



# **IEA Energy Technology Modelling: Computational Challenges**

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# Presentation Overview

- **IEA Modelling Activities**
- **The IEA-ETP Project & Model**
- **Modelling Technology Development**
- **Case Study Renewables**



## **IEA Modelling Activities**

### ***World Energy Outlook***

- **2004 edition includes a Reference Scenario and an Alternative Policy Scenario through the 2030 horizon**
- **Based on econometric modelling of energy demand and various modules for energy supply**
- **Disaggregated enough to represent main energy policies**
- **Alternative Policy Scenario reflects impact of policies “in the pipeline”, analysed “bottom-up”**
- **WEO does not include analysis of radical energy technology development**



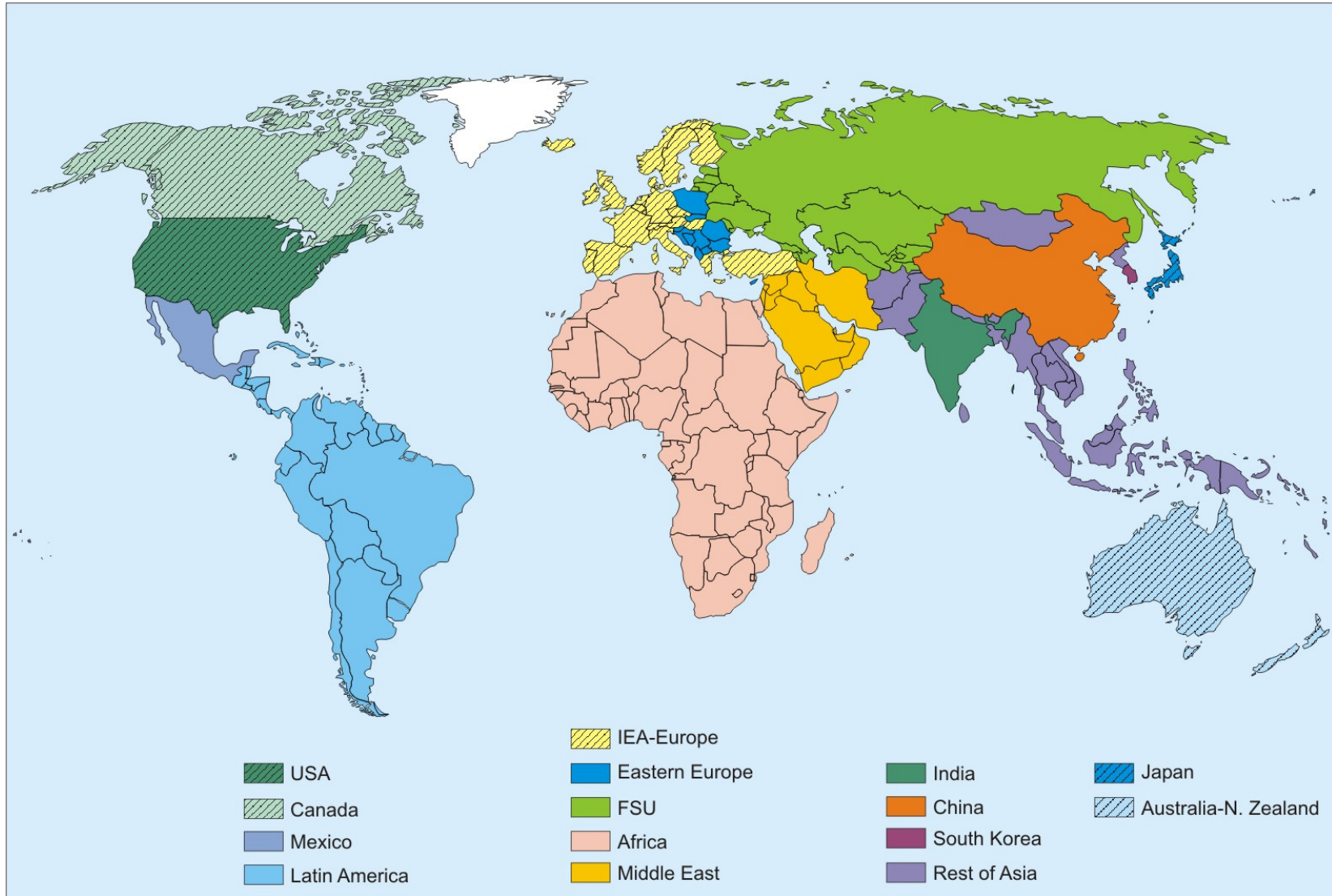
## **IEA Modelling Activities**

### ***The Energy Technology Perspectives Project***

- **Global 15-region energy technology model**
- **Least cost optimisation (MARKAL)**
- **Developed in collaboration with ETSAP**
- **Extensive technology database**
- **Full coverage of energy system from fuel extraction to energy service demand**
- **Time horizon: 2050**
- **So far provided input to IEA analysis on CCS, hydrogen, transport, and renewables**

