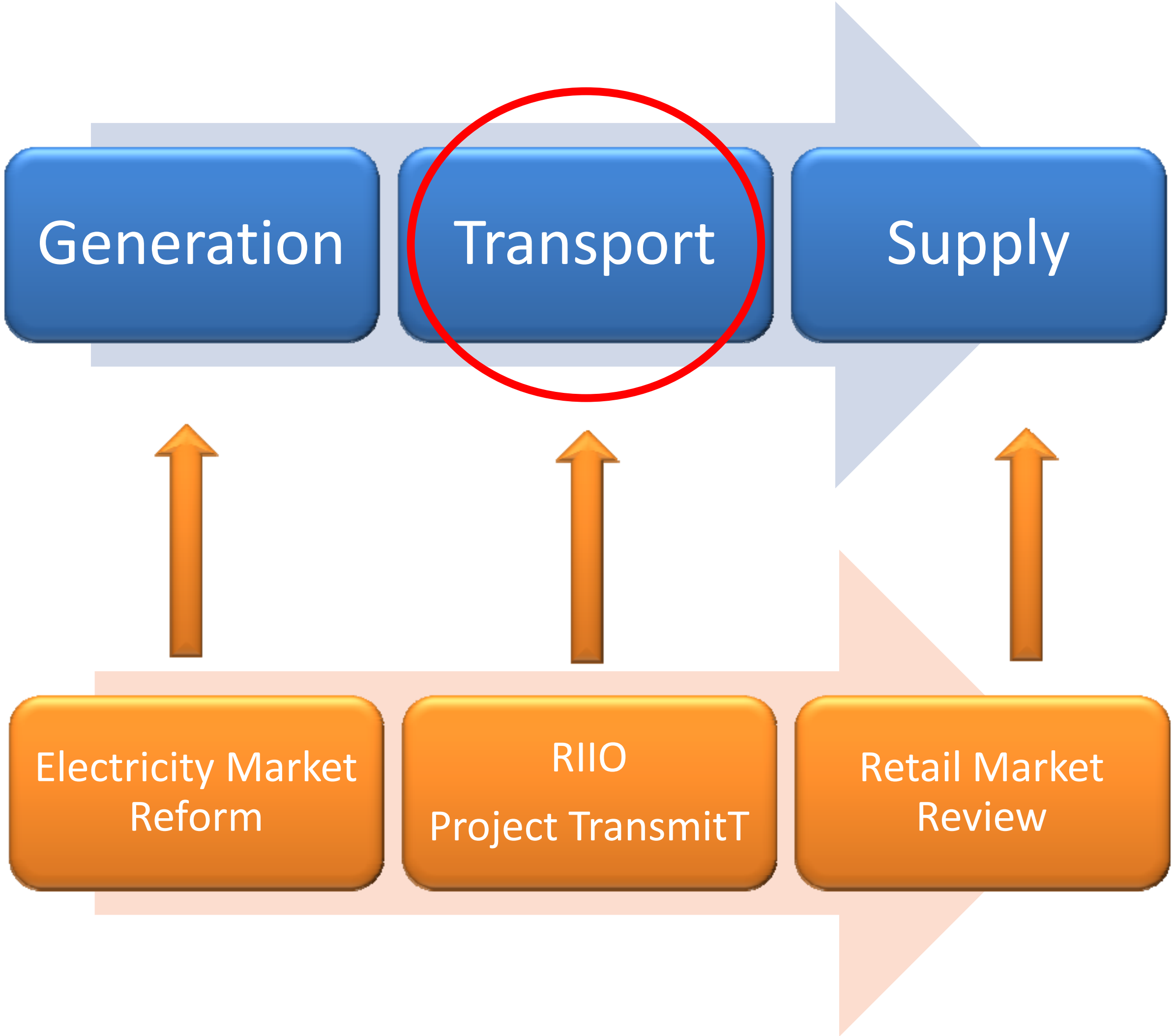
GB Policy and Regulation

- Climate Change
- Security of Supply
- Competitiveness



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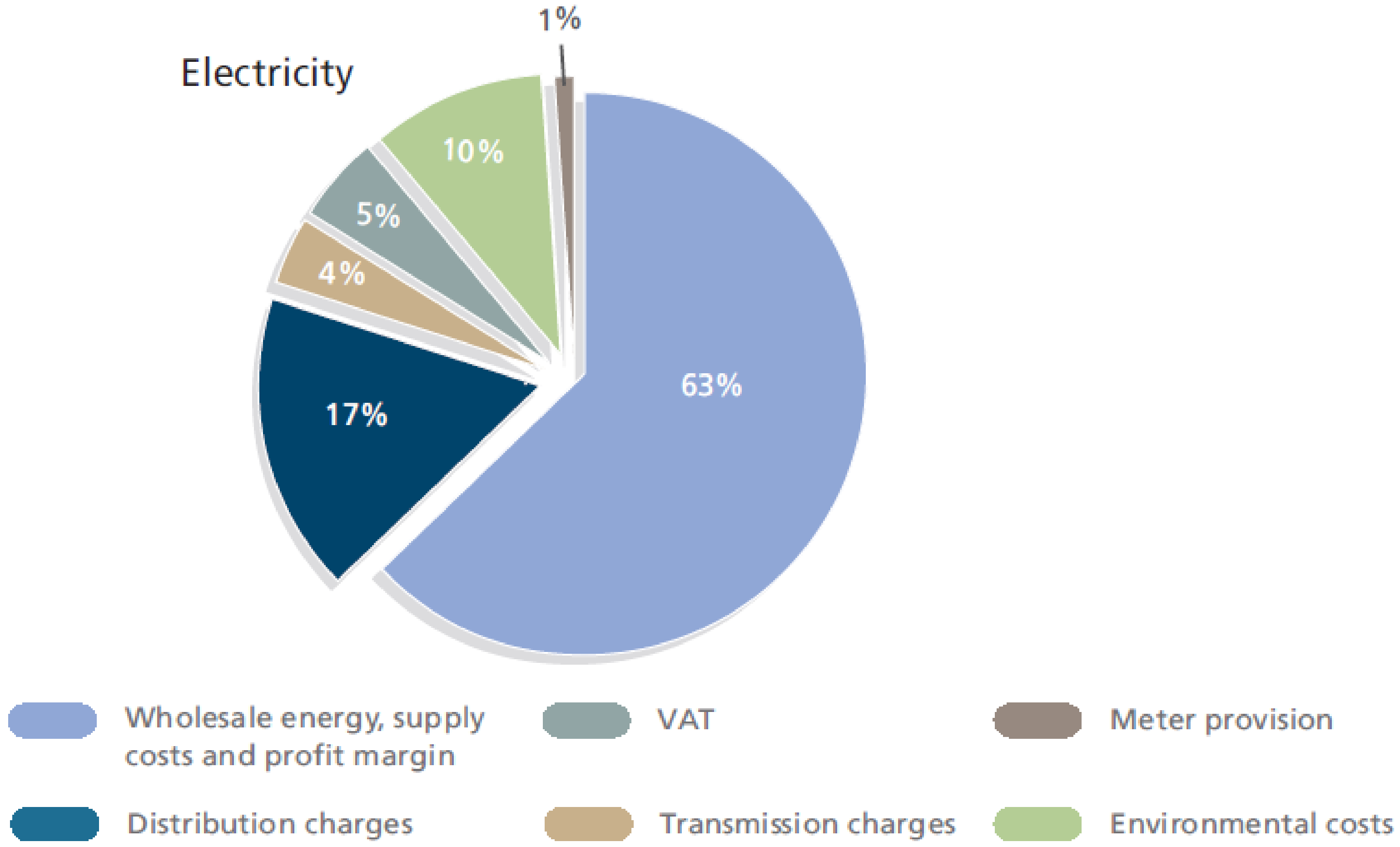
The British «problem»: the network issue

