International Energy Agency

WORLD ENERGY OUTLOOK 2012

RENEWABLE ENERGY OUTLOOK

Renewable energy outlook

A shining future?

Highlights

- Renewables make up an increasing share of primary energy use in all scenarios in *WEO-2012*, thanks to government support, falling costs, CO_2 pricing in some regions, and rising fossil fuel prices in the longer term. In the New Policies Scenario, electricity generation from renewables nearly triples from 2010 to 2035, reaching 31% of total generation. In 2035, hydropower provides half of renewables-based generation, wind almost one-quarter and solar photovoltaics (PV) 7.5% (even though solar PV generation increases 26-fold from 2010-2035).

- Biofuels use more than triples in the New Policies Scenario, from 1.3 million barrels of oil equivalent per day (mboe/d) in 2010 to 4.5 mboe/d in 2035, driven primarily by blending mandates. Ethanol remains the dominant biofuel, with supply rising from 1 mboe/d in 2010 to 3.4 mboe/d in 2035. Biofuels meet 37% of road transport demand in 2035 in Brazil, 19% in the United States and 16% in the European Union.

- Our assessment indicates that global bioenergy resources are more than sufficient to meet projected demand without competing with food production, although the land-use implications will have to be managed in a sustainable manner. As policy goals exceed the production capacity in some regions, international trade of solid biomass for power generation and biofuels for transport increases about six-fold, driven by imports to the European Union, Japan and India.

- Investment in renewables of $6.4 trillion is required over the period 2012-2035. The power sector accounts for 94% of the total – including wind ($2.1 trillion), hydro ($1.5 trillion) and solar PV ($1.3 trillion) – with the remainder in biofuels. Investment in OECD countries accounts for 48% of the total, focusing mainly on wind and solar PV, while in non-OECD countries most investment is in hydro and wind.

- Renewable energy subsidies jumped to $88 billion in 2011, 24% higher than in 2010, and need to rise to almost $240 billion in 2035 to achieve the trends projected in the New Policies Scenario. Cumulative support to renewables for power generation amounts to $3.5 trillion, of which over one-quarter is already locked-in by commitments to existing capacity (and about 70% is set to be locked-in by 2020). While vital to growth of the industry, subsidies for new renewables capacity need to be reduced as costs fall to avoid them becoming an excessive burden on governments and end-users.

- The deployment of renewables in the New Policies Scenario reduces CO_2 emissions by over 4.1 Gt in 2035, contributes to the diversity of the energy mix, lowers oil and gas import bills, cuts local air pollution and, in most cases, reduces stress on water resources.

Recent developments

The use of renewable energy, including traditional biomass,[1] was 1 684 million tonnes of oil equivalent (Mtoe) in 2010, accounting for 13% of global primary energy demand. This share has remained steady since 2000, but with changing contributions of the different renewable sources. The share of traditional biomass out of total renewable energy fell from 50% in 2000 to 45% in 2010, while biofuels (transport fuels produced from biomass feedstocks) met a growing share of transportation fuel needs. Hydropower, the largest source of renewables-based electricity, remained stable. Electricity generation from wind grew by 27% and solar photovoltaics (PV) by 42% per year on average during this period. The renewables sector has not been immune to the recent global economic crisis, but weaker performance in some regions, for example, in parts of Europe and the United States, was largely offset by strong growth in the rest of the world, notably Asia.

Government policies have been essential to recent growth in renewable energy, especially in the power sector. Environmental concerns have been a key policy driver, targeting emissions reductions of carbon dioxide (CO_2) and local pollutants. Renewables have also been supported to stimulate economies, enhance energy security and diversify energy supply. The main focus has been on the electricity sector, followed by biofuels. In most cases, subsidies have been required as renewables are still more expensive than conventional energy sources. Driven by policies, more than 70 countries are expected to deploy renewable energy technologies in the power sector by 2017 (IEA, 2012).

The United Nations recently launched its Sustainable Energy for All initiative, which calls for a global target of doubling the share of renewable energy by 2030 (along with targets to ensure universal access to modern energy and to double the rate of energy efficiency improvements); the IEA is working with the United Nations to define the baseline for this target and monitor progress. The most significant shift in renewables policy in the last year occurred in Japan, where support has been sharply increased to promote additional renewables capacity and generation to compensate for lower nuclear power output. Recent developments in Japan and other major countries are summarised below.[2]

In 2009, the European Union released the Renewable Energy Directive, which set legally binding targets for the share of renewable energy (covering electricity, heat and biofuels) in gross final energy consumption of each member state by 2020, equating to 20% in total. To ensure that their targets are met, each country is required to prepare an action plan and provide regular progress reports. Renewable energy is expected to continue to be central to EU energy policy beyond 2020. A recent European Commission report indicated that renewable energy could meet 55-75% of final energy consumption by 2050, compared with less than 10% in 2010 (EC, 2011; EU, 2011).