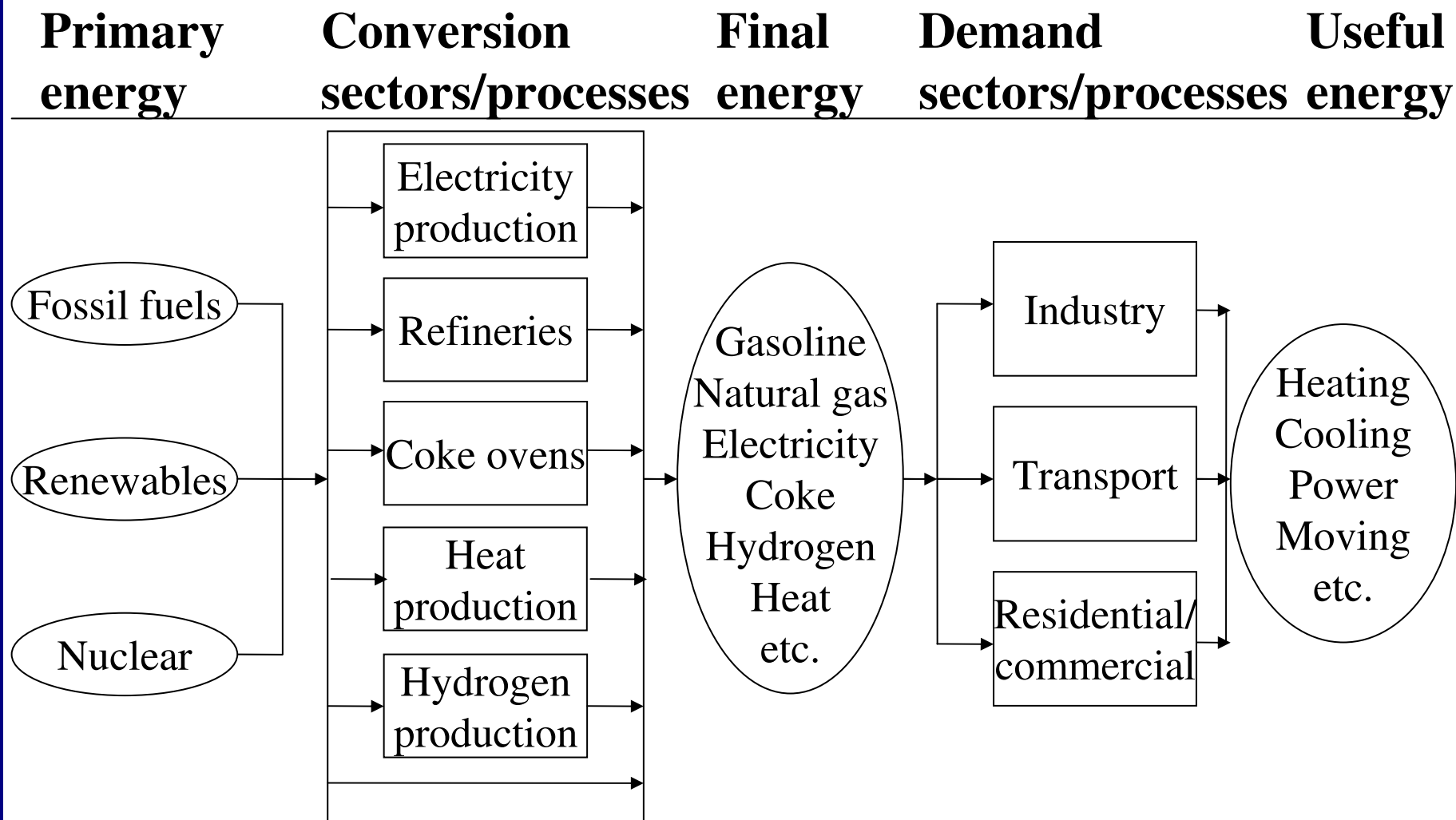


# ETP regions



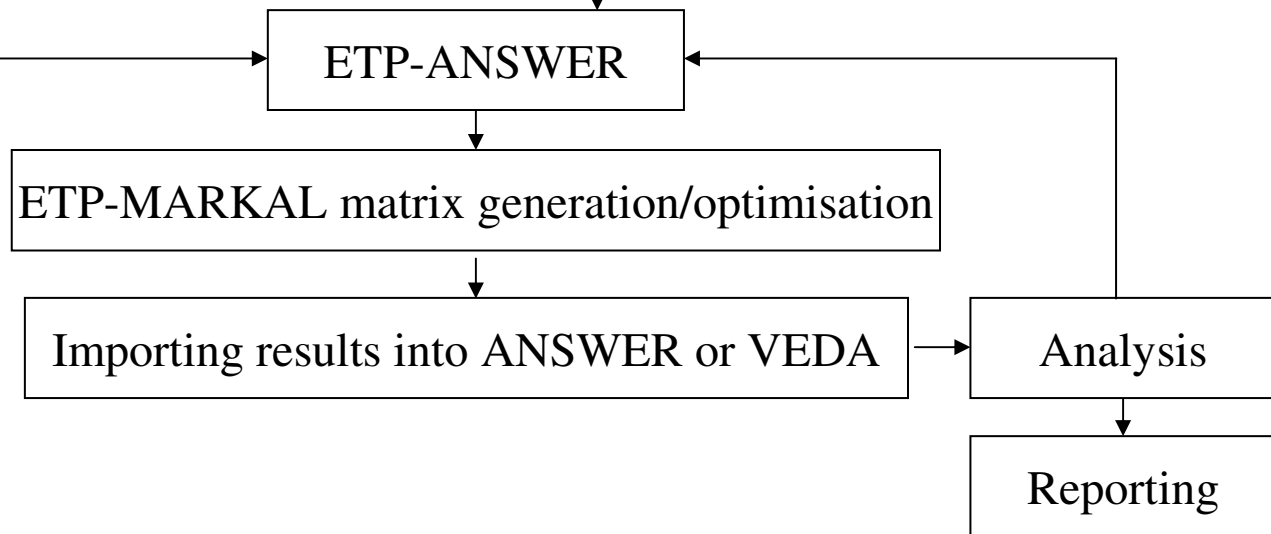