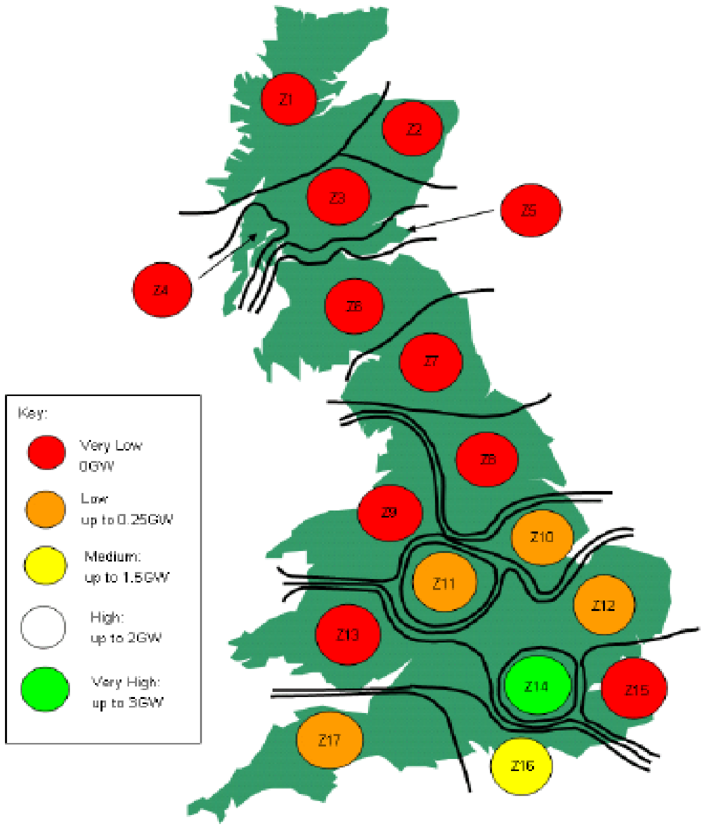
Household electricity bill in GB (2011)



Source: OFGEM 2011

The British «problem»: the network issue

Connection opportunities
Locational (TNUoS) but not OPTIMAL pricing is applied



Source: NGC 2009

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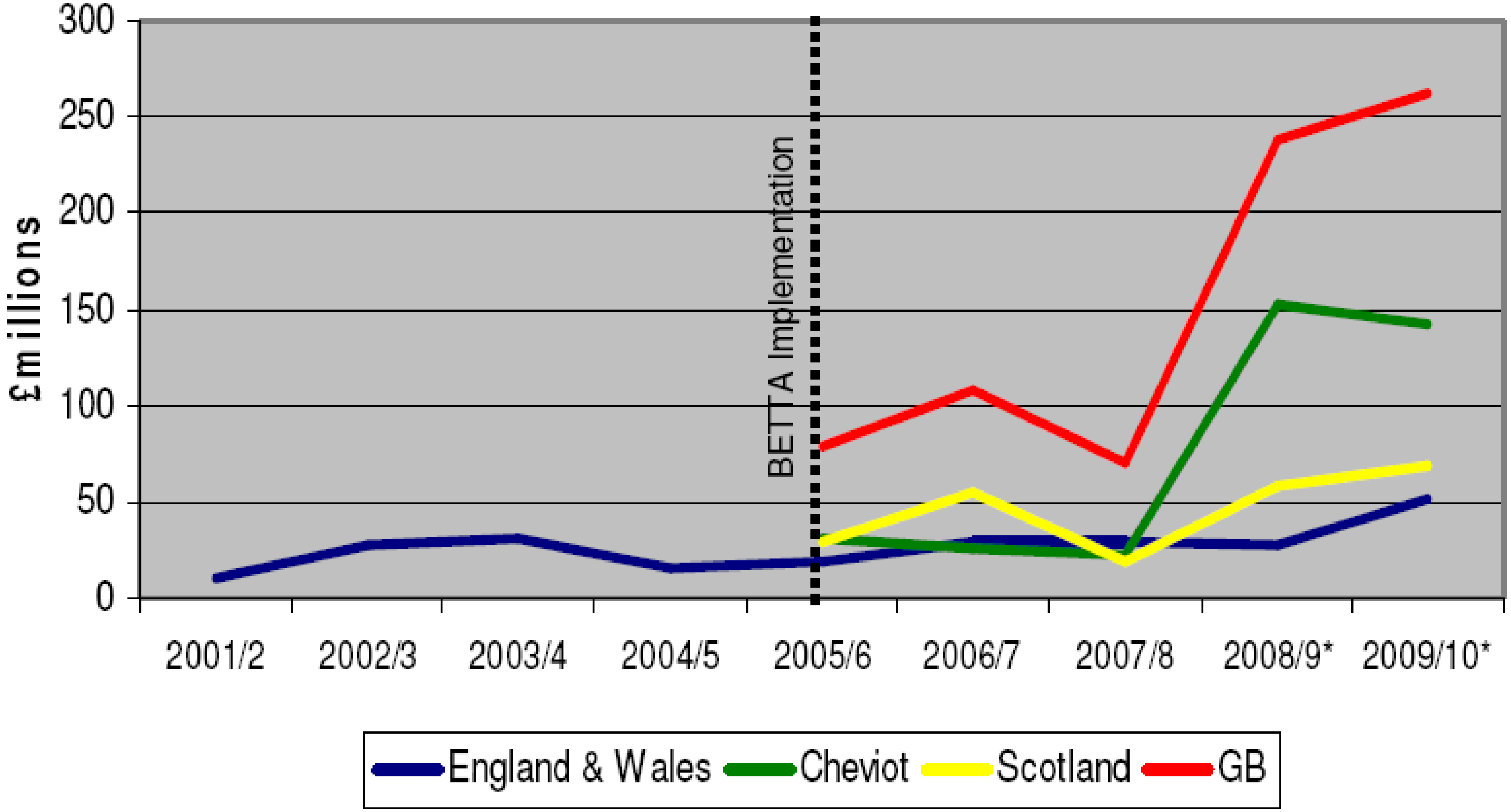
The British «problem»: the network issue

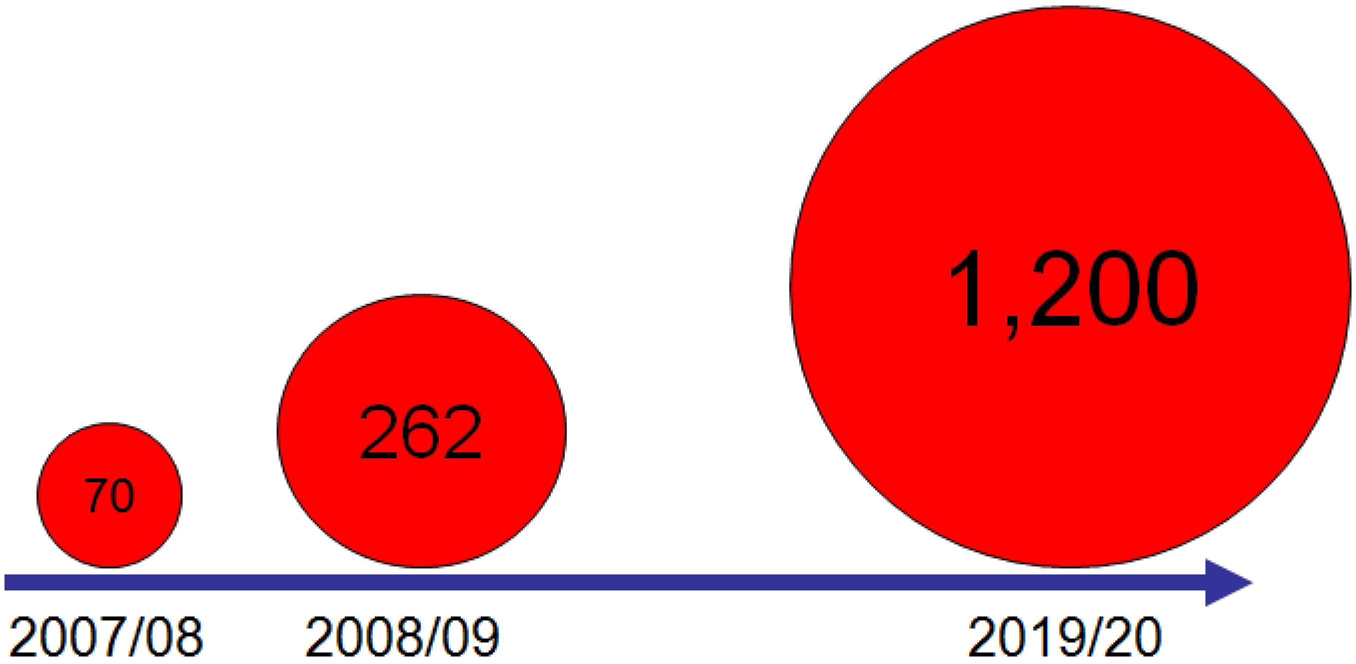
Congestion costs



Source: NGC 2009

The British «problem»: the network issue

Increasing level of constraint costs under BETTA (in £m)



