Renewable Energy for Climate Change Mitigation: How Far and How Fast?

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Note: data for 2008 are provisional based on draft 2009 report, and subject to revision

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Seminar Topics

1. Renewable energy situation globally – markets, industry, policies
2. Global scenarios for renewable energy and carbon mitigation
3. Low-carbon transport: electric vehicles, energy storage, and "smart grids"
4. Technologies, policies and transitions for NZ – how far and how fast?

SELECTED INDICATORS	2006 ➔	2007 ➔	2008
Investment in new renewable capacity (annual) (*)	63 ➔	104 ➔	117 billion USD
Renewables power capacity (existing, excl. large hydro)	207 ➔	240 ➔	280 GW
Renewables power capacity (existing, incl. large hydro)	970 ➔	1,010 ➔	1,100 GW
Wind power capacity (existing)	74 ➔	94 ➔	121 GW
Grid-connected solar PV capacity (existing)	5.1 ➔	7.5 ➔	11.7 GW
Solar PV production (annual)	2.5 ➔	3.7 ➔	6.4 GW
Solar hot water capacity (existing)	105 ➔	125 ➔	140 GWth
Ethanol production (annual)	39 ➔	50 ➔	67 billion liters
Biodiesel production (annual)	6 ➔	9 ➔	12 billion liters
Countries with policy targets		66 ➔	73
States/provinces/countries with feed-in policies		46 ➔	55
States/provinces/countries with RPS policies		44 ➔	48
States/provinces/countries with biofuels mandates		53 ➔	56

Figure 1. Wind Power, Existing World Capacity, 1996–2008

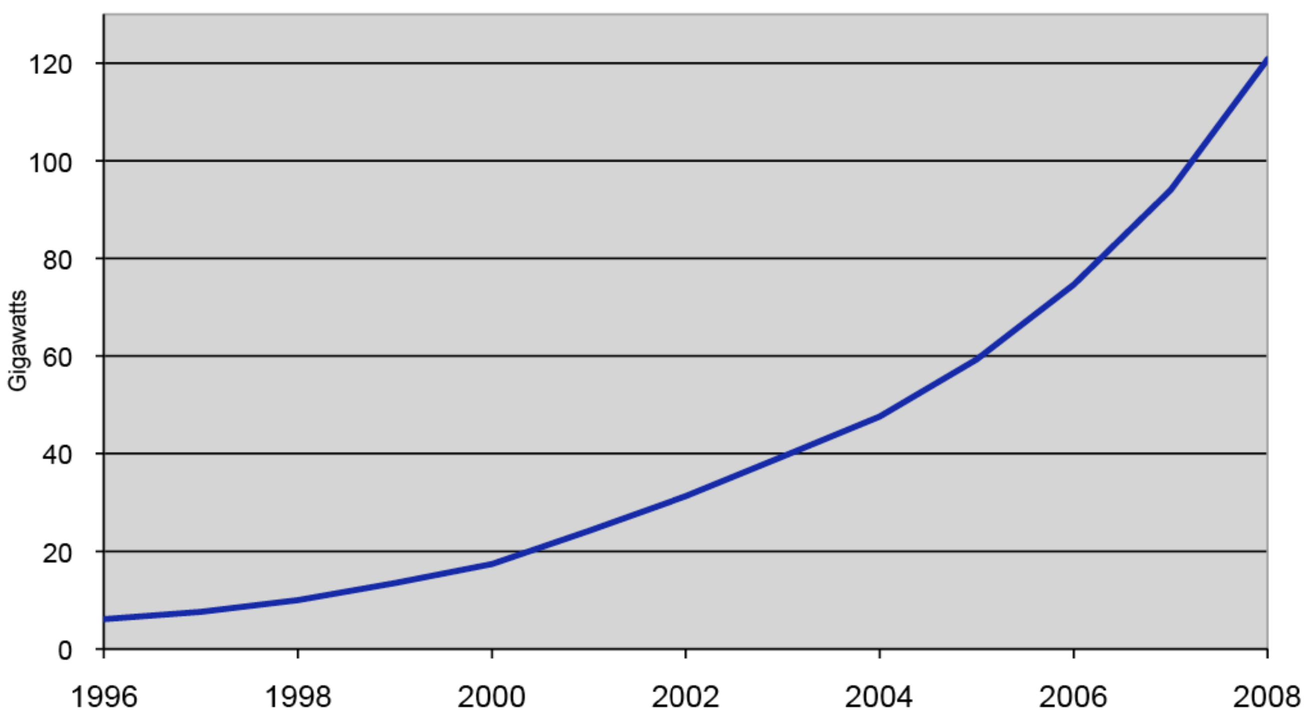


Figure 2. Wind Power Capacity, Top 10 Countries, 2008

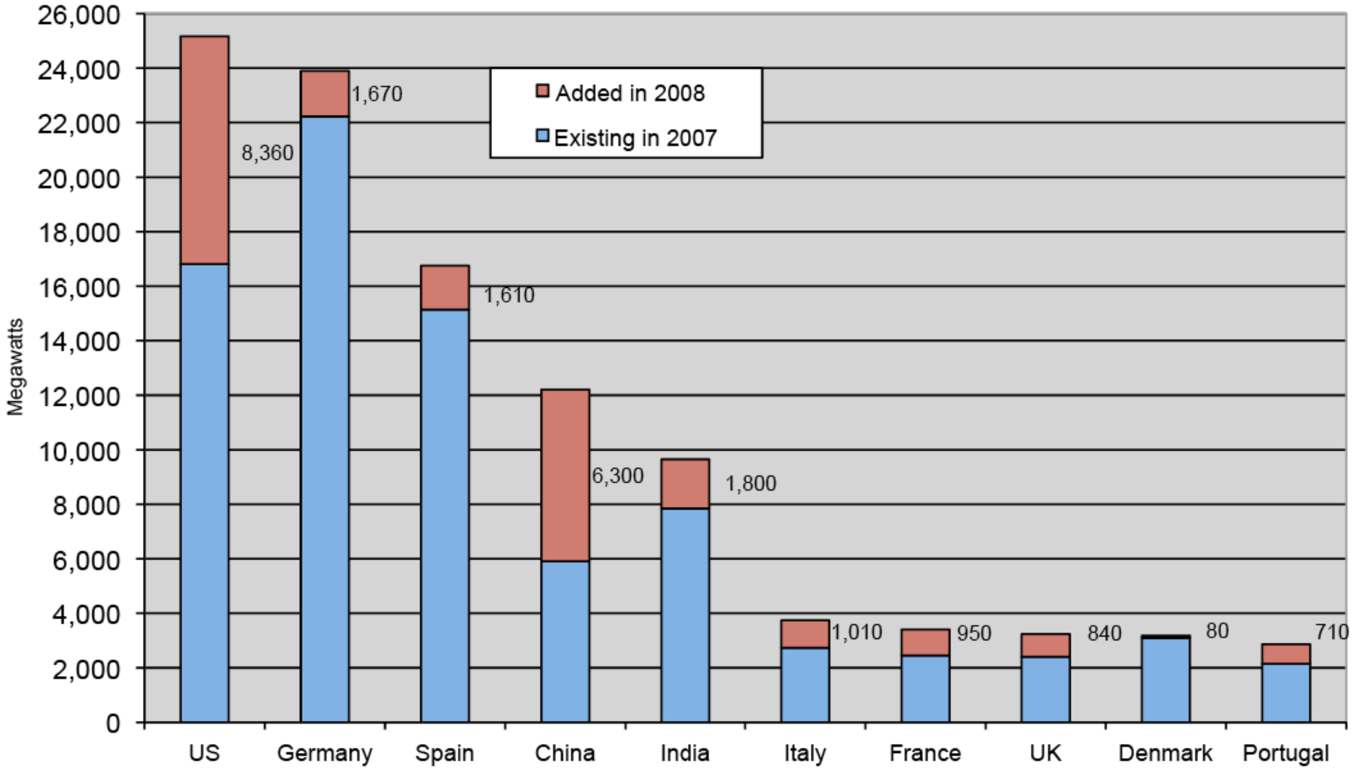


Figure 3. Solar PV, Existing World Capacity, 1995–2008

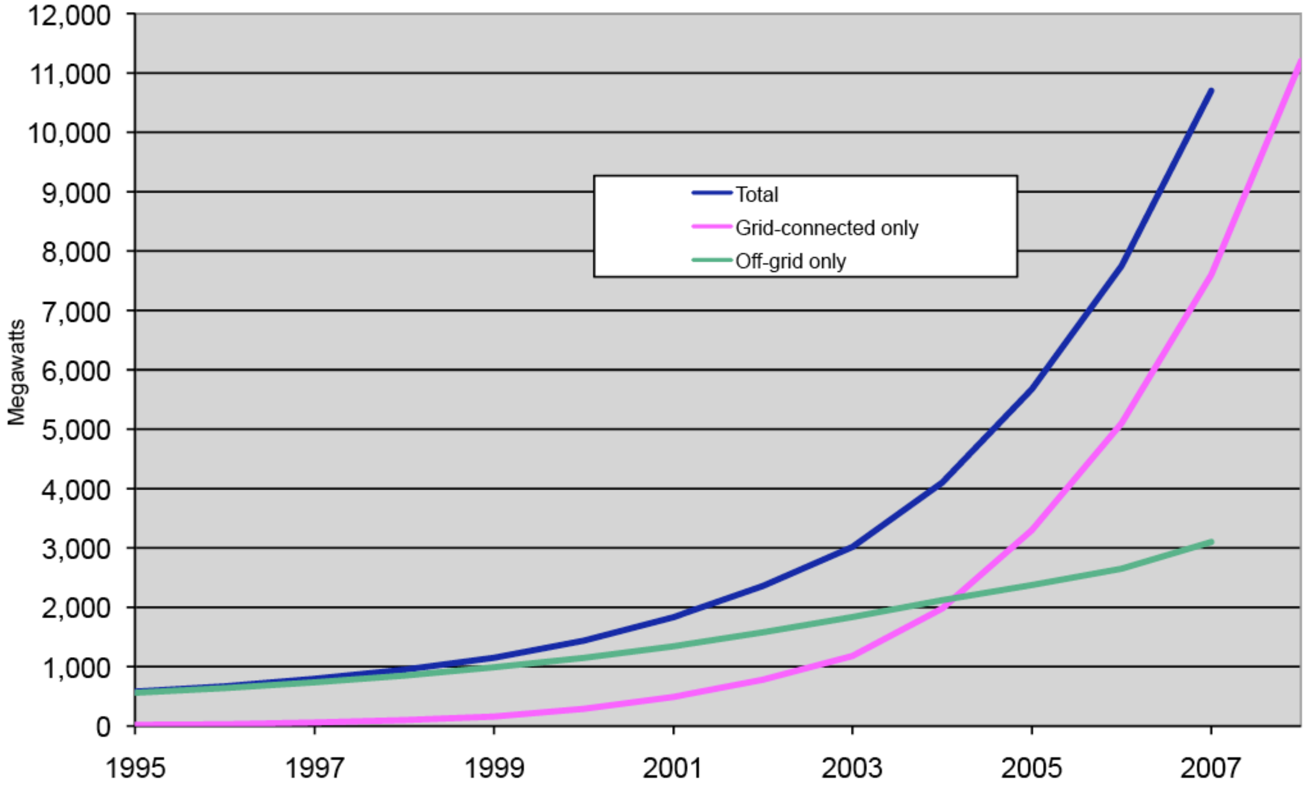


Figure 4. Renewable Power Capacities, Developing World, EU, and Top Six Countries, 2008