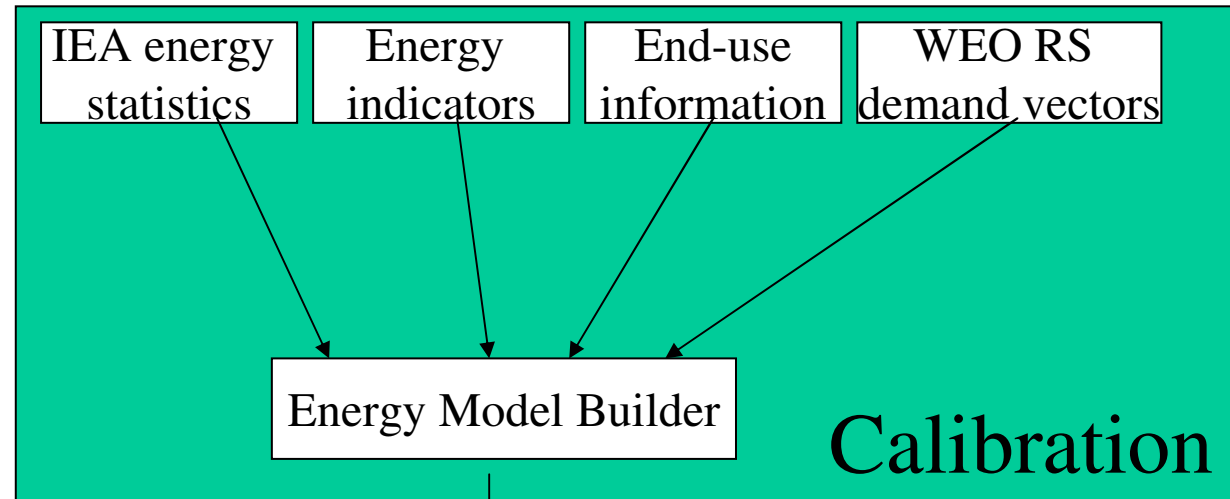
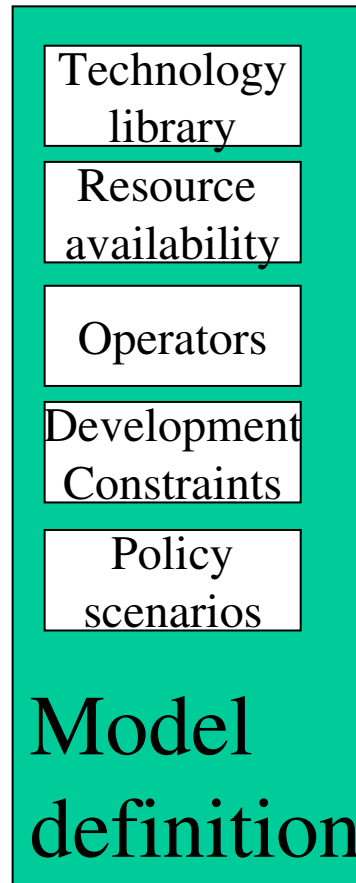