Source: Ofgem 2010

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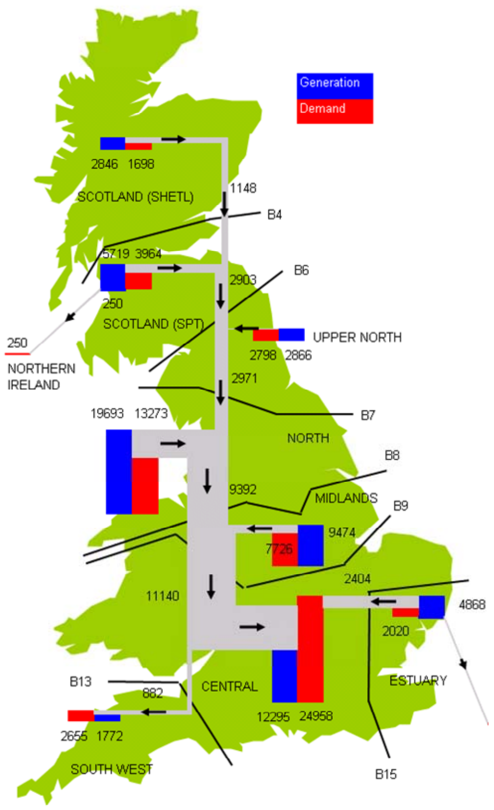
The British «problem»: the network issue

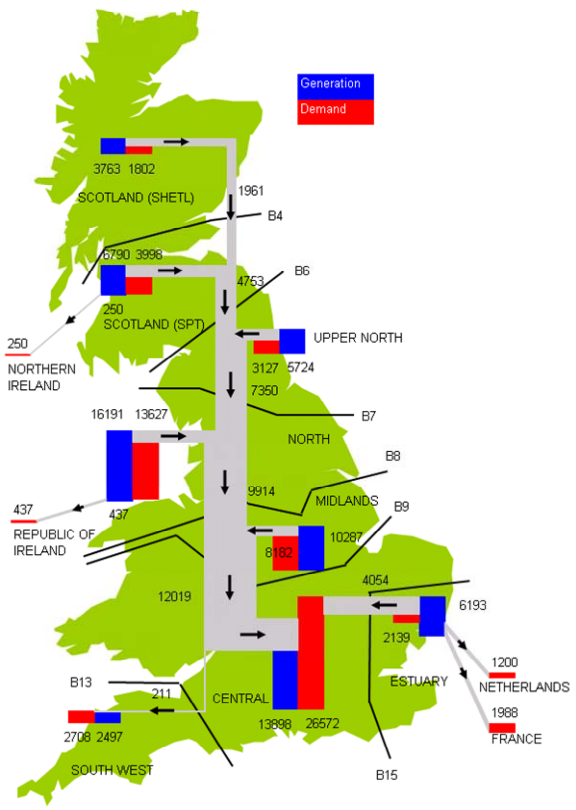
UK energy imbalance

2009/10 **2015/2016**

ACS Power Flow Pattern for 2009/10



ACS Power Flow Pattern for 2015/16



Source: NGC 2009

The British “problem”

The renewable issue

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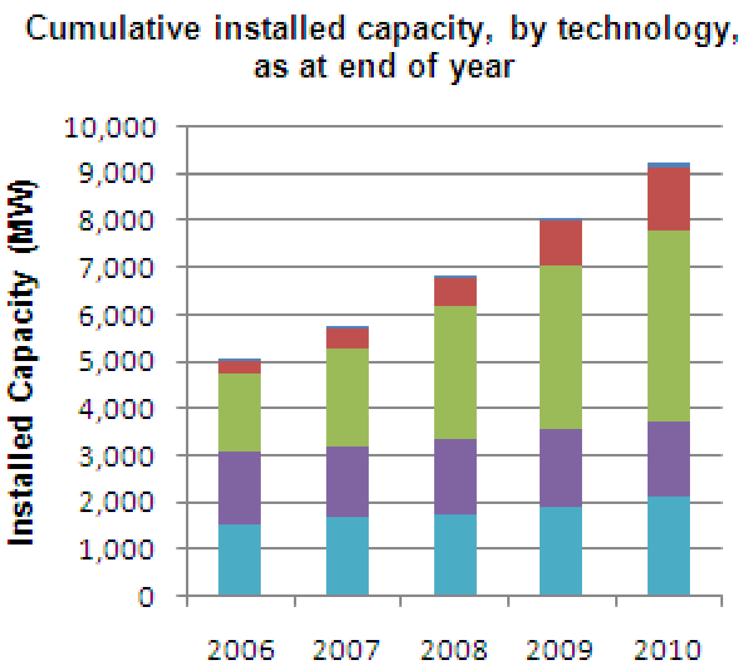
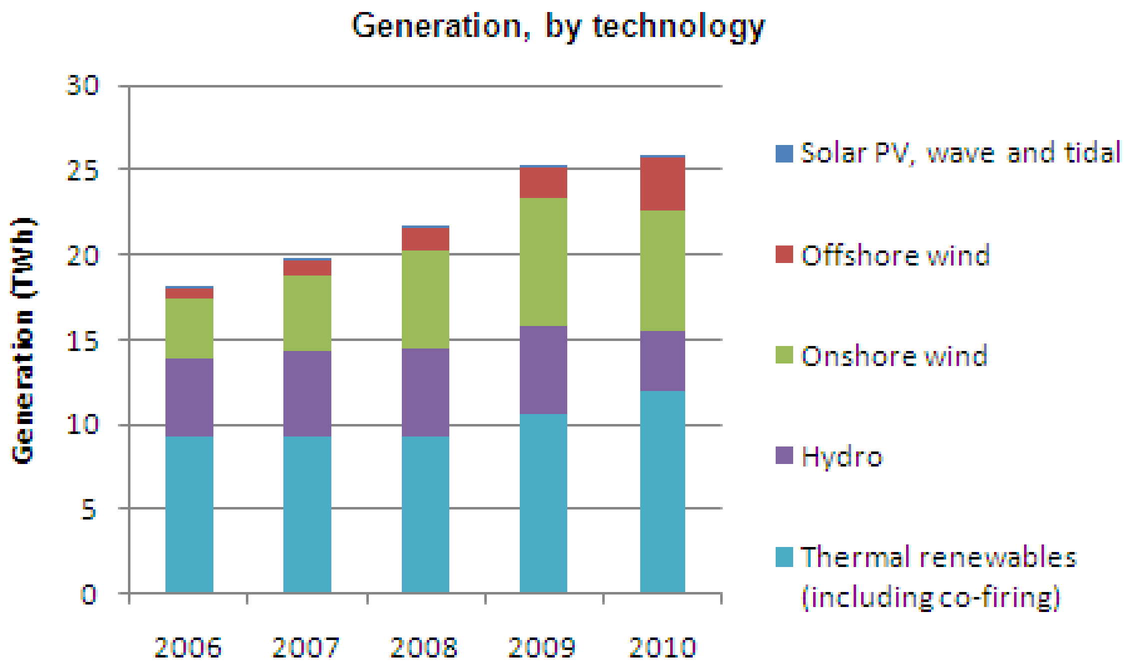
The British «problem»: the renewable issue