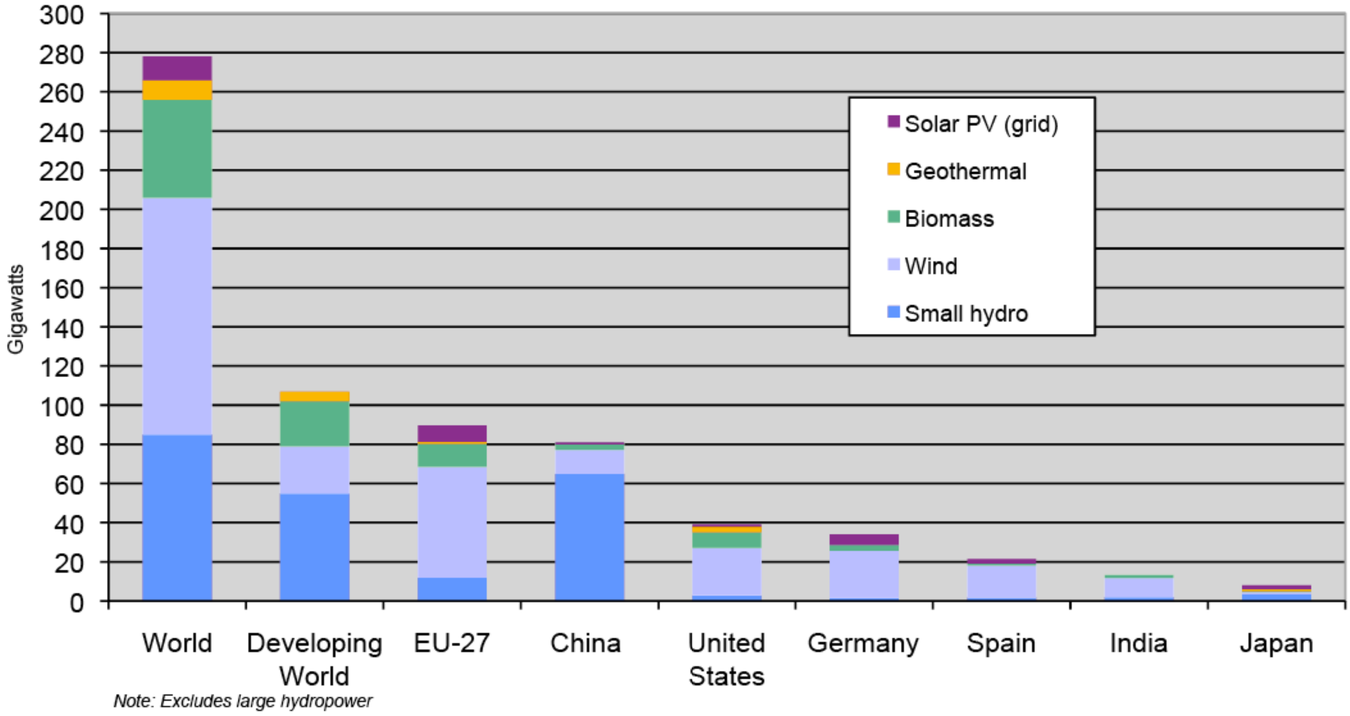


Figure 5. Share of Solar Hot Water/Heating Capacity Existing, Top 10 Countries, 2007

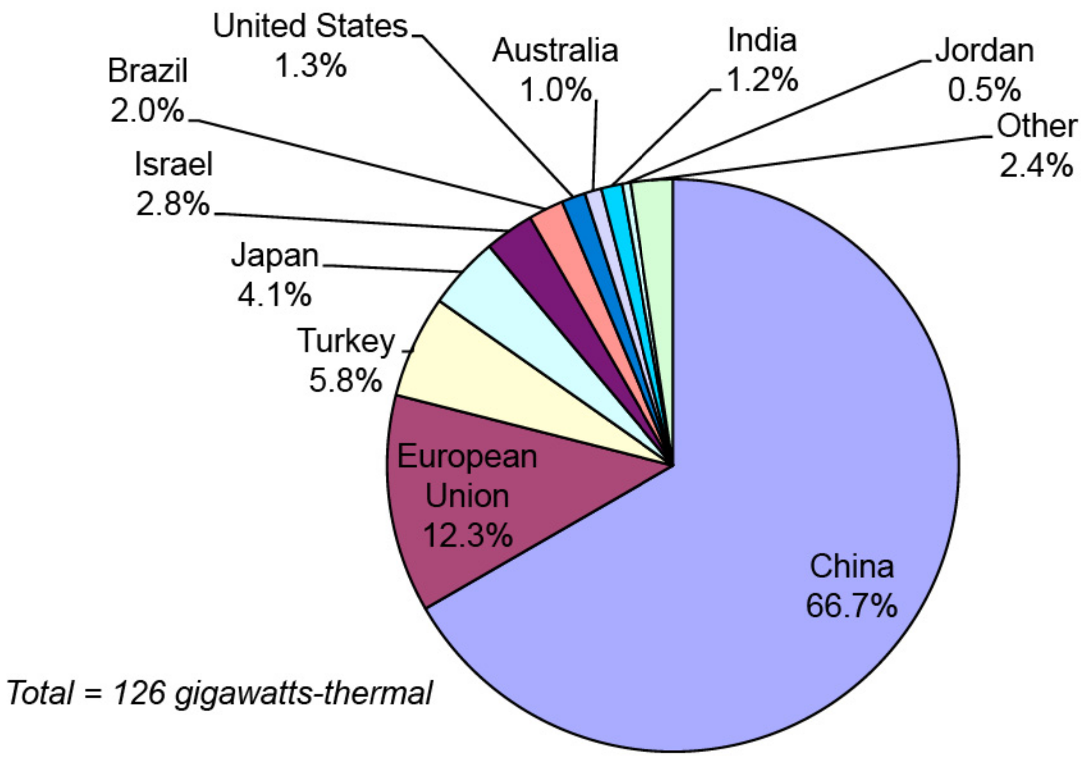


Figure 6. Share of Solar Hot Water/Heating Capacity Added, Top 10 Countries, 2007

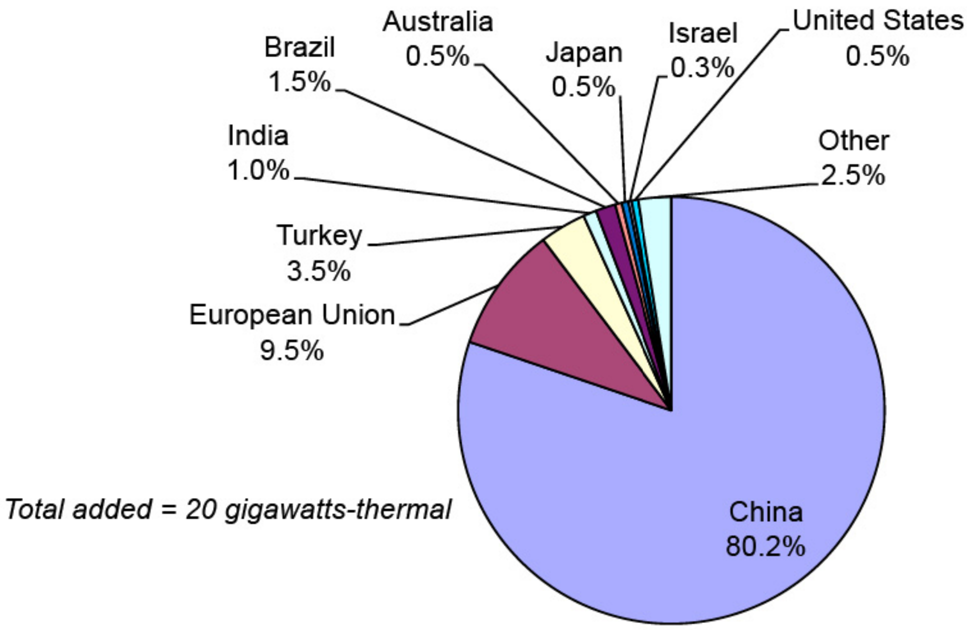
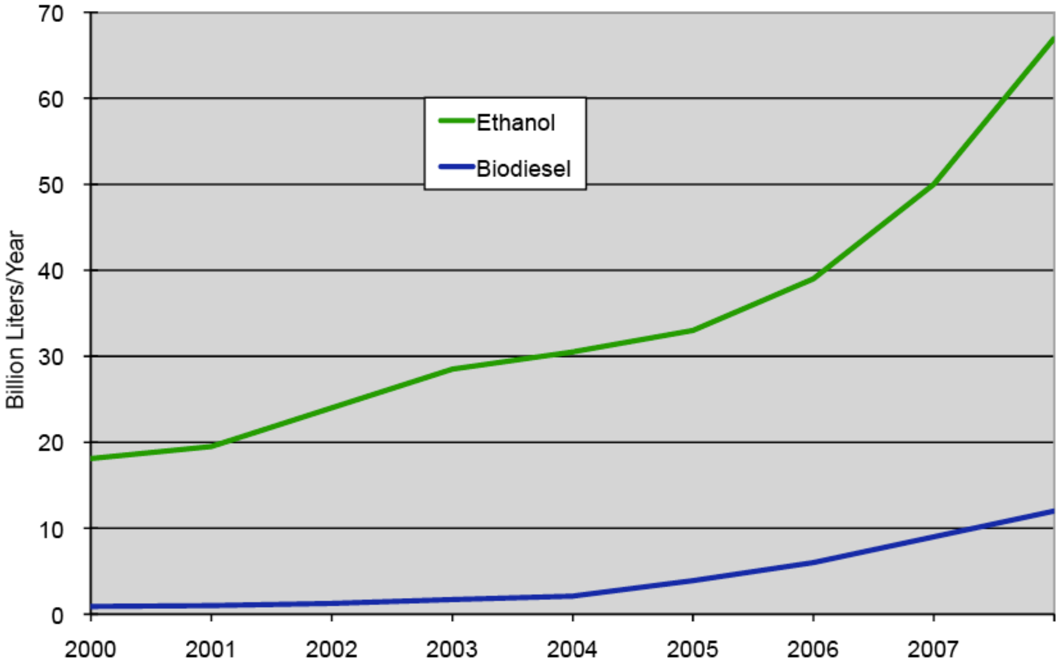


Figure 7. Ethanol and Biodiesel Production, 2000–2008



Global Market Trends

- Renewable power capacity of about 280 GW in 2008 (ex. large hydro) represents 6% of total global power capacity (~4,700 GW) and the share is increasing.
- Over 80 countries now have wind power, and many developing countries have joined the trend recently
- Offshore wind power grew significantly in 2006-2008, with several projects in the 100-300 MW range underway in Europe and the United States.
- Solar PV market growth is centered in Germany, Japan, Spain, Italy, South Korea, California, and New Jersey, but with the market now broadening to more countries and states (such as France).
- Rooftop solar collectors provide hot water to over 50 million households worldwide, most in China. China now represents 75% of global annual additions of solar hot water.
- Geothermal heat pumps are a rapidly growing market, with over 2 million heat pumps used in over 30 countries, mostly in Europe and the U.S.