# Total Energy System Coverage





# ETP Model Structure





## **ETP – Model Size**

- **~1000 technologies included for each region**
- **Generates a matrix with around 700,000 rows and 750,000 columns (5 million non-zero elements)**
- **LP formulation solves in roughly 40 minutes**



## ETP – Model

# Modelling Technology Learning

- Learning by doing:  
Investment cost per unit capacity =  
function of cumulative installed capacity
- Ideally need for NLP, but can be simplified  
using MIP
- However, MIP approach for 5 technologies  
solves in 6-10 hours...

**=> *Endogenously learning is a key  
modelling challenge***



## **Case Study:**

### **Role of Renewables in under different learning/deployment scenarios**

- **Focus on wind and solar PV in electricity supply**
- **Scenarios include combination of:**
  - ◆ **4 levels of wind deployment and 5 levels solar deployment**
  - ◆ **3 CO<sub>2</sub> penalty levels (0, 25\$/t, 50\$/t)**
  - ◆ **3 learning rates**



# Deployment Levels

Level	Capacity growth					2050 Cumulative capacity [GW]
	2000-2005	2005-2010	2010-2015	2015-2020	2025-2050	
WIND						
0	0.0%	0.0%	0.0%	0.0%	0.0%	11.6
1	20.0%	10.0%	5.0%	3.0%	3.0%	167.2
2	20.0%	15.0%	15.0%	10.0%	5.0%	671.6
3	25.0%	20.0%	15.0%	10.0%	10.0%	3131.7

SOLAR	2000-2010	2010-2020	2020-2025	2025-2030	2030-2035	2035-2040	2040-2050	2050 Cumulative capacity [GW]
	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	
1	15.0%	15.0%	10.0%	10.0%	5.0%	5.0%	5.0%	38.3
2	20.0%	15.0%	15.0%	10.0%	10.0%	10.0%	5.0%	116.7
3	20.0%	20.0%	15.0%	15.0%	10.0%	10.0%	10.0%	281.5
4	25.0%	20.0%	20.0%	15.0%	15.0%	10.0%	10.0%	654.1