Renewable energy consumption

≈ 7% in 2010
≈ 40% target in 2020





Source: DECC 2011

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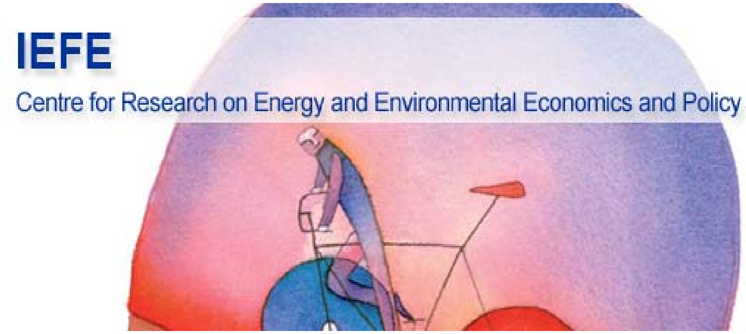
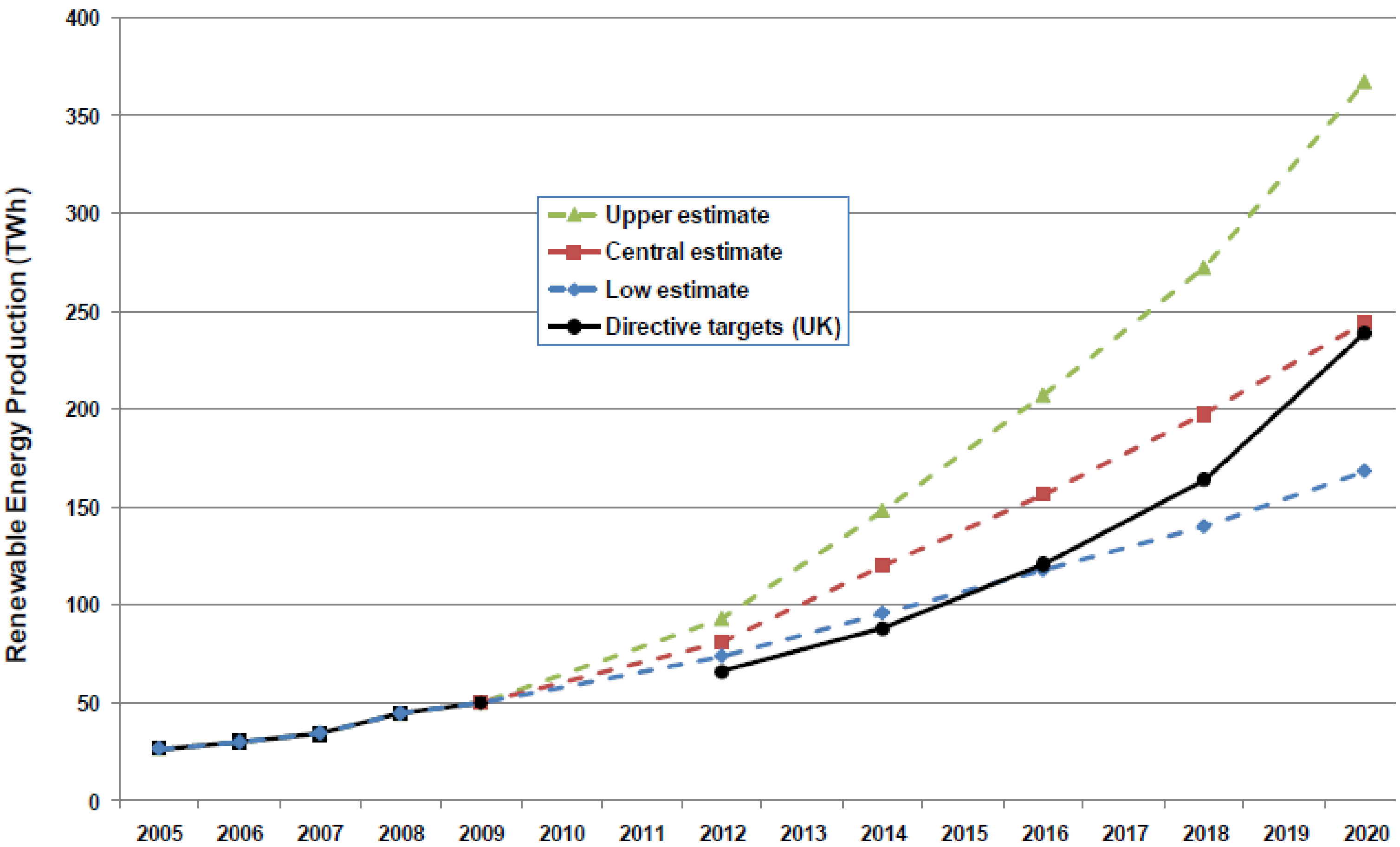


The British «problem»: the renewable issue

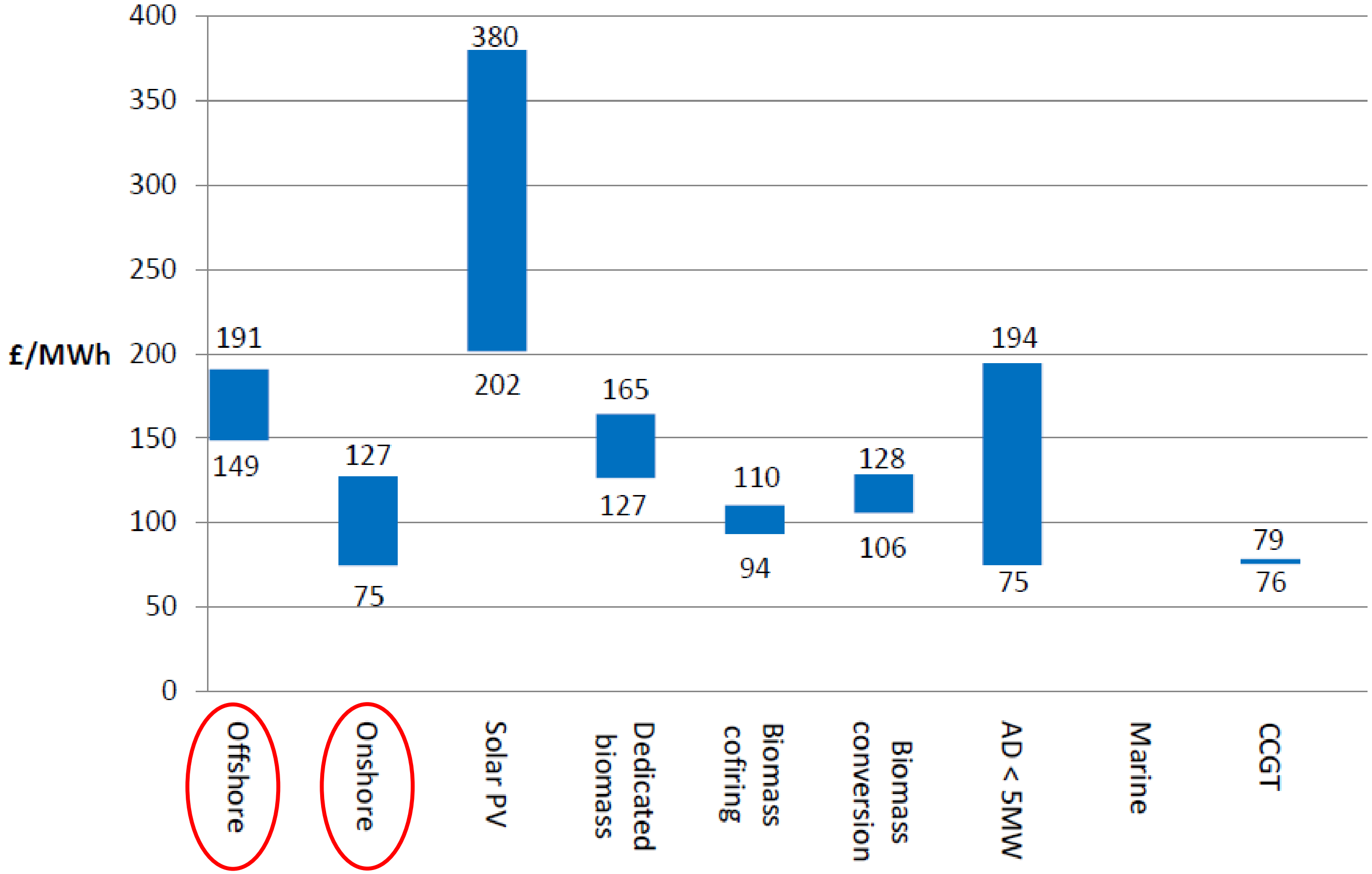
Renewable energy production 2005 - 2009 and projection to 2020renewable energy consumption (TWh)