Industry Trends

- The number of jobs worldwide in the renewable energy industry exceeds 3 million.
- Market capitalization exceeded $100 billion in 2007 for the 135 publicly traded renewable energy companies with market capitalization greater than $40 million each.
- The wind industry in China exploded in 2008, with 14 Chinese turbine manufacturers, dozens of component suppliers, and 6 major foreign subsidiary/JV manufacturers.
- Solar PV production worldwide in 2008 is estimated at more than 6.5 GW, up from 1.8 GW in 2005. China is the third largest producer, behind Japan and Germany.
- New investment in ethanol production facilities was more than $15 billion in 2008, with major increases in Brazil and the US, and 8 billion liters/year under construction in the US and 3.5 billion liters/year under construction in Europe.
- Serious commercial investment in cellulose-to-ethanol plants began during 2006/2007, with hundreds of millions of dollars flowing and several commercial-scale plants under construction.
- Many new solar thermal power plants (CSP) under construction or development in US and Europe.

Technology	Typical Characteristics	Typical Energy Costs (U.S. cents/kilowatt-hour)
Power Generation		
Large hydro	*Plant size:* 10 megawatts (MW)–18,000 MW	3–4
Small hydro	*Plant size:* 1–10 MW	4–7
On-shore wind	*Turbine size:* 1–3 MW *Blade diameter:* 60–100 meters	5–8
Off-shore wind	*Turbine size:* 1.5–5 MW *Blade diameter:* 70–125 meters	8–12
Biomass power	*Plant size:* 1–20 MW	5–12
Geothermal power	*Plant size:* 1–100 MW *Type:* binary, single- and double-flash, natural steam	4–7
Solar PV (module)	*Cell type and efficiency:* single-crystal 17%; polycrystalline 15%; amorphous silicon 10%; thin film 9-12%	—
Rooftop solar PV	*Peak capacity:* 2–5 kilowatts-peak	20–80*
Concentrating solar thermal power (CSP)	*Plant size:* 50–500 MW (trough), 10-20 MW (tower); *Types:* trough, tower, dish	12–18†

Table 1. Status of Renewables Technologies—Characteristics and Cost

But…. Direct Cost-of-Electricity Comparisons Are Not "Fair"!

Renewables more competitive considering subsidies, external costs and fuel-price risk

- Subsidies: to competing fuels or technologies, or from one type of customer to another
  - Subsidies to fossil fuels worldwide estimated at $150 billion/year (UNEP 2004)
  - Subsidies to nuclear power in OECD countries estimated at $16 billion/year (UNEP 2004). Also government reactor accident insurance (indemnity) and waste disposal are forms of subsidies (1-3 cents/kWh?).
  - Military costs of protecting oil supplies and shipping routes?
- External costs:
  - Damages to human health, agriculture, fisheries, ecosystems, and infrastructure.
  - EC (2003) estimates external cost of coal power generation at 2-15 eurocents/kWh
  - Costs of nuclear waste disposal and risk of radioactive contamination of ground water over next 10,000 years?
  - Costs of climate change are potentially huge – how to value? ("Avoidance costs"?)
- What is the Cost of Future Fossil-Fuel Price Risk?
  - Can estimate from market-based hedging costs – futures, swaps, options
  - California in 2004: added 0.5 cents/kWh for natural-gas hedging cost
  - Long-term physical storage costs

Policy Landscape

- Policy targets exist in at least 73 countries worldwide, including 22 developing countries, all 27 EU countries, and many states/provinces in the US and Canada.

- At least 63 countries worldwide now have some type of renewable energy promotion policy. including 25 developing countries.

- At least 41 countries and 14 states/provinces have adopted feed-in policies, more than half of which have been enacted since 2002.

- At least 48 states, provinces, and countries have enacted renewable portfolio standards (RPS), half since 2003.

- Many countries continue to actively supplement, revise, and clarify targets and promotion policies, including feed-in tariffs and rules.

- Targets for renewables as a share of transport energy exist in EU (EU-wide 10% by 2020 plus individual country targets)

- Mandates for blending biofuels into vehicle fuels have been enacted in at least 36 states/provinces and 19 countries, typically 10-15% for ethanol and 2-5% biodiesel.

Policy Landscape (continued)

- Biofuels tax exemptions have been enacted in a growing number of countries during 2005-2007. Many are for 100% tax exemptions.

- Solar PV policies continue to multiply, including:
  - Feed-in tariffs in Europe (typical 38-55 eurocents/kWh for small installations) and at state/province levels, including Washington State (USA), Ontario (Canada), State of South Australia
  - National building code requirement in Spain for solar PV on new buildings
  - U.S. national tax credit (30%)
  - Capital subsidies in several U.S. states ($0.5-4/watt), Australia (A$4/watt), Korea (70% subsidy), 300 Japanese municipalities, UK, and Sweden.

- Solar hot water tax credits and subsidies exist in many jurisdictions.

- There are more than 4 million green power consumers in Europe, US, Canada, Australia, and Japan, most of these in Europe.

- Municipalities around the world are also setting targets for future shares of renewable energy, CO_2-reduction targets, and enacting policies for solar PV and solar hot water.

Table 2. Renewable Energy Promotion Policies

Country	Feed-in tariff	Renewable portfolio standard	Capital subsidies, grants, or rebates	Investment or other tax credits	Sales tax, energy tax, excise tax, or VAT reduction	Tradable renewable energy certificates	Energy production payments or tax credits	Net metering	Public investment, loans, or financing	Public competitive bidding
Developed and transition countries										
Australia		✓	✓			✓			✓	
Austria	✓		✓	✓		✓			✓	
Belgium		✓	✓		✓	✓		✓		
Canada	(*)	(*)	✓	✓	✓			(*)	✓	(*)
Croatia	✓			✓					✓	
Cyprus	✓		✓							
Czech Republic	✓		✓	✓	✓	✓		✓		
Denmark	✓				✓	✓		✓	✓	✓
Estonia	✓				✓					
Finland			✓		✓	✓	✓			
France	✓		✓	✓	✓	✓			✓	✓
Germany	✓		✓	✓	✓				✓	
Greece	✓		✓	✓						
Hungary	✓				✓	✓			✓	
Ireland	✓		✓	✓		✓				✓
Italy	✓	✓	✓	✓		✓		✓		
Israel	✓									
Japan	(*)	✓	✓			✓		✓	✓	
Korea	✓		✓	✓	✓				✓	
Latvia	✓								✓	✓
Lithuania	✓		✓	✓					✓	
Luxembourg	✓		✓	✓						
Malta	✓				✓					
Netherlands	✓		✓	✓		✓	✓			
New Zealand			✓						✓	
Norway			✓	✓		✓				✓
Poland		✓	✓		✓				✓	✓
Portugal	✓		✓	✓	✓					
Romania					✓					
Russia			✓			✓				
Slovak Republic	✓			✓					✓	
Slovenia	✓								✓	
Spain	✓		✓	✓					✓	
Sweden		✓	✓	✓	✓	✓	✓			
Switzerland	✓									
United Kingdom		✓	✓		✓	✓				
United States	(*)	(*)	✓	✓	(*)	(*)	✓	(*)	(*)	(*)

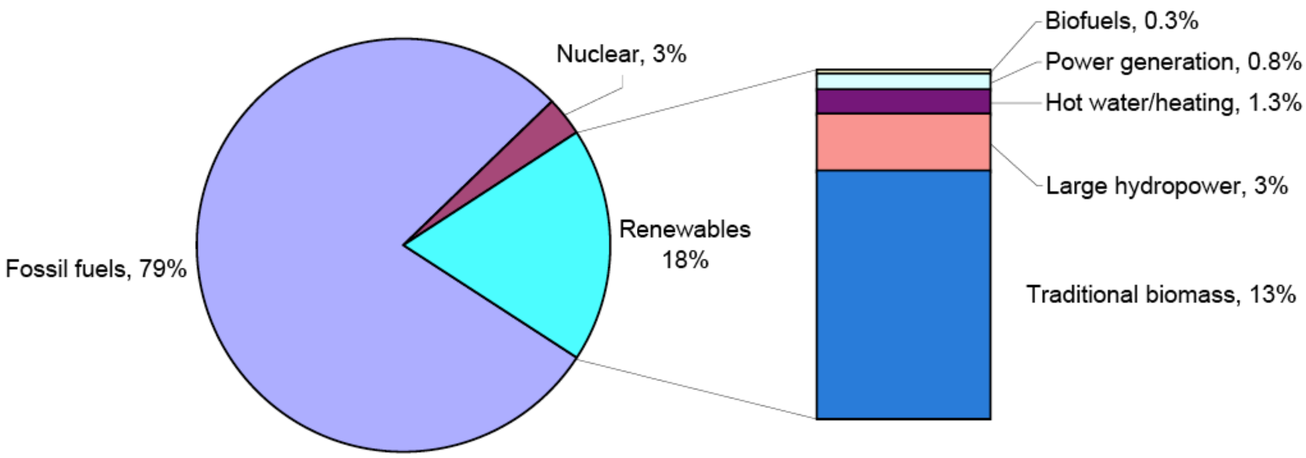
Table R10. Cumulative Number of Countries/States/Provinces Enacting Feed-in Policies

Year	Cumulative Number	Countries/States/Provinces Added That Year
1978	1	United States
1990	2	Germany
1991	3	Switzerland
1992	4	Italy
1993	6	Denmark, India
1994	8	Spain, Greece
1997	9	Sri Lanka
1998	10	Sweden
1999	13	Portugal, Norway, Slovenia
2000	13	—
2001	15	France, Latvia
2002	21	Algeria, Austria, Brazil, Czech Republic, Indonesia,Lithuania
2003	28	Cyprus, Estonia, Hungary, South Korea, Slovak Republic, Maharashtra (India)
2004	34	Italy, Israel, Nicaragua, Prince Edward Island (Canada), Andhra Pradesh and Madhya Pradesh (India)
2005	41	Karnataka, Uttaranchal, and Uttar Pradesh (India); China; Turkey; Ecuador; Ireland
2006	44	Ontario (Canada), Argentina, Thailand
2007	46	South Australia (Australia), Croatia