1. Traditional biomass comprises wood, charcoal, crop residues and animal dung mainly used mainly for heating and cooking.

2. Information about other countries can be found in IEA (2012) and in the IEA's Policies and Measures Database: *www.iea.org/policiesandmeasures/renewableenergy/*.

In the United States, both federal and state-level policies push the continued deployment of renewables. Renewable portfolio standards – regulations requiring a specified share of electricity sales from renewables or a minimum amount of renewables capacity – now exist in 29 states and the District of Columbia.[3] The Clean Energy Standard Act of 2012, currently being considered by the US Congress, would set the first nation-wide targets for clean electricity, defined as that produced from renewables, nuclear power and gas-fired generation. The Renewable Fuel Standard, adopted in 2005 and extended in 2007, mandates 36 billion gallons (136 billion litres) of biofuels to be blended into transportation fuel by 2022. The US Environmental Protection Agency (EPA) gave approval in June 2012 for retailers to sell fuel blends containing 15% ethanol (E15), compared with 10% (E10) commonly sold today, creating an opportunity for greater biofuels use. The United States also provides tax incentives (credits, rebates and exemptions), grants and loans to support the growth of renewables. Production tax credits for wind power, biodiesel and advanced biofuels are set to expire at the end of 2012, though extensions are under debate. Solar tax credits are set to expire in 2016. The future of these tax credits remains uncertain. Ethanol import tariffs were removed in late 2011, increasing competition with domestic biofuels.

Japan's renewable energy policy was reviewed and extended through legislation passed in 2009 and a revised Basic Energy Plan in 2010. Following Fukushima Daiichi, Japan released the Innovative Strategy for Energy and the Environment in September 2012, which includes the goal of reducing the role of nuclear power. This would be compensated in part by increasing the deployment of renewable energy. By 2030, the strategy calls for power generation from renewables to triple compared to 2010, reaching about 30% of total generation. In July 2012, Japan launched a new feed-in tariffs system for wind and solar power and other renewables, creating incentives which are among the most generous in the world. Other subsidy mechanisms include investment grants, loans and tax reductions.

In Australia, renewable energy policy focuses mainly on electricity and heat. In 2010, the government set the target of adding 45 terawatt-hours (TWh) of renewables-based electricity and heat by 2020. The target is expected to be met through the issue of renewable energy certificates (tradable certificates of proof that electricity has been generated from an eligible source). In addition, a number of states offer feed-in tariffs for solar PV. Biofuels blending mandates exist in New South Wales and Queensland.

China's renewables policy is laid down in the Renewable Energy Law, passed in 2005 and subsequent amendments. In 2009, China set a target to increase the share of non-fossil energy (nuclear and renewables) in the power sector to 15% by 2020. The 12th Five-Year Plan, covering the period 2011-2015, calls for 70 gigawatts (GW) of additional wind capacity, 120 GW of additional hydropower and 5 GW of additional solar capacity by 2015. An update to the 12th Five-Year Plan, released in July 2012, calls for wind and solar capacity to reach 200 GW and 50 GW respectively by 2020. Targets have been set for the first time for geothermal and marine power. Nine provinces have ethanol-blending mandates of 10%,

3. As of July 2012. Details about incentives at state levels are available at: *www.dsireusa.org*.

supported through production-tax incentives, though incentives for grain-based ethanol were substantially reduced in 2012. A nation-wide diesel fuel blend standard, mandating 5% biodiesel, has been in place since 2011, but on a voluntary basis. It is applied only in Hainan province (USDA, 2011).

In India, the Jawaharlal Nehru National Solar Mission, launched in 2010, is a major policy initiative targeting 20 GW of grid-connected solar power by 2022. The plan also covers off-grid solar power, with special attention on rural electrification, solar lighting and heat (solar water heaters). The main subsidy mechanisms for solar and wind power are feed-in tariffs. The successful expansion of large hydropower, provided for in the country's five-year plan, is uncertain due in part to re-settlement issues. Provisions for small hydro indicate that it will play an increasing role. Non-binding biofuel-blending targets were introduced in 2009, starting at 5% for ethanol and reaching 20% for ethanol and biodiesel by 2017. Current blending targets of 5% are not being met due to high ethanol prices arising from competition for supply from the chemicals and distillery industry.