Source: AEA 2011



The British «problem»: the renewable issue

Estimated levelised cost ranges for electricity technologies in 2010



Source: DECC 2011

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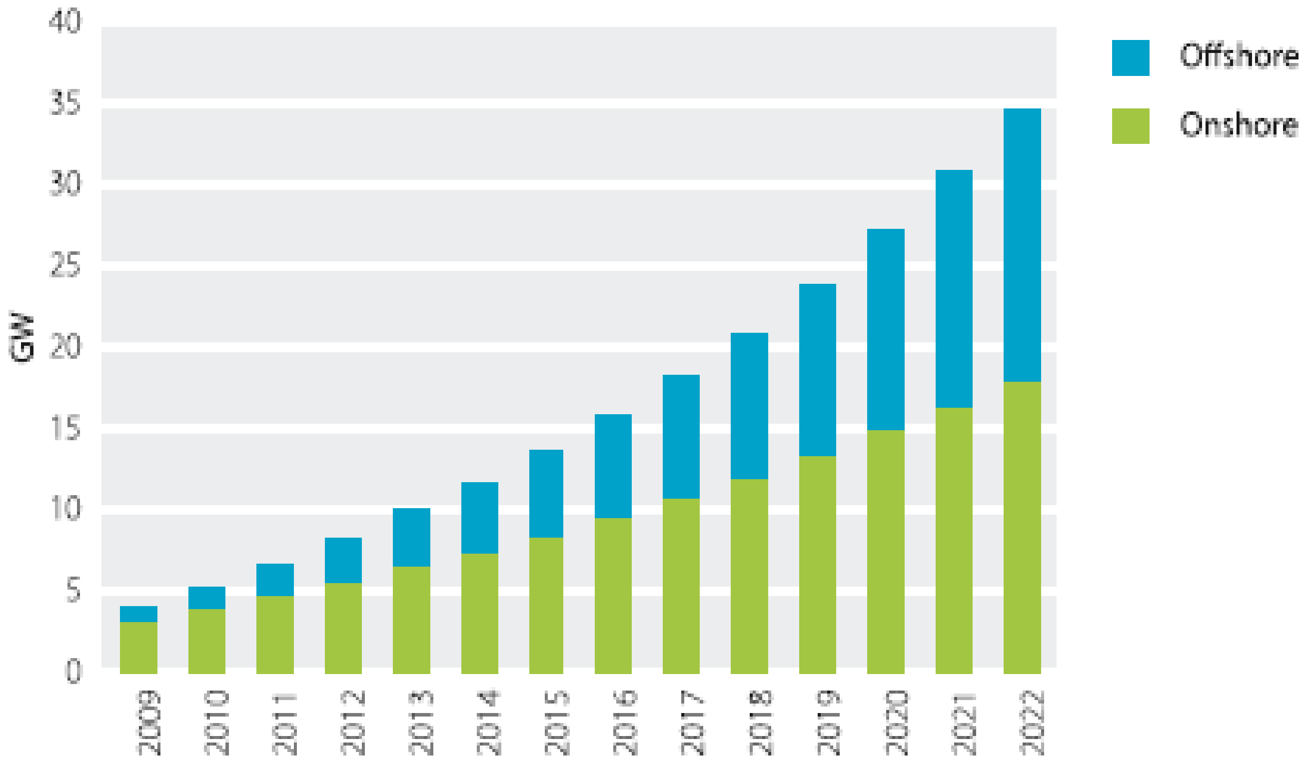
The British «problem»: the renewable issue

Wind potential capacity (GW)



Source: CCC 2009

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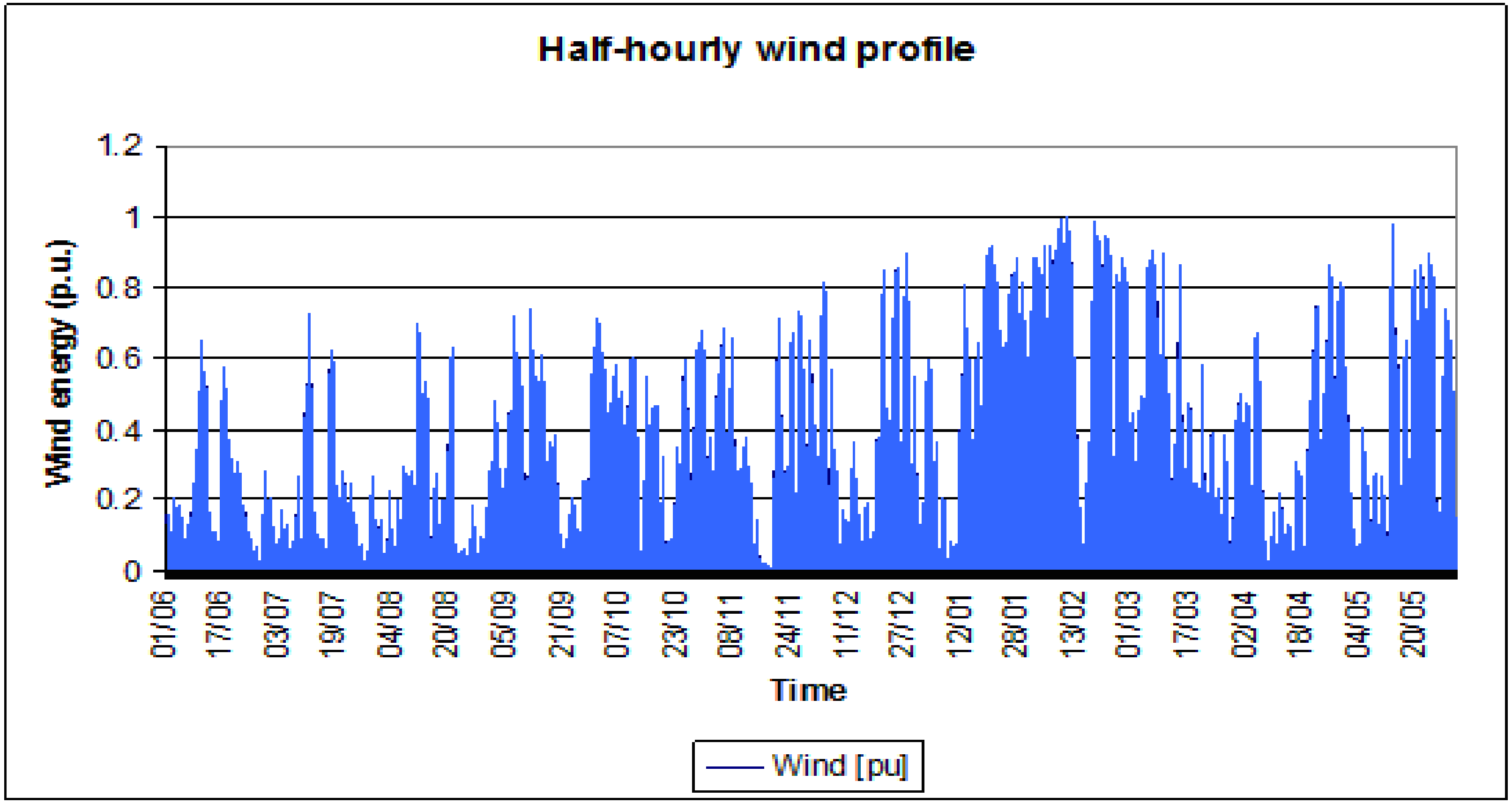
The British «problem»: the renewable issue

Wind intermittency



Research question and methodology

Research question

- Can the objectives of a locationally efficient network policy and those of a renewable policy be achieved simultaneously?
- Sub-questions
    - Given the adoption of optimal spatial pricing, how does this affect the level of production from renewable energy (wind in particular)?
    - How can we develop a more sophisticated approach to renewable policy which takes into account these trade-offs?

Methodology

- A non-linear optimization model, combining Economics and Electrical Engineering principles, which compares social welfare in two different “worlds” in 2015, under the constraint of a renewable target:
  - Uniform pricing (e.g. most European markets)
  - LMP (e.g. a few US markets, New Zealand, etc.)

Methodology

LMP model

$$\max_{\underline{d},\underline{g}} \sum_n \int_0^{d_n^*} p_n(d_n)\,dd_n - \sum_n \sum_k tc_{n,k}$$

Subject to

$$\sum_n \sum_k g_{n,k} = \sum_n d_n + l \qquad \text{(energy balance)}$$

$$g_{n,k} \le g_{n,k}^{\max} \qquad \text{for any } n, k \qquad \text{(max individual generation)}$$

$$z_i \le z_i^{\max} \qquad \text{for each line } i \qquad \text{(max power flow)}$$

Key results and conclusions

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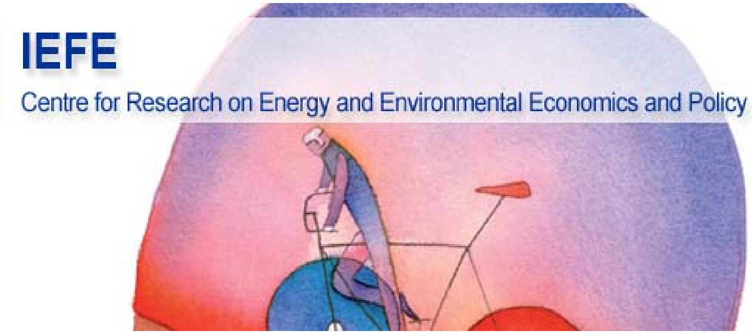

Key results

Energy results in 2015 (TWh)

UNI

Summary of annual results		Total demand (TWh)	Total generation (TWh)	Total wind energy (TWh)	Total wind energy (% of total generation)
Central elasticity	-0.25	370.28	375.89	33.04	8.79%
High elasticity	-0.50	383.12	389.05	33.04	8.49%

LMP

Summary of annual results		Total demand (TWh)	Total generation (TWh)	Total wind energy (TWh)	Total wind energy (% of total generation)
Central elasticity	-0.25	378.45	384.12	33.04	8.60%
High elasticity	-0.50	394.19	400.03	33.04	8.26%

Difference between LMP and UNI		% Difference in demand	% Difference in generation	% Difference in wind energy
Central elasticity	-0.25	2.21%	2.19%	0.00%
High elasticity	-0.50	2.89%	2.82%	0.00%