Table R11. Cumulative Number of Countries/States/Provinces Enacting RPS Policies

Year	Cumulative Number	Countries/States/Provinces Added
1983	1	Iowa (USA)
1994	2	Minnesota (USA)
1996	3	Arizona (USA)
1997	6	Maine, Massachusetts, Nevada (USA)
1998	9	Connecticut, Pennsylvania, Wisconsin (USA)
1999	12	New Jersey, Texas (USA); Italy
2000	13	New Mexico (USA)
2001	15	Flanders (Belgium); Australia
2002	18	California (USA); Wallonia (Belgium); United Kingdom
2003	19	Japan; Sweden; Maharashtra (India)
2004	34	Colorado, Hawaii, Maryland, New York, Rhode Island (USA); Nova Scotia, Ontario, Prince Edward Island (Canada); Andhra Pradesh, Karnataka, Madhya Pradesh, Orissa (India); Poland
2005	38	District of Columbia, Delaware, Montana (USA); Gujarat (India)
2006	39	Washington State (USA)
2007	44	Illinois, New Hampshire, North Carolina, Oregon (USA); China

Figure 1. Renewable Energy Share of Global Final Energy Consumption, 2006



Source: REN21 Renewables 2007 Global Status Report, www.ren21.net

Figure 12. EU Renewable Energy Targets—Share of Final Energy by 2020

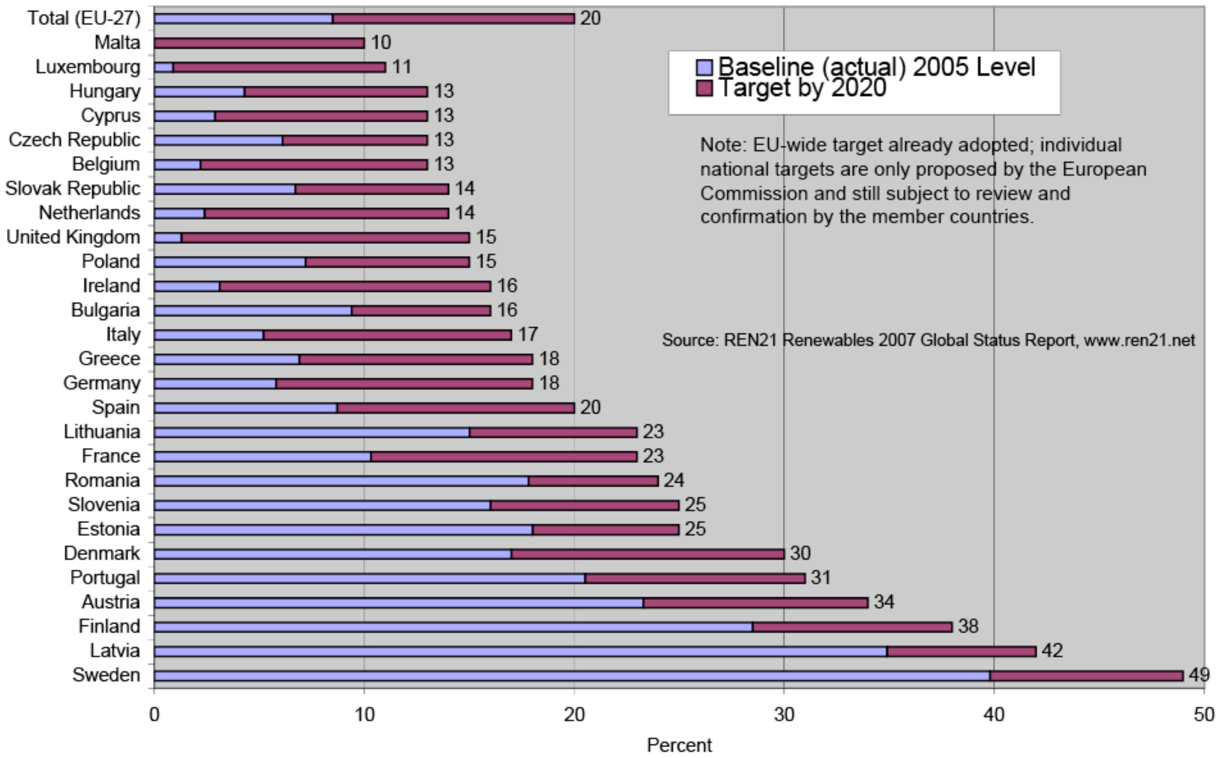


Table R7. Share of Primary and Final Energy from Renewables, Existing in 2006 and Targets

	Primary energy (IEA method)		Final energy (EC method)	
Country/region	Existing share (2006)	Future target	Existing share (2005–06)	Future target
World	13%	—	18%	—
EU-25/EU-27	6.5%	12% by 2010	8.5%	20% by 2020
Selected EU Countries				
Austria	20%	—	23%	34% by 2020
Czech Republic	4.1%	8–10% by 2020	6.1%	13% by 2020
Denmark	15%	30% by 2025	17%	30% by 2020
France	6.0%	7% by 2010	10%	23% by 2020
Germany	5.6%	4% by 2010	5.8%	18% by 2020
Italy	6.5%	—	5.2%	17% by 2020
Latvia	36%	6% by 2010	35%	42% by 2020
Lithuania	8.8%	12% by 2010	15%	23% by 2020
Netherlands	2.7%	—	2.4%	14% by 2020
Poland	4.6%	14% by 2020	7.2%	15% by 2020
Spain	6.5%	12.1% by 2010	8.7%	20% by 2020
Sweden	28%	—	40%	49% by 2020
United Kingdom	1.7%	—	1.3%	15% by 2020
Other Developed/OECD Countries				
Canada	16%	—	20%	—
Japan	3.2%	—	3.2%	—
Korea	0.5%	5% by 2011	0.6%	—
Mexico	9.4%	—	9.3%	—
United States	4.8%	—	5.3%	—
Developing Countries				
Argentina	8.2%	—	—	—
Brazil	43%	—	—	—
China*	8%	15% by 2020	—	—
Egypt	4.2%	14% by 2020	—	—
India	31%	—	—	—
Indonesia	3%	15% by 2025	—	—
Jordan	1.1%	10% by 2020	—	—
Kenya	81%	—	—	—
Mali	—	15% by 2020	—	—
Morocco*	4.3%	10% by 2010	—	—
Senegal	40%	15% by 2025	—	—
South Africa	11%	—	—	—
Thailand*	4%	8% by 2011	—	—

Figure 2. Share of Global Electricity from Renewable Energy, 2006

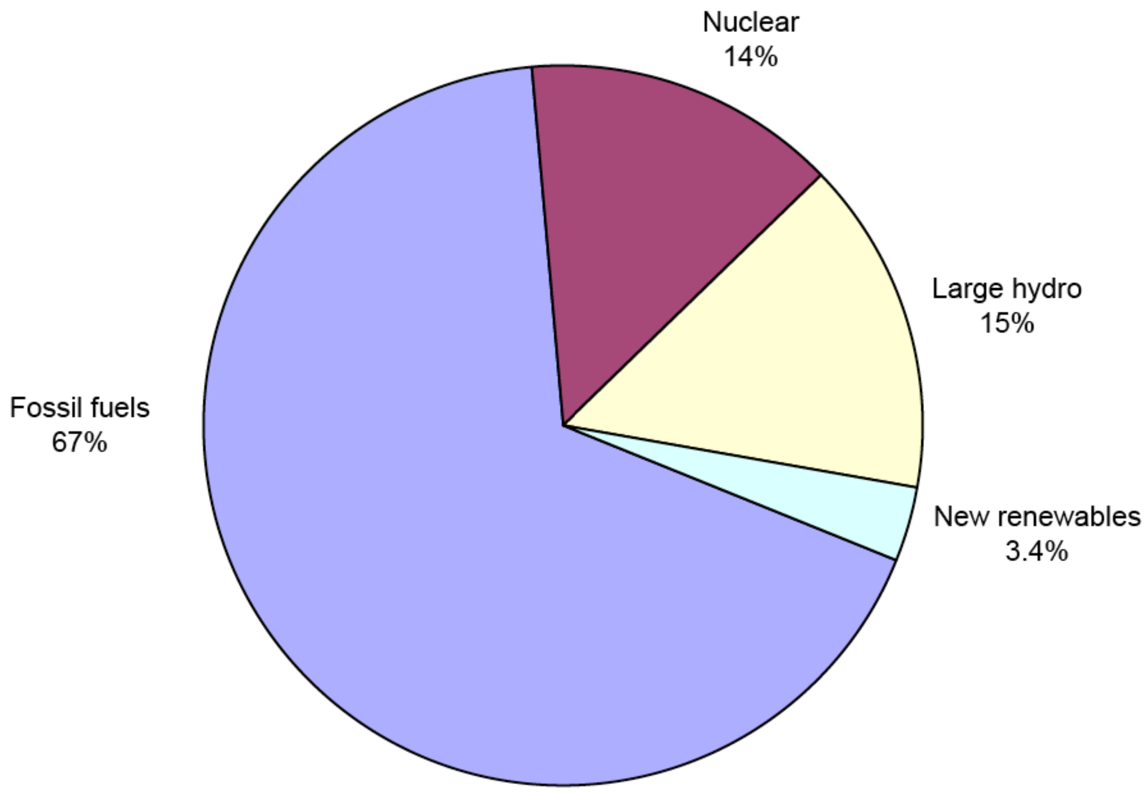
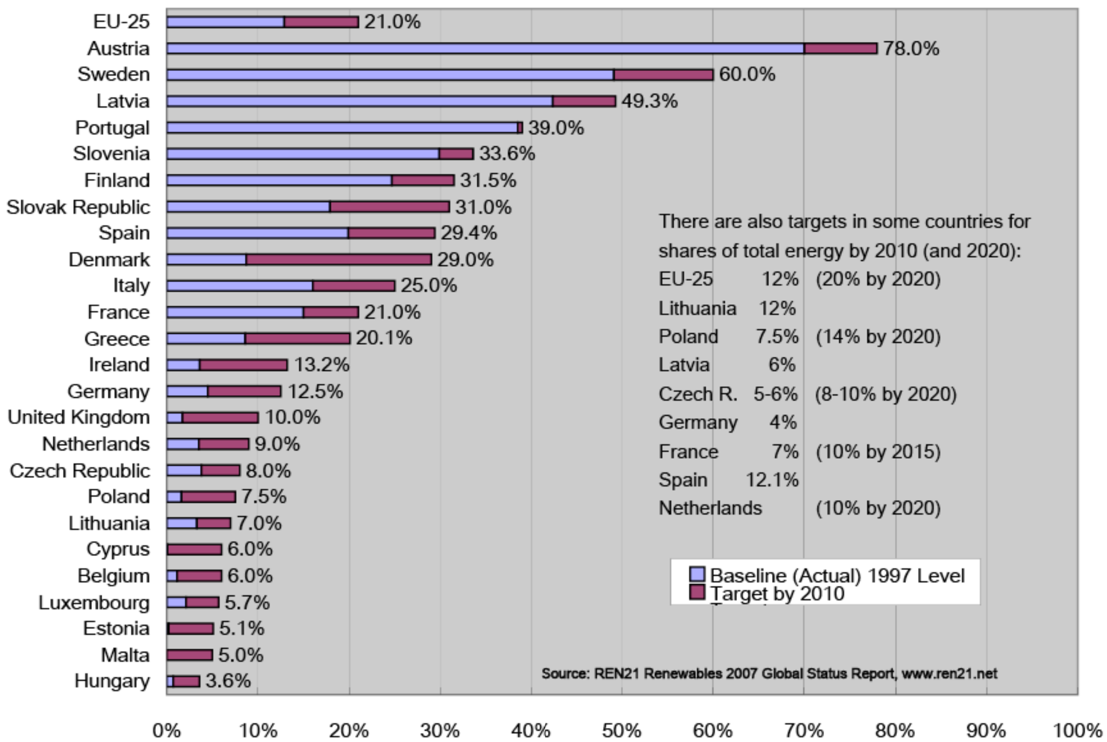