## Investment Costs as Function of Deployment Levels and Learning Rates

<b>PV</b>		<b>15% LR</b>	<b>18% LR</b>	<b>20% LR</b>
		<b>2000</b>	<b>2050</b>	<b>2050</b>
		<b>[\$/kW]</b>	<b>[\$/kW]</b>	<b>[\$/kW]</b>
	0	5500	5500	5500
	1	5500	1817	1422
	2	5500	1400	1034
	3	5500	1138	804
	4	5500	934	631

<b>Wind</b>		<b>5% LR</b>	<b>7% LR</b>	<b>10% LR</b>
		<b>2000</b>	<b>2050</b>	<b>2050</b>
		<b>[\$/kW]</b>	<b>[\$/kW]</b>	<b>[\$/kW]</b>
	0	1000	1000	1000
	1	1000	821	756
	2	1000	741	654
	3	1000	661	557



## Model Implementation

- **Two approaches:**
  - ◆ **Simplified model representing wind and solar PV together with main competing coal and gas power generation technologies**  
=> used as a “reality check” and to investigate impact of discount rates
  - ◆ **ETP model: Implementation of deployment rates (lower bounds) and corresponding investment cost for all LR and CO2 penalties**



# Simplified Model

## Discount Rate Impact on System Costs

LR Solar = 18 % LR Wind = 7% Discount Rate = 5%				
[mln US\$]	WIN			
PV	0	1	2	3
0	0	5263	-2995	-55504
1	9903	15164	6900	-45632
2	15385	20642	12369	-40204
3	19566	24817	16526	-36130
4	16847	22076	13723	-39204



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LR Solar = 18 % LR Wind = 7% Discount Rate = 10%					
[mln US\$]	WIN				
PV	0	1	2	3	
0	0	5978	8650	6438	
1	4185	10162	12833	10617	
2	6463	12439	15108	12885	
3	8221	14197	16862	14626	
4	10583	16554	19208	16930	



# ETP Model

## Learning Rate Impact on System Costs

LR Solar = 18 % LR Wind = 7%

Regional Discount Rates = 3-10%

[mln US\$] PV	WIN			
	0	1	2	3
0	0	-128	-594	2613
1	2173	2047	1601	4847
2	1950	1889	1543	4990
3	587	568	343	4151
4	-2252	-2246	-2199	2242



# ETP Model

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**LR Solar = 15 % LR Wind = 5%**

Regional Discount Rates = 3-10%

[mln US\$] PV	WIN			
	0	1	2	3
0	0	1240	3846	15522
1	2807	4048	6680	18383
2	3945	5187	7857	19605
3	4418	5676	8412	20300
4	4883	6155	9013	21367



# ETP Model

## CO2 Penalty Impact on System Costs

25 \$/t CO2, LR Solar = 18 % LR Wind = 7%

Regional Discount Rates = 3-10%

[mln US\$] PV	WIN			
	0	1	2	3
0	0	-15572	-32131	-46582
1	1274	-14170	-30679	-45083
2	-1087	-16064	-32343	-46447
3	-5491	-19838	-35782	-49413
4	-15071	-28416	-43460	-56376