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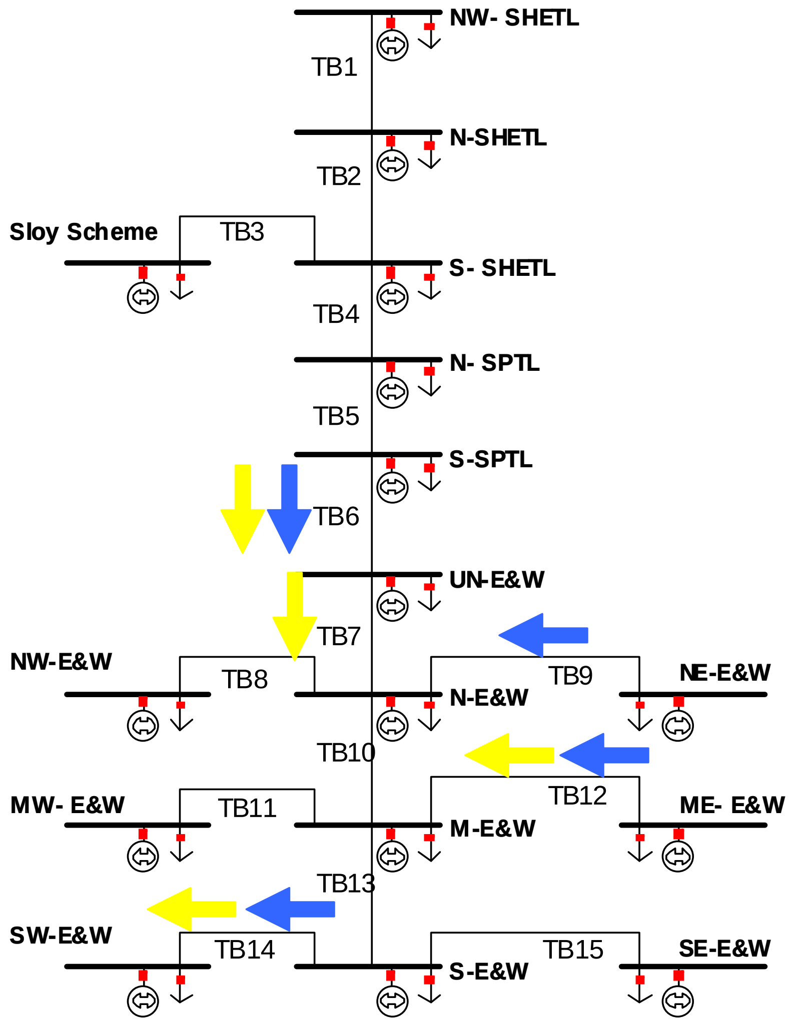
Key results

Congestion on transmission lines under LMP and UNI in 2015



Uniform marginal pricing

Locational marginal pricing

Key results

Welfare results in 2015 (£million)

		2008	2015			
Difference in welfare between LMP and UNI using different T/G (in £ million, 2008 money)		T/G=81%	T/G=81%	T/G=86%	T/G=88%	T/G=96%
Central elasticity	-0.25	N/A	2,470	128	31	9

Difference between LMP and UNI		% Difference in social welfare	% Difference in consumer surplus	% Difference in cost of dispatch
Central elasticity	-0.25	0.19%	4.31%	3.35%
High elasticity	-0.50	0.36%	5.59%	4.22%
Difference between LMP and UNI		**% Difference in generators' profit**	**% Difference in wind profit**	**% Difference in average price**
Central elasticity	-0.25	-31.41%	-18.63%	-8.79%
High elasticity	-0.50	-24.57%	-12.72%	-6.26%

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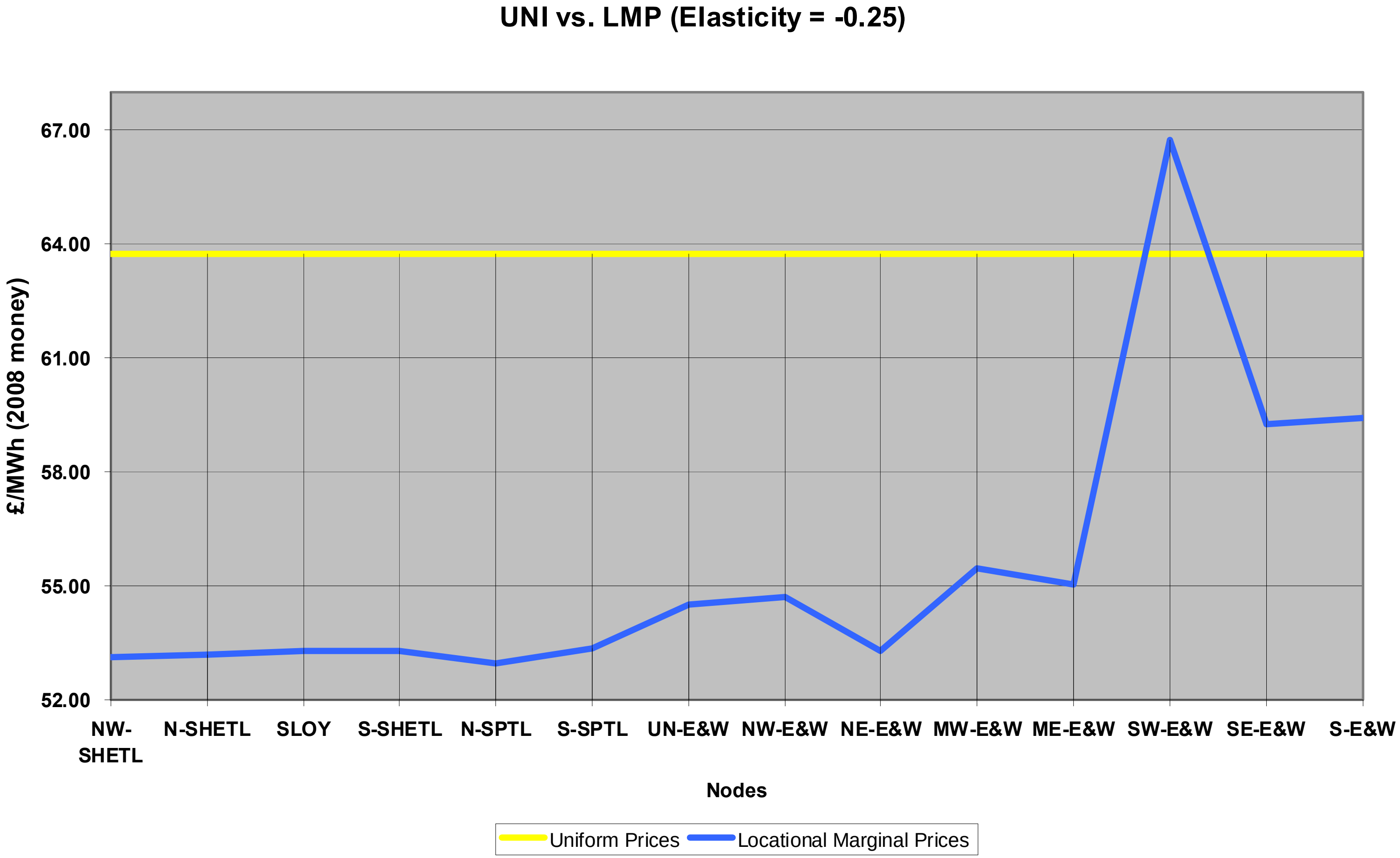
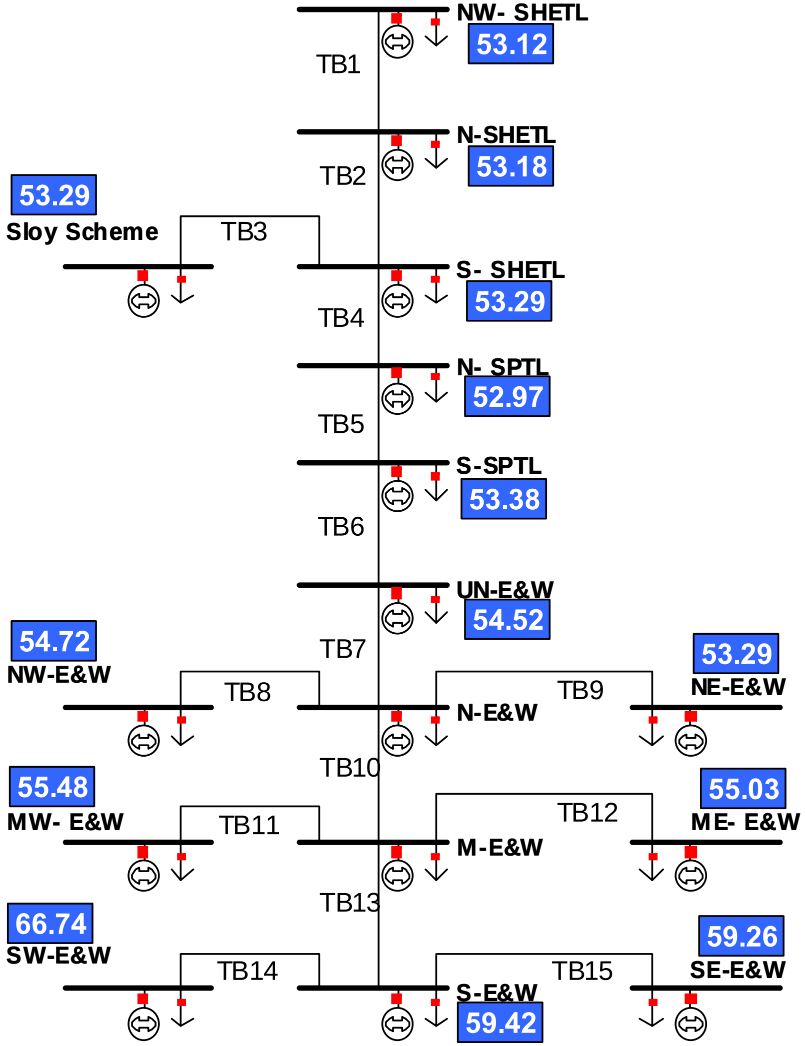
Key results