Figure 11: EU Renewable Energy Targets -- Share of Electricity by 2010



Source: REN21 Renewables 2007 Global Status Report, www.ren21.net

Table R8. Share of Electricity from Renewables, Existing in 2006 and Targets

Country/region	Existing share (2006)	Future target
World	18%	—
EU-25	14%	21% by 2010
Selected EU Countries		
Austria	62%	78% by 2010
Belgium	2.8%	6.0% by 2010
Czech Republic	4.2%	8.0% by 2010
Denmark	26%	29% by 2010
Finland	29%	31.5% by 2010
France	10.9%	21% by 2010
Germany	11.5%	12.5% by 2010
Greece	13%	20.1% by 2010
Hungary	4.4%	3.6% by 2010
Ireland	10%	13.2% by 2010
Italy	16%	25% by 2010
Luxembourg	6.9%	5.7% by 2010
Netherlands	8.2%	9.0% by 2010
Poland	2.6%	7.5% by 2010
Portugal	32%	45% by 2010
Slovak Republic	14%	31% by 2010
Spain	19%	29.4% by 2010
Sweden	49%	60% by 2010
United Kingdom	4.1%	10% by 2010

Country/region	Existing share (2006)	Future target
Other Developed/OECD Countries		
Australia	7.9%	—
Canada	59%	—
Israel	—	5% by 2016
Japan*	0.4%	1.63% by 2014
Korea	1.0%	7% by 2010
Mexico	16%	—
New Zealand	65%	90% by 2025
Switzerland	52%	—
United States	9.2%	—
Developing Countries		
Argentina*	1.3%	8% by 2016
Brazil*	5%	—
China	17%	—
Egypt	15%	20% by 2020
India	4%	—
Malaysia	—	5% by 2005
Morocco	10%	20% by 2012
Nigeria	—	7% by 2025
Pakistan	—	10% by 2015
Thailand	7%	—

Table R12. Biofuels Blending Mandates

Country	Mandate
Australia	E2 in New South Wales, increasing to E10 by 2011; E5 in Queensland by 2010
Argentina	E5 and B5 by 2010
Bolivia	B2.5 by 2007 and B20 by 2015
Brazil	E22 to E25 existing (slight variation over time); B2 by 2008 and B5 by 2013
Canada	E5 by 2010 and B2 by 2012; E7.5 in Saskatchewan and Manitoba; E5 by 2007 in Ontario
China	E10 in 9 provinces
Colombia	E10 existing; B5 by 2008
Dominican Republic	E15 and B2 by 2015
Germany	E2 and B4.4 by 2007; B5.75 by 2010
India	E10 in 13 states/territories
Italy	E1 and B1
Malaysia	B5 by 2008
New Zealand	3.4 percent total biofuels by 2012 (ethanol or biodiesel or combination)
Paraguay	B1 by 2007, B3 by 2008, and B5 by 2009
Peru	B5 and E7.8 by 2010 nationally; starting regionally by 2006 (ethanol) and 2008 (biodiesel)
Philippines	B1 and E5 by 2008; B2 and E10 by 2011
South Africa	E8-E10 and B2-B5 (proposed)
Thailand	E10 by 2007; 3 percent biodiesel share by 2011
United Kingdom	E2.5/B2.5 by 2008; E5/B5 by 2010
United States	Nationally, 130 billion liters/year by 2022 (36 billion gallons); E10 in Iowa, Hawaii, Missouri, and Montana; E20 in Minnesota; B5 in New Mexico; E2 and B2 in Louisiana and Washington State; Pennsylvania 3.4 billion liters/year biofuels by 2017 (0.9 billion gallons)
Uruguay	E5 by 2014; B2 from 2008-2011 and B5 by 2012

Table 3. Selected Cities with Renewable Energy Goals and/or Policies

City	Renewable energy goals	CO_2 reduction goals	Policies for for solar hot water	Policies for solar PV	Urban planning, pilots, and other policies
Adelaide, Australia	✓	✓			✓
Austin (Texas), USA	✓	✓			✓
Barcelona, Spain			✓		
Berlin, Germany		✓	✓	✓	
Betim, Brazil		✓	✓		✓
Cape Town, South Africa	✓	✓			✓
Chicago, USA	✓				
Daegu, Korea	✓	✓			✓
Freiburg, Germany	✓	✓	✓	✓	✓
Gwangju, Korea	✓	✓			✓
The Hague, Netherlands		✓			
Leicester, UK	✓				✓
London, UK		✓			
Malmö, Sweden		✓			✓
Melbourne, Australia	✓	✓			✓
Mexico City, Mexico				✓	✓
Minneapolis, USA	✓				✓
Nagpur, India		✓	✓	✓	
New York, USA		✓		✓	✓
Oxford, UK	✓	✓	✓	✓	✓
Portland, United States	✓	✓	✓	✓	✓
Rizhao, China			✓	✓	
Salt Lake City, USA	✓	✓			✓
Santa Monica, USA	✓				✓
São Paulo, Brazil			✓		
Sapporo, Japan		✓			✓
Stockholm, Sweden	✓	✓			✓
Toronto, Canada		✓			
Tokyo, Japan	✓		✓	✓	✓
Townsville, Australia			✓	✓	
Vancouver, Canada		✓			
Växjö, Sweden	✓	✓	✓	✓	✓
Woking, UK	✓	✓	✓	✓	✓

Global Scenarios for Renewable Energy and Carbon Mitigation

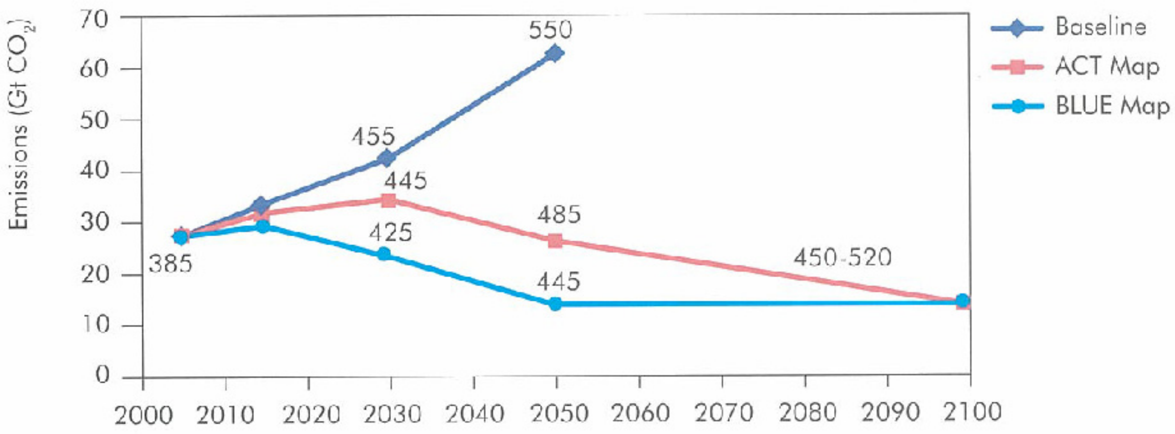
- Existing ***carbon-constrained scenarios*** show trade-offs between levels of renewables, nuclear, and coal with carbon capture and storage (CCS), all under accelerated energy efficiency improvements to keep demand growth at minimum.

- Many global energy scenarios are based on stabilization of atmospheric CO2 concentration at 450 ppm, 500 ppm, or 550 ppm by 2050.

- IEA "Energy Technology Perspectives" (2008) shows "Blue Map" scenario that achieves 450 ppm stabilization by 2050.

> *IEA ETP (2008) "Electricity will play an increasing role as a CO2-free energy carrier. The near elimination of CO2 emissions in the power sector is the cornerstone of achieving deep CO2 emissions worldwide. …To cope with increasing amounts of variable renewables, electricity grids will need to be improved and electricity storage technologies will need to be deployed on a larger scale. …Decarbonizing the transport sector is a major challenge. ...Biofuels, electricity from the grid, and cleanly [produced] hydrogen are the three CO2-free energy carriers that can be used."*

Figure 1.1 ▶ Energy-related CO_2 emission and CO_2 concentration profiles for the Baseline, ACT Map and BLUE Map scenarios



Note: Figures refer to CO_2 concentrations by volume (ppm CO_2).

Key point

Only the BLUE Map scenario is consistent with a long-term stabilisation at 450 ppm CO_2.