Brazil relies on capacity tenders to increase renewables-based electricity generation. The ten-year plan for energy expansion through 2020 aims for renewables to account almost 80% of total installed capacity in 2020. This target is expected to be met mainly by hydropower, but also with wind power and biomass. The development of large hydropower projects continues through different programmes. Biofuels is the other major focus of Brazilian renewable energy policy. Mandatory minimum blending levels for ethanol in gasoline were revised down in 2011, from 25% to 20%, because of a reduced sugarcane harvest and record sugar prices in that year. Brazil has had a 5% biodiesel blending mandate since 2010.

Outlook for renewable energy by scenario

The use of renewable energy increases considerably from the 2010 level (1 684 Mtoe) in all scenarios over the *Outlook* period. By 2035, it reaches 3 079 Mtoe in the New Policies Scenario, 2 702 Mtoe in the Current Policies Scenario, and 3 925 Mtoe in the 450 Scenario (Table 7.1). This growth is entirely due to additional supply of modern renewables (all renewables including hydro, except traditional biomass).

Traditional biomass at 751 Mtoe in 2010 falls to 687 Mtoe in the New Policies Scenario, about 650 Mtoe in the 450 Scenario and just under 700 Mtoe in the Current Policies Scenario over the projection period. Despite greater access to modern fuels, many people in non-OECD countries, particularly in sub-Saharan Africa, continue to rely heavily on traditional biomass, essentially for cooking (see Chapter 18). Traditional biomass represents 42% of total primary energy demand in that region in 2035. Its use declines in India and China, as both countries shift towards modern fuels.

In the New Policies Scenario, our central scenario in this *Outlook*, primary energy demand for modern renewables increases from 933 Mtoe in 2010 to 1 459 Mtoe in 2020 and 2 392 Mtoe in 2035, with significant increases across all regions and sectors. Demand increases substantially in the European Union and China, and by 2035, both regions account for 16% of the world's modern renewable energy use. The United States makes up 14% of the total in 2035, boosted by policies to support electricity at the state level and by nation-wide policies mandating large increases in the use of biofuels. In India, demand for modern renewables more than triples between 2010 and 2035.

Table 7.1 ▷ Total primary demand for renewable energy by region and scenario (Mtoe)

			New Policies		Current Policies		450 Scenario	
	1990	2010	2035	2010-35*	2035	2010-35*	2035	2010-35*
OECD	**277**	**443**	**1 005**	**3.3%**	**861**	**2.7%**	**1 393**	**4.7%**
Americas	153	199	461	3.4%	402	2.9%	686	5.1%
United States	100	131	338	3.9%	298	3.3%	522	5.7%
Europe	98	208	423	2.9%	373	2.4%	533	3.8%
Asia Oceania	26	36	121	5.0%	86	3.6%	173	6.5%
Japan	15	18	63	5.2%	39	3.2%	89	6.7%
Non-OECD	**847**	**1 241**	**2 073**	**2.1%**	**1 840**	**1.6%**	**2 500**	**2.8%**
E. Europe/Eurasia	40	47	103	3.2%	84	2.3%	165	5.2%
Russia	26	22	53	3.6%	41	2.6%	101	6.3%
Asia	497	676	1 133	2.1%	955	1.4%	1 412	3.0%
China	211	284	483	2.1%	401	1.4%	629	3.2%
India	140	182	287	1.8%	247	1.2%	335	2.5%
Middle East	2	2	33	11.5%	19	9.1%	68	14.8%
Africa	196	339	483	1.4%	478	1.4%	500	1.6%
Latin America	112	177	322	2.4%	305	2.2%	355	2.8%
Brazil	66	117	210	2.4%	200	2.2%	230	2.8%
World	**1 124**	**1 684**	**3 079**	**2.4%**	**2 702**	**1.9%**	**3 925**	**3.4%**
European Union	74	184	384	3.0%	338	2.5%	481	3.9%

* Compound average annual growth rate.

Note: Includes traditional biomass.

In the New Policies Scenario, global electricity generation from renewable energy sources grows 2.7 times between 2010 and 2035 (Table 7.2). Consumption of biofuels more than triples over the same period to reach 4.5 million barrels of oil equivalent per day (mboe/d) (expressed in energy-equivalent volumes of gasoline and diesel), up from 1.3 mboe/d in 2010. Almost all biofuels are used in road transport, but the consumption of aviation biofuels make inroads towards 2035. The use of modern renewables to produce heat almost doubles, from 337 Mtoe in 2010 to 604 Mtoe in 2035. This heat is used mainly by industry (where biomass is used to produce steam, in co-generation and in steel production) but also by households (where biomass, solar and geothermal energy are used primarily for space and water heating). These overall trends are much more pronounced in the 450 Scenario: renewables-based electricity generation supplies almost half the world's electricity in 2035, while biofuel use grows to 8.2 mboe/d – equivalent to