Price results in 2015 (£/MWh)



Key results

Average prices (£/MWh) under LMP in 2015 (demand elasticity -0.25)



Conclusions

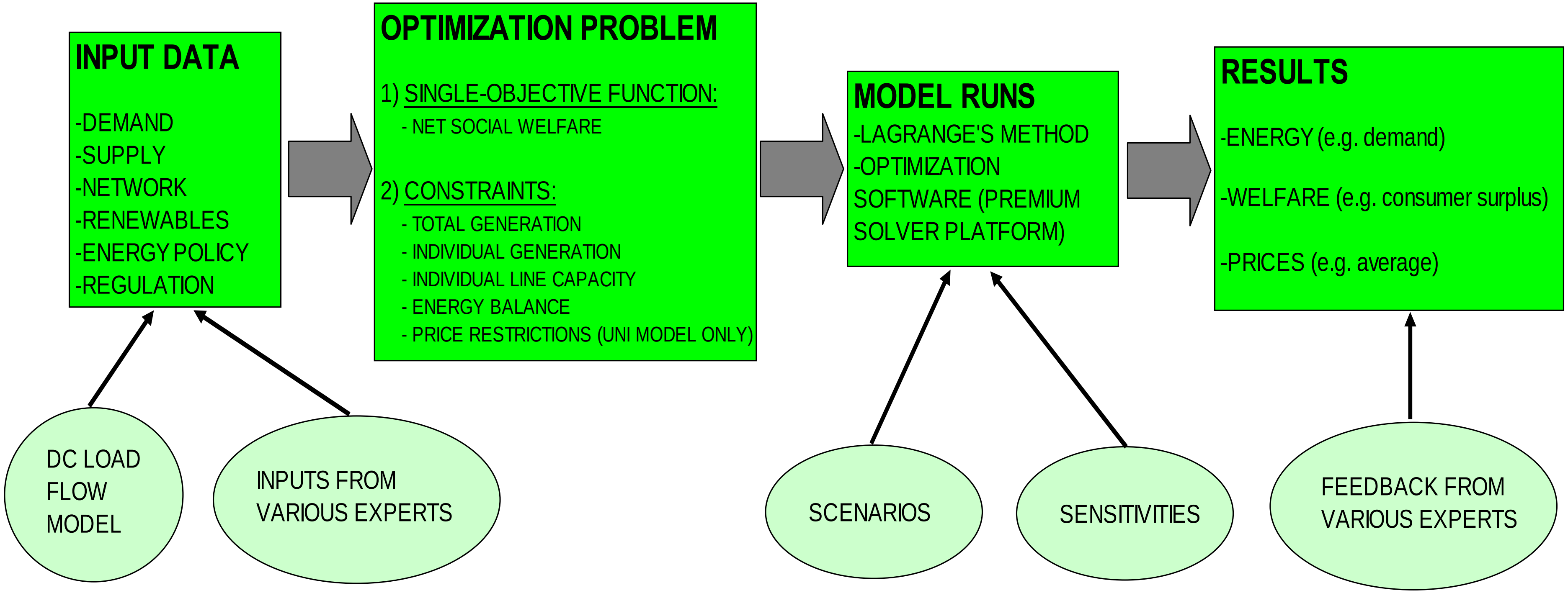
- The model results indicate that the objectives of a locationally efficient network policy and those of a renewable policy may be hard to achieve simultaneously
  - Total profits for wind are 19% lower under LMP
  - As uniform pricing model is “cleverer” than the real world (two-stage process), welfare differences would be greater.

- However this does not mean that a more sophisticated renewable policy could not address such trade-offs
  - Higher LMPs for off-shore wind farms
  - Higher carbon price.

Appendix

Details about the model

GB Electricity Market (1)



Theory

Adapted from Schweppe et al. (1988)

$$\max_{\underline{d},\underline{g}} \sum_n \int_0^{d_n^*} p_n(d_n)\,dd_n - \sum_n \sum_k tc_{n,k}$$

Subject to

$$\sum_n \sum_k g_{n,k} = \sum_n d_n + l \qquad \text{(energy balance)}$$

$$g_{n,k} \le g_{n,k}^{\max} \qquad \text{for any } n, k \qquad \text{(max individual generation)}$$

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ELMAR 16-15

(A)=(B)-(C) Objective function Max social welfare (in £)	(Welfare LMP)-(Welfare UNI)	(B) Total consumer benefit (in £)	(C) Total cost of dispatch (in £)	(D) Total consumer surplus (in £)	(E) Total generators' profit (in £)	(F)=(G)-(E)-(C) Total grid profit (in £)	(G) Total revenue (in £)	Check (A)=(D)+(E)+(F)	Nr negative profits	Demand-weighted average price (£/MWh)
11,056,440	4,953,960	13,527,524	2,471,084	9,050,372	1,175,672	830,396	4,477,152	11,056,440	0	72.38
	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
Prices (£/MWh)	52.57	53.07	54.04	54.04	54.70	55.07	57.64	58.89	37.71	0
Scenarios	Demand and Generation input				Demand elasticity scenario			Demand reference price (£/MWh)		
	Winter_Annual peak_0.75				-0.25			73.00		
Demand nodes	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
Ref D and Max G	566.27	540.12	0	660.05	1142.73	3060.75	3284.75	7732.67	6123.04	0
Credible upper bounds for D* and G*	679.5249727	648.1456348	0	792.0577708	1371.275854	3672.902851	3941.698567	9279.207831	7347.653773	0
	1	1	0	1	1	1	1	1	1	0
Choice variables D* and G*	605.89	576.99	0	702.91	1214.36	3248.69	3457.59	8106.27	6863.00	0
Change initial values D* and G*	D*=1,0	G*=1,0		D*=Ref D	G*=Max G					
Consumer benefit and cost of dispatch (in £)	126,501	120,610	0	147,273	254,831	682,339	730,650	1,718,093	1,381,908	0
Consumer surplus and generators' profit (in £)	94,648	89,990	0	109,291	188,409	503,433	531,371	1,240,697	1,123,087	0
Choice variables	605.89	576.99	0	702.91	1214.36	3248.69	3457.59	8106.27	6863.00	0
Generation nodal injections										
Net nodal injections (=G-D)	897.86	731.47	0.00	-702.91	895.24	1,105.40	-669.49	-414.87	6,397.53	0.00