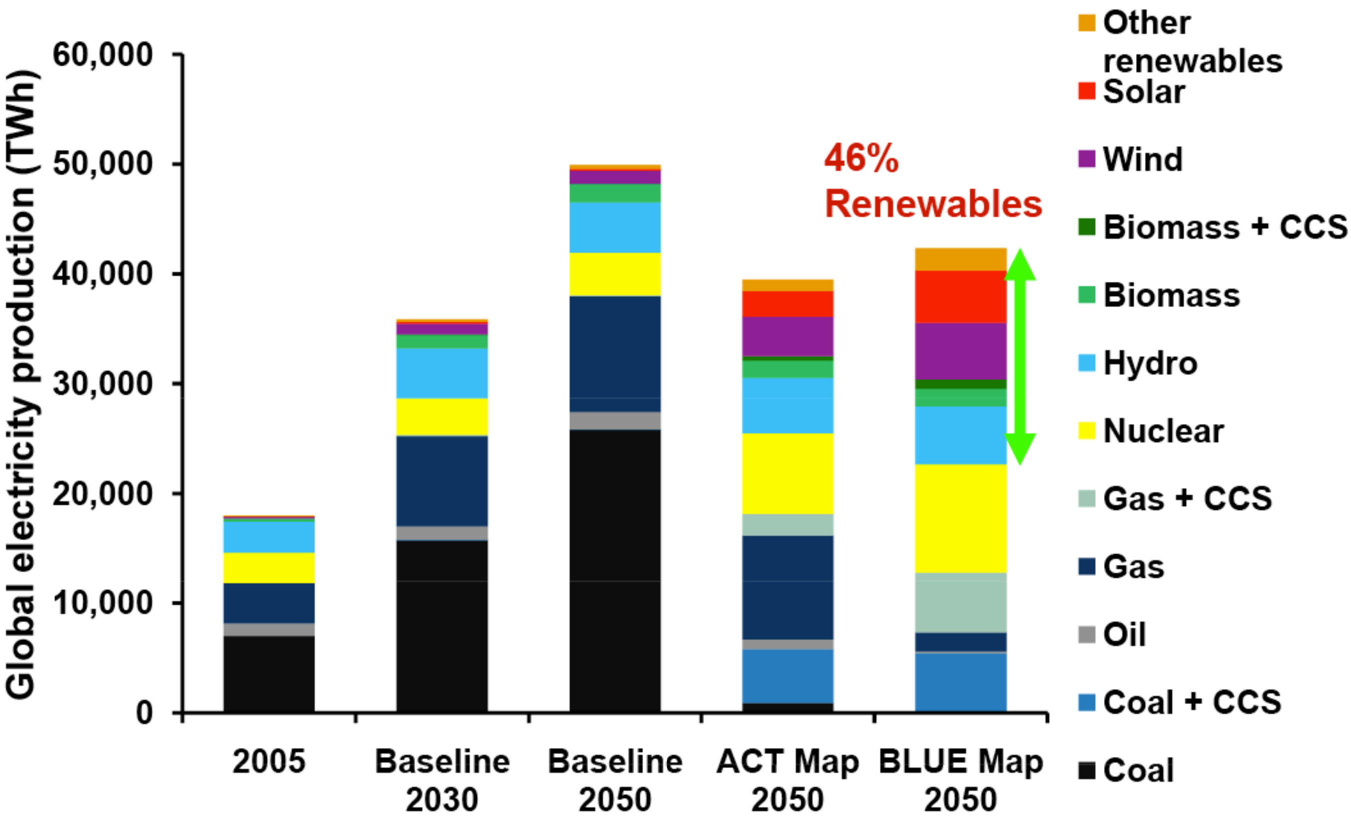
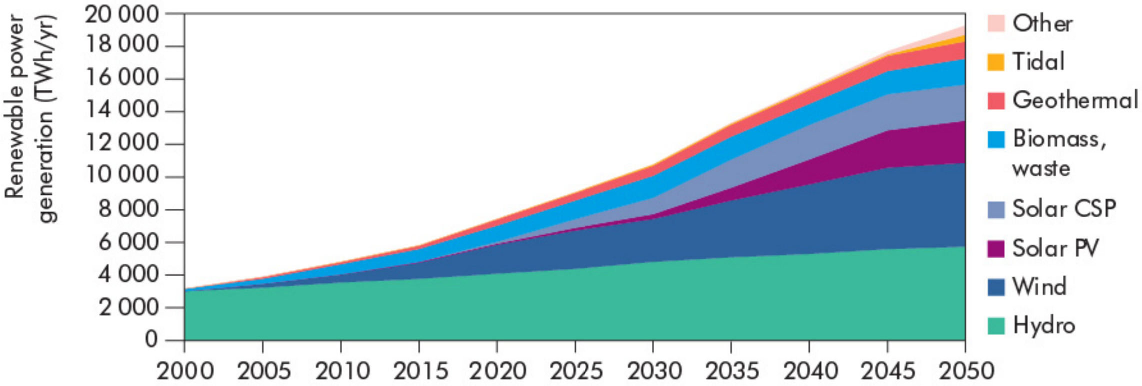


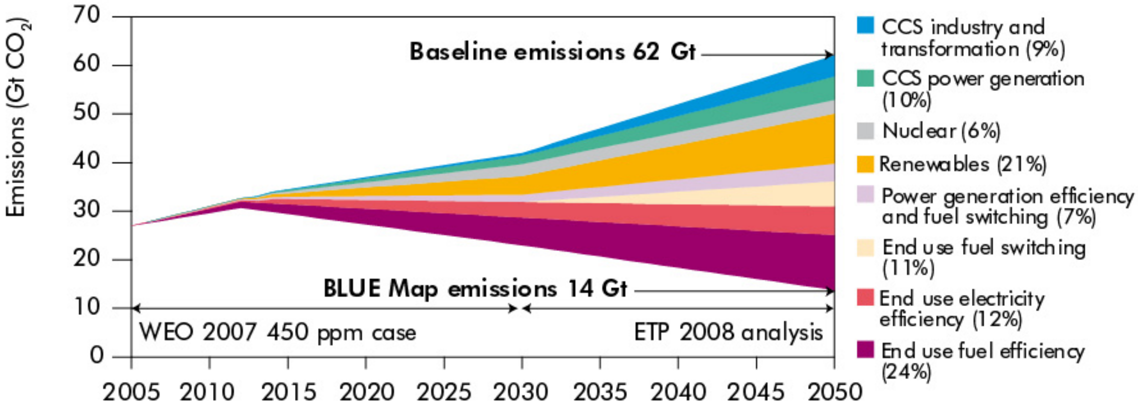
Figure 2.18 ▶ **Growth of renewable power generation in the BLUE Map scenario, 2000-2050**



Key point

There is a very strong growth of different renewables options in BLUE Map.

Figure ES.2 ▶ **Comparison of the *World Energy Outlook 2007* 450 ppm case and the BLUE Map scenario, 2005-2050**



Global Scenarios for Renewable Energy and Carbon Mitigation (continued)

- Greenpeace advanced "revolution" scenario (2008): renewables 77% of electricity by 2050.
- Global Wind Energy Council (GWEC) advanced scenario: wind power provides 20-25% of global electricity by 2030, using growth rates much less than current growth.
- My own review of dozens of global scenarios for renewable energy in 2007 showed a 10-50% share of primary energy by 2050, with many policy-intensive scenarios projecting 40-50%. European policy-intensive scenarios project 45% to 60% by 2030. (Global CO2 emissions vary from 10 to 100 Gt by 2050 across the range of scenarios reviewed.)
- Distributed generation (DG), including solar PV, biomass and biogas power, small wind: most scenarios do not envision a large role, but one group of European experts estimated 30% of total electricity in the EU from DG by 2020.
- Distributed solar PV provides 30% of global electricity beyond 2040? Some analysts have constructed scenarios based on radical cost reduction in solar PV technology.

figure 0.5: global: electricity generation advanced energy [r]evolution scenario until 2100

COAL POWER PLANTS PHASED OUT BY 2050 (20 YEARS LIFETIME)

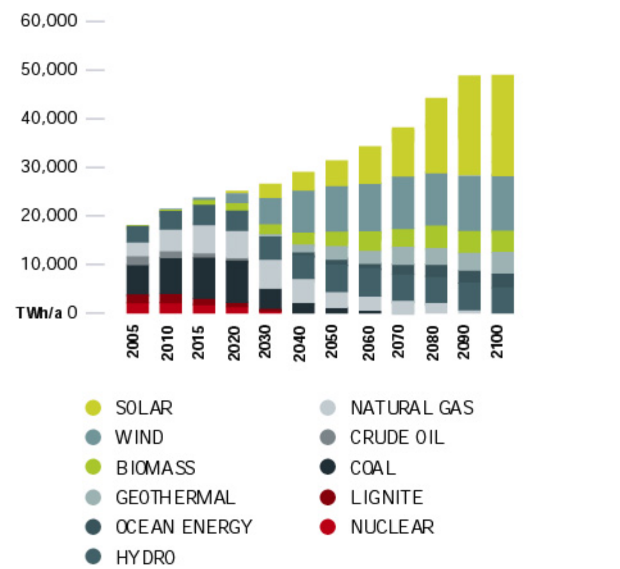


figure 0.7: global: CO_2 emissions advanced energy [r]evolution scenario until 2100

80% GLOBAL CO_2 REDUCTION BY 2075

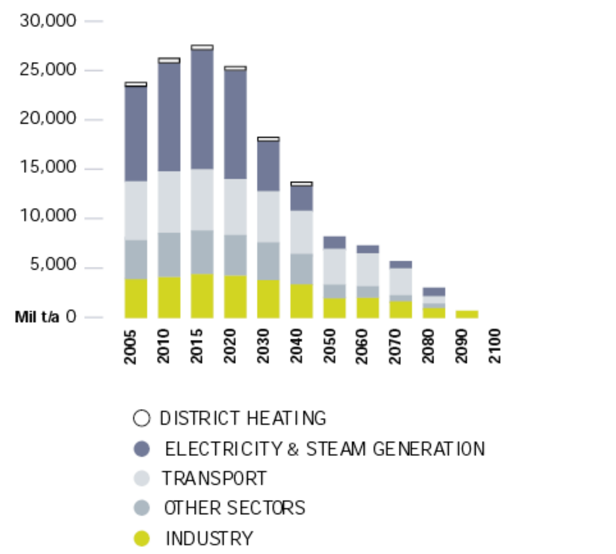


Table 2 Share of primary energy from renewables—policy targets and scenarios[a]

Region/ country	2004 actual[b]	2010 policy targets[c]	2020 policy targets or scenarios[d]	Up to 2050 scenarios[e]
World	3.8% or 8.2% or 13.0% or 16.5%	—	5%–15% low/reference	10%–15% low/reference
			15%–20% medium	25%–30% medium
			25% high	40%–50% high
Europe (EU25)	6.5%	12%	10% reference/ carbon constrained	15%–20% reference (by 2030)/carbon constrained
			20% target	30%–40% policies (by 2030)
			23% revolution	50% revolution
United States	4.2%	—	7% reference	8% reference
			20% revolution	50% revolution

Table 3 Share of electricity from renewables—policy targets and scenarios[a]

Region/ country	2005 actual[b]	2010 policy targets	2020 scenarios or policy targets[c]	Up to 2050 scenarios[d]
World	19%	—	15%–20% low/reference	15%–25% low/reference
			20%–25% medium	30%–40% medium
			35%–40% high	50%–80% high
Europe[e] (EU25)	14%	21%	15%–20% reference	20%–25% reference (by 2030)
			25% carbon constrained	30% carbon constrained
			30% policies	45%–60% high (by 2030)
			35% revolution	70% revolution
United States[f]	8%	5%–30% state targets	5%–33% state targets	9%–11% reference 11%–15% alternative (by 2030)
			20% advanced and blueprint	50% high[g]
			30% revolution	80% revolution

Low-Carbon Transport: Electric Vehicles, Energy Storage, “Smart Grids”

A New Paradigm: ***Integration of smart power grid technologies with energy storage technologies and electric vehicles will make renewable energy cheaper and viable at large scales, due to five key trends:***

(1) Emergence of energy storage technologies – still costly, but prices expected to decline with economies of scale and technology improvement. Options include:

- Grid-smoothing stationary storage such as vanadium redox flow batteries, high-temperature sodium batteries, compressed air storage, supercapacitors, flywheels.
- Mobile storage in electric vehicles, primarily lithium batteries now under development but possibly including compressed air or hydrogen/fuel cells.
- Thermal heat storage, for building space heating and hot water and industrial process heat. This includes seasonal storage to store heat during summer for use in winter.
- Renewable-embedded storage -- molten salt reservoirs or compressed air -- allow solar thermal power plants to operate as base load with higher economic value.