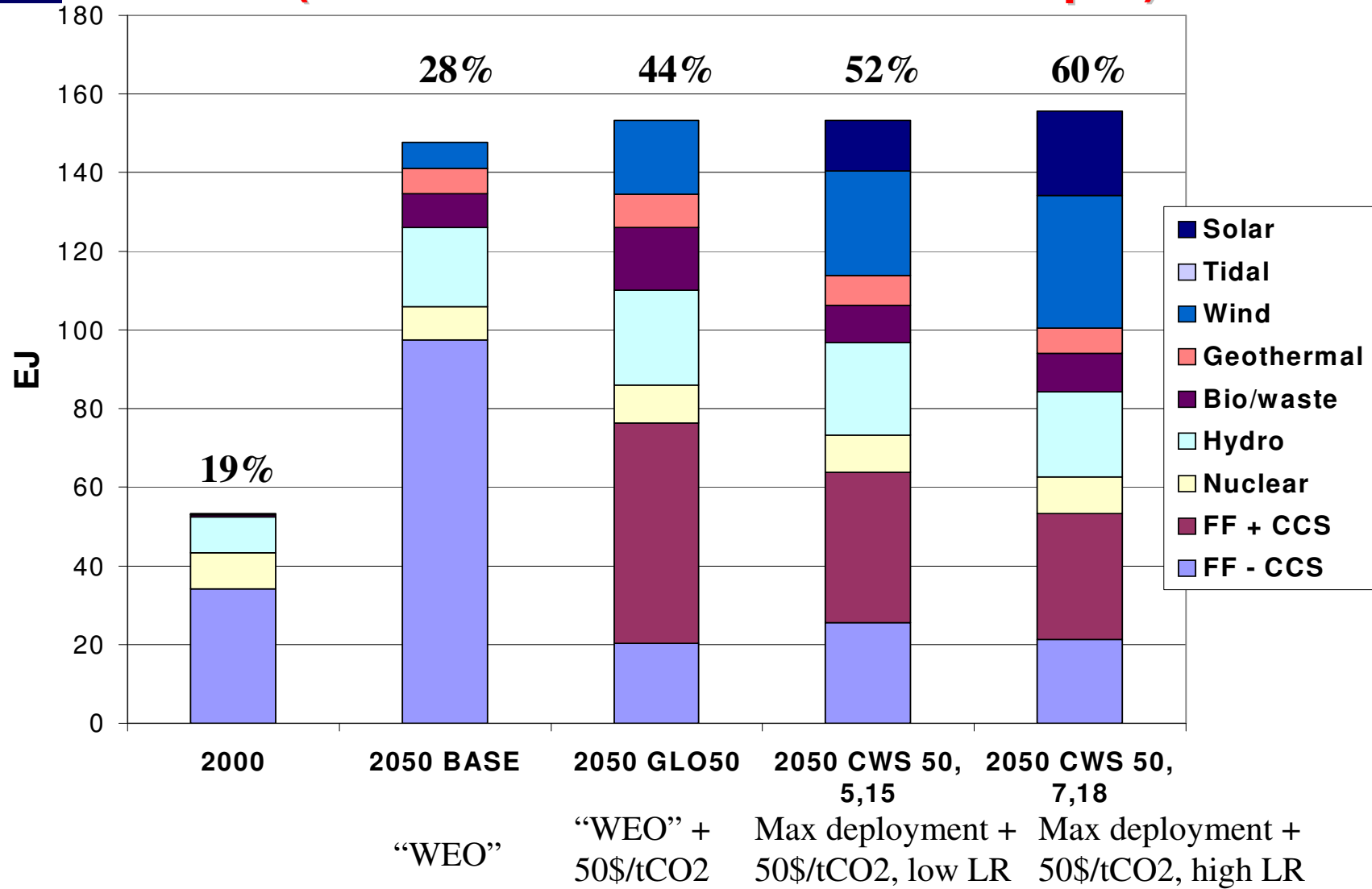
25 \$/t CO2, LR Solar = 15 % LR Wind = 5%

Regional Discount Rates = 3-10%

[mln US\$] PV	WIN			
	0	1	2	3
0	0	-8325	-16805	-24436
1	2160	-6131	-14580	-22195
2	2335	-5886	-14232	-21789
3	1239	-6844	-15072	-22445
4	-1348	-9279	-17019	-24069



# Electricity Output by Fuel (& Renewable share of total output)





## Conclusions

- Discount rates important, high rates imply lower value of early investment
- Learning assumptions are more important for PV than wind
- With CO<sub>2</sub> penalties and lower discount rates even moderate learning assumptions indicate that early investments in renewables are cost optimal
- Assumptions on CCS affect the results, but with CO<sub>2</sub> penalties a significant amount of renewables remains competitive with CCS



## Conclusions (cont.)

- Learning assumptions are more important for the results when CO<sub>2</sub> penalties are not included
- Without CO<sub>2</sub> penalty results are not robust enough to support investments in renewables
- Including learning is crucial to provide energy technology policy advice, but remains tricky to implement in energy technology models