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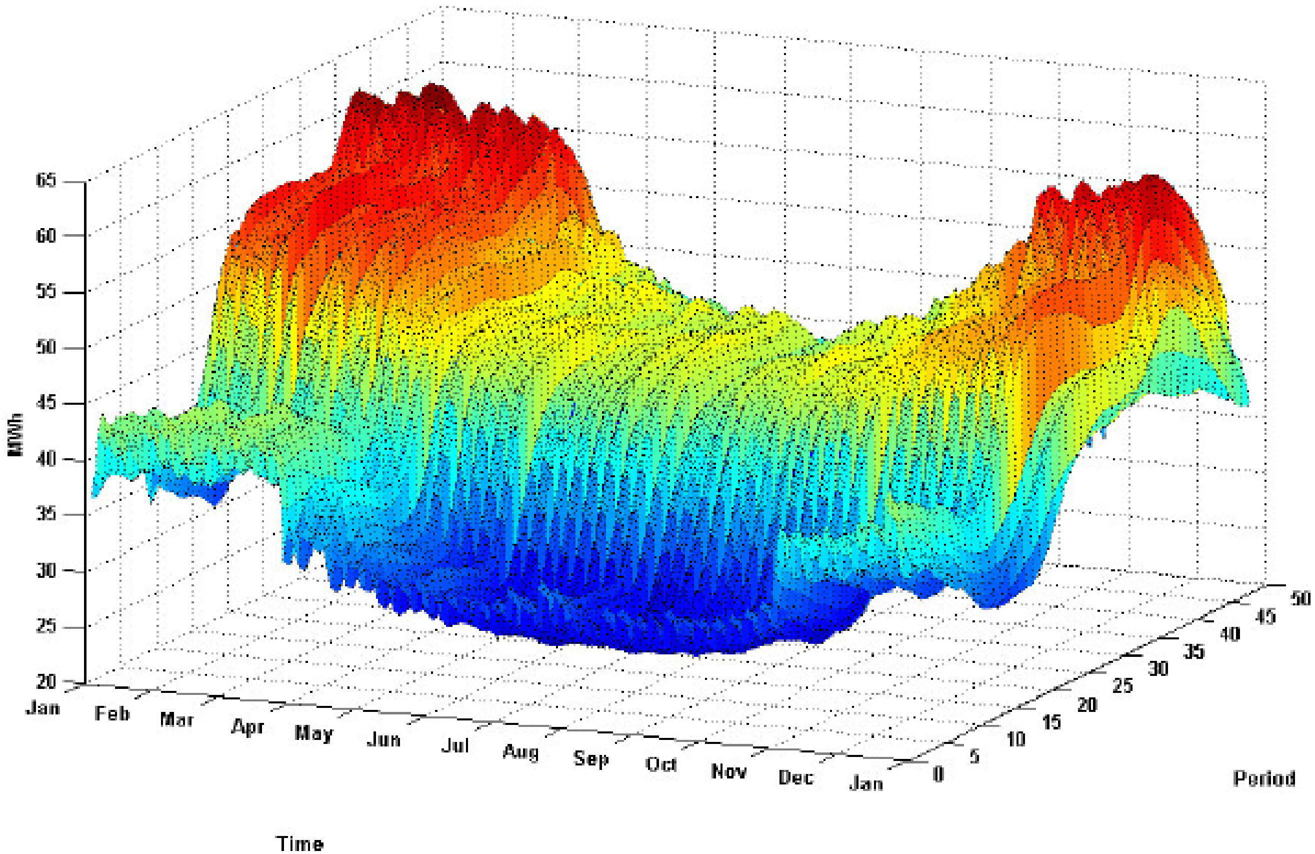
Inputs

GB demand data in 2015 (MWh)



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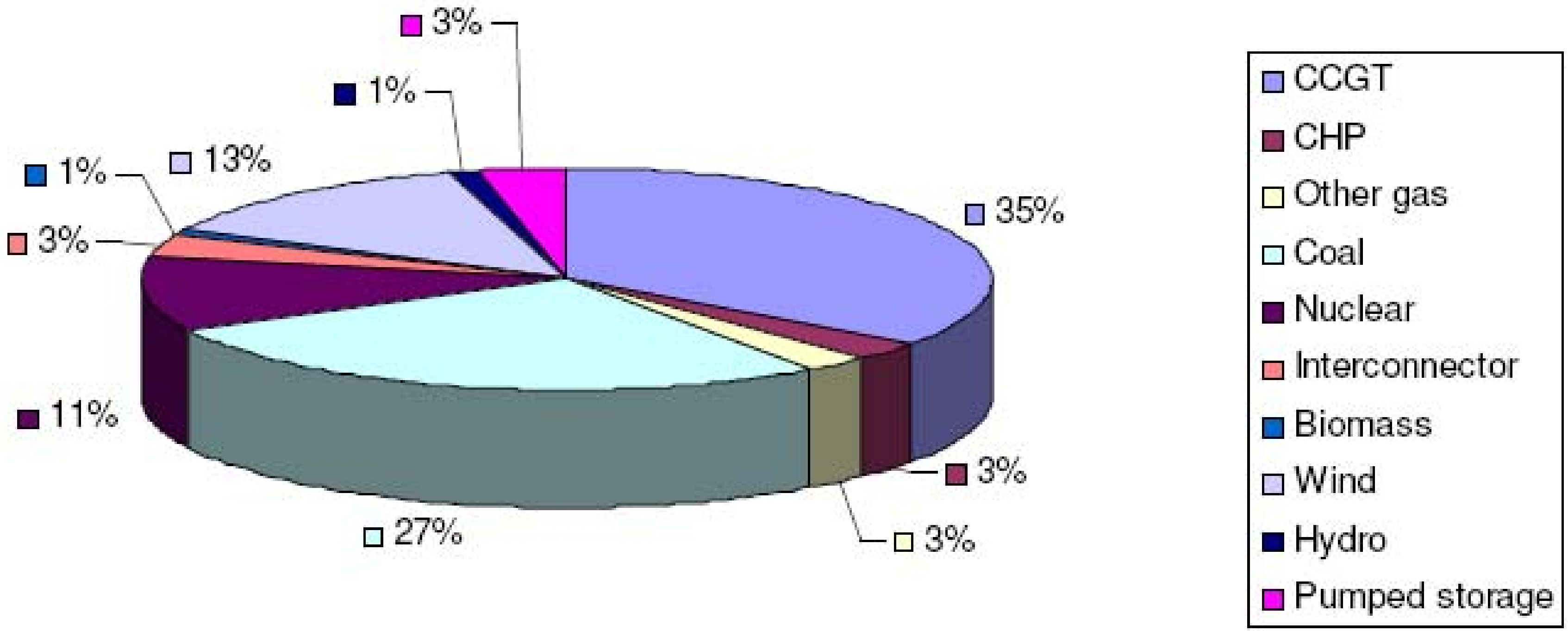
Inputs

GB Installed Generation Capacity in 2015



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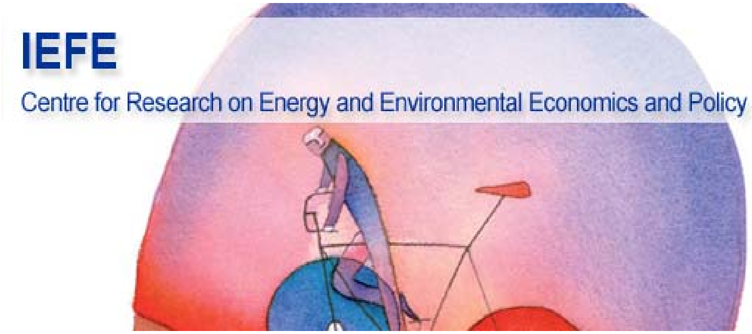
Inputs

Total Transmission connected Capacity in "Gone Green"

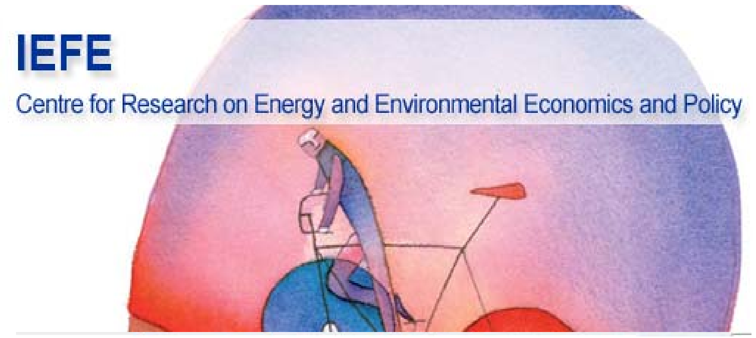
Generation Type	Capacity (GW) 2010/11	2020/21
Coal	28.2	14.5
Coal (CCS)	0.0	0.6
Nuclear	10.8	11.2
Gas	31.9	34.7
Oil	3.4	0.0
Pumped Storage	2.7	2.7
Wind	3.8	26.8
Interconnectors	3.3	5.8
Hydro	1.1	1.1
Biomass	0.0	1.6
Marine	0.0	1.4
Total	**85.3**	**100.5**

Source: NGC 2011



Contributions

- Gaps in the literature
    - Renewable + Network policy
- Improved engineering-economic model
    - DCLF radial network
    - Demand elasticity
- Enhanced demand modelling
    - Theory (consumer behaviour)
    - Practice (energy consumption)
- Adding the renewable dimension into a welfare economic model with spatial pricing
- Several open issues in the current debate



Grazie per l'attenzione!

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