(2) The evolution of power systems, from centralized to distributed and from dumb to smart

- “Smart grids” allow electricity customers to be micro-generators and/or provide system balancing and stability. Two-way communication and real-time demand and pricing signals take place between interconnected elements of the power system.
- Electric vehicles supply peak power and soak up (“follow”) variable renewable power.

Low-Carbon Transport: Electric Vehicles, Energy Storage, “Smart Grids”

(3) The paradigm-changing concept that “load follows supply” on a power grid (i.e., the loads know about the supply situation and adjust themselves as supply changes).

- Electric vehicles can represent a variable-demand component of the power system that can adjust itself, automatically within pre-established parameters, according to prevailing supply conditions, from variable renewable power. With enough vehicles connected, total demand can shift significantly in response to variable output from even large installations of variable renewables.

(4) The institutional and technical interconnection of the electric power and transport systems, really for the first time in history.

- Never before have the transport and electric power industries had any significant common ground or reason to interact, commercially and institutionally speaking. In the future, there need to be new forms of interaction and new management structures.

(5) Changing institutional and managerial role of (local) power distribution companies.

- Historical role to ensure that customers are served with adequate capacity.
- May become “power managers” who balance distributed generation and variable loads and sources, as well as foster end-use energy efficiency.
- New regulation and business models needed to ensure all this happens efficiently.

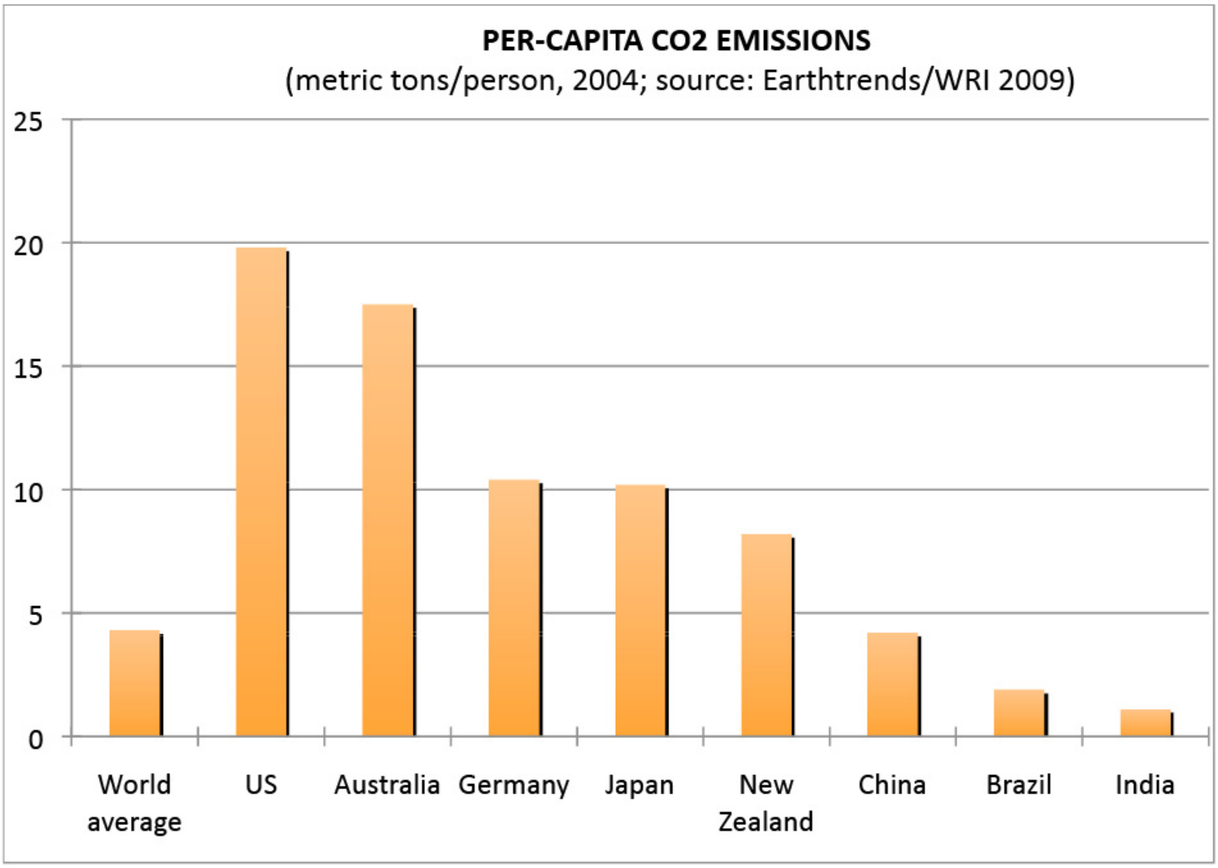
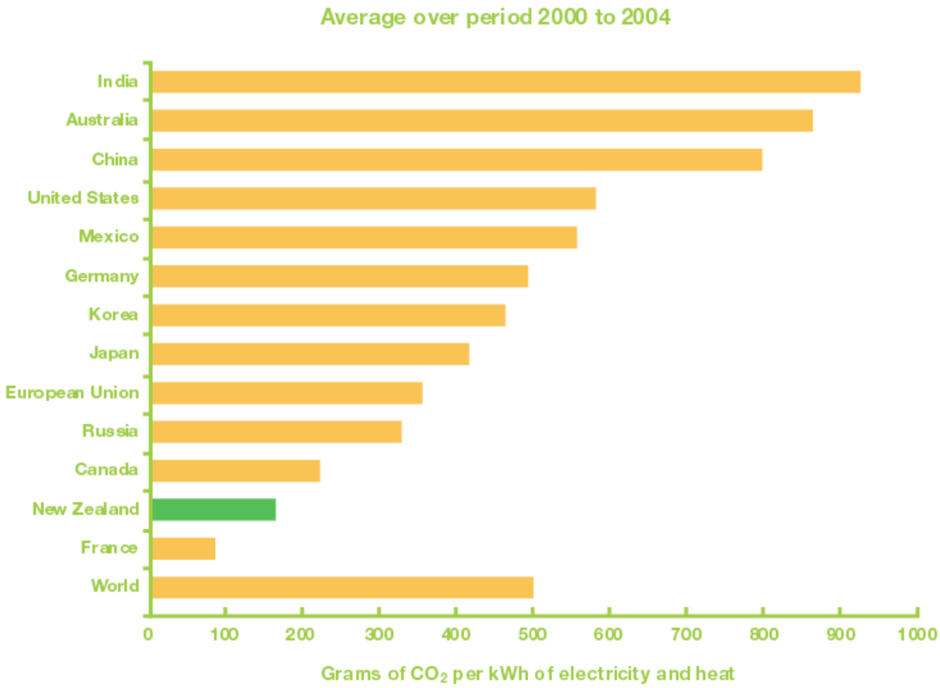
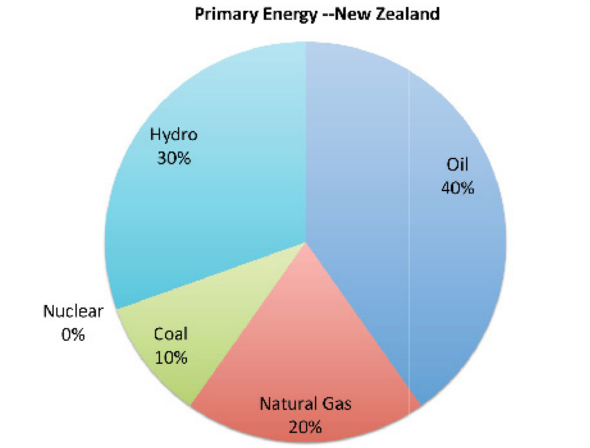
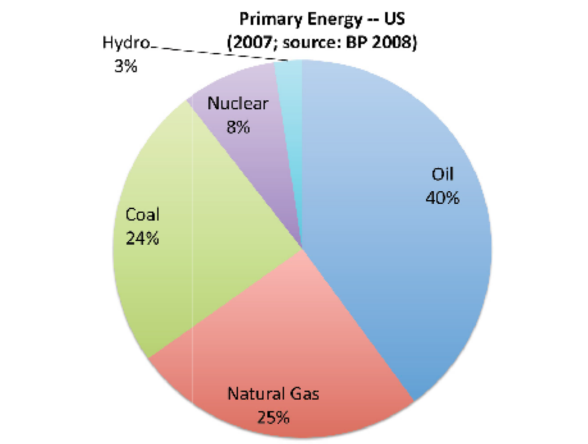


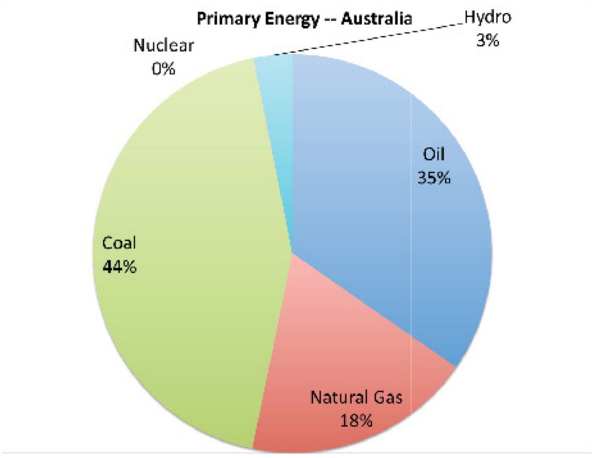
Figure 5.8: Carbon intensity of electricity generation



Source: International Energy Agency







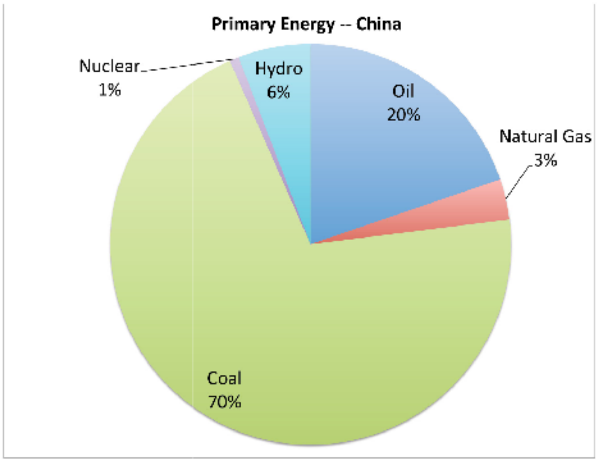


figure 20: new zealand: development of CO_2 emissions by sector under the reference scenario

('EFFICIENCY' = REDUCTION COMPARED TO THE REFERENCE SCENARIO)

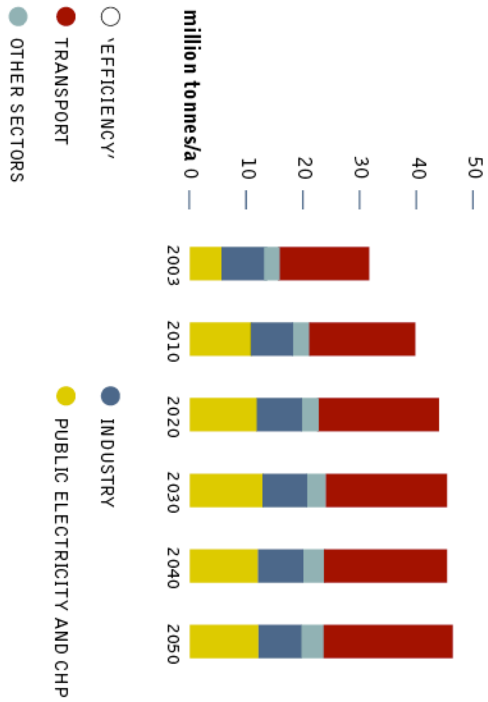
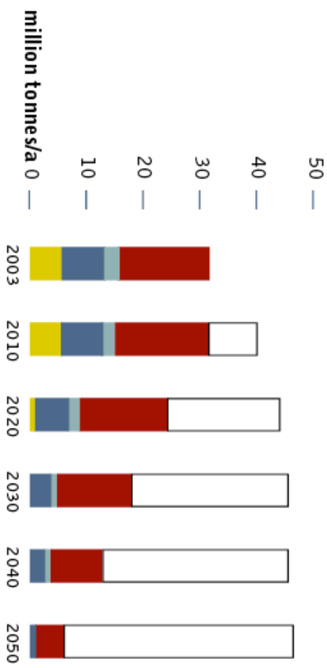


figure 21: new zealand: development of CO_2 emissions by sector under the energy revolution scenario

('EFFICIENCY' = REDUCTION COMPARED TO THE REFERENCE SCENARIO)



Technologies, Policies and Transitions for NZ – How Far and How Fast? (1)

Technology Priorities

1. Wind power
2. Electric vehicles for large-scale energy storage and peak-power capacity
3. Pumped hydro storage
4. Geothermal power
5. Solar hot water and other end-use building efficiency
6. Biogas for small-scale power generation, cooking, heating
7. Solar electricity (PV)
8. Other forms of grid-based storage like vanadium redox flow batteries

- Wind power should be centerpiece of a renewables strategy
  - Currently consented and/or in pipeline: 900 MW
  - Greenpeace "revolution" scenario: 2200 MW by 2020
  - My own view: 4000 MW by 2025 – few better places exist in the world
  - At higher penetrations (> 25-35%), storage and smart grids become important
  - Resource consents and social acceptance still major issues – but farmers like wind farms for the extra revenue
  - Balance wind geographically around the country to reduce variability
  - No reason to site wind turbines near population centers when so many remote windy slopes are available, although costs may be higher due to transmission line costs and sub-optimal wind resources away from visible ridge tops.

figure 13: new zealand: growth of renewable electricity generation under the energy revolution scenario, by source

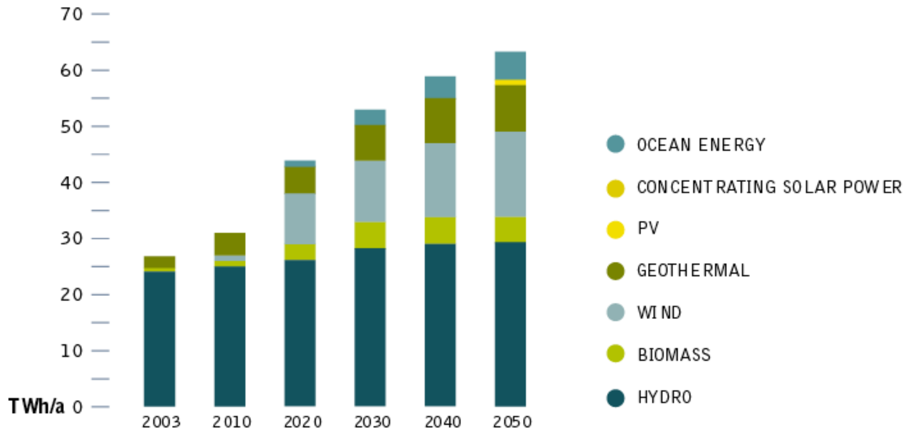


table 4: new zealand: projection of renewable electricity generation capacity under the energy revolution scenario

IN MW

	2003	2010	2020	2030	2040	2050
Hydro	5,222	5,501	5,707	5,922	6,079	6,108
Biomass	184	174	440	768	881	1,007
Wind	38	353	2,272	2,922	3,421	3,895
Geothermal	406	584	824	923	1,118	1,231
PV	0	0	0	71	286	436
Ocean energy	0	0	106	596	787	1,106
Total	**5,850**	**6,612**	**9,349**	**11,202**	**11,572**	**13,783**

Technologies, Policies and Transitions for NZ – How Far and How Fast? (2)

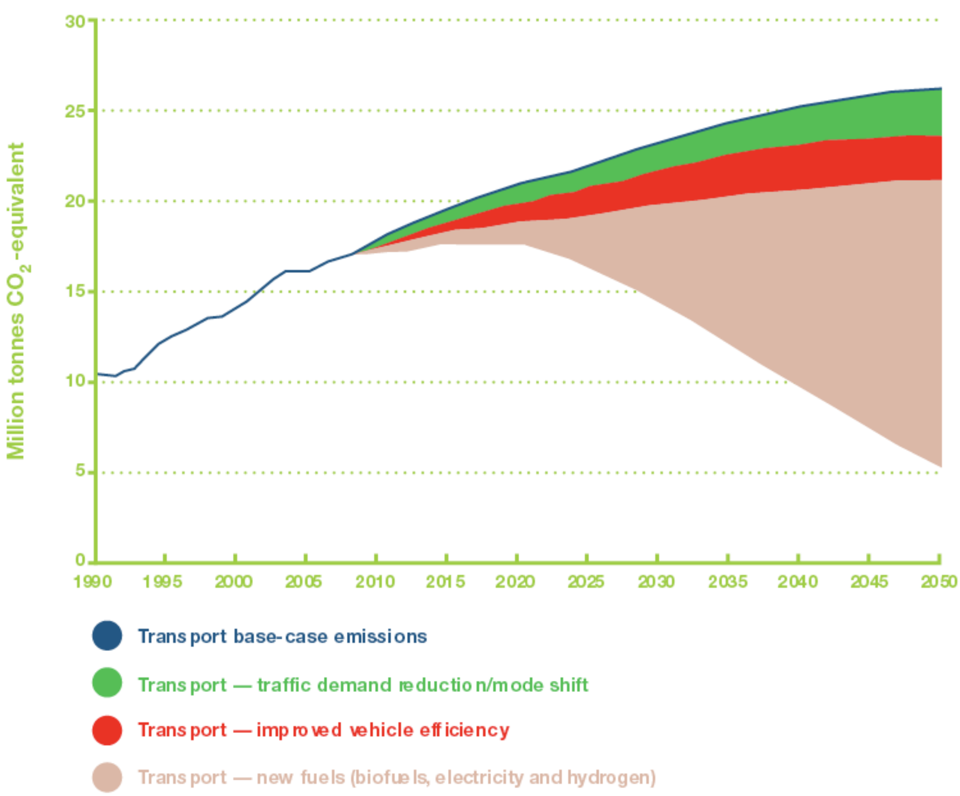
  - So far, only the easiest and cheapest wind sites developing, which can't continue – all good reasons for policies to strongly support wind power!

- Electric vehicles are the most important aspect of carbon reductions in transport
  - Costs still higher than conventional vehicles and performance much less, and major technology improvements, especially for batteries, are needed (but likely)
  - Consider 1.5 million electric vehicles could cut carbon emissions from transport in half, while providing 75 GW of peak power capacity (vs. current NZ grid total of 9 GW), and provide 20 GWh of power storage – enough to run NZ for 5 hours.
  - Very important: need policy and smart power management to integrate renewables so that vehicle charging (day or night) comes from renewables as the marginal generation source – the charging load must "follow" renewables supply. This is unlikely to happen under the current electricity market structure. Also depends on battery technology development towards fast charge times, which enables the load to more quickly follow supply and only charge when appropriate.

- Pumped hydro difficult, requires specific topography for reservoirs, faces RMA hurdles and higher costs than normal hydro. Good sites must be identified. How much is viable?

- A national strategy for biogas coupled with a feed-in tariff could enable many farms to make biogas from animal wastes and produce electricity – a good side-business

Figure 5.3: Emissions reduction opportunities in the transport sector



Technologies, Policies and Transitions for NZ – How Far and How Fast? (3)

Policy Priorities

- Carbon emissions trading system: a good start, but probably not enough to promote rapid change. Carbon price of $50/tonne CO2 could add at least 2 cents/kWh to coal power price
- Feed-in tariff or renewables portfolio standard (RPS) – might require changes to electricity market structure and rules. Not clear how these policies could operate under current structure.
- Full benefits from distributed generation and end-use energy-efficiency savings (i.e., from solar PV, biogas, small-scale wind, solar hot water, and residential end-use energy efficiency improvements) will require non-trivial changes to the structure and rules of NZ's electricity market.
- Capital subsidies for solar hot water: 15% in NZ vs. 30-50% in many other countries. Also need policies to explicitly target "market transformation" of solar hot water industry (especially sales and installation) to reduce costs and improve quality
- Demand growth must be kept close to zero through end-use efficiency improvements (Greenpeace "revolution" scenario)

Technologies, Policies and Transitions for NZ – How Far and How Fast? (4)

NZ's 20-Year Transition

- World could achieve 50-70% electricity from renewables by 2040 with major increases in energy storage, including electric vehicles, and continued rapid growth driven by policy until costs become fully competitive
- NZ should achieve 100% electricity from renewables by 2030 and be approaching full use of electric vehicles in transport, powered from renewable electricity
- NZ is in best position to serve as model and inspiration to the rest of world for using renewables and electric vehicles and for reducing carbon by 50-80% from 1990 levels.

Count me personally as a partner in making it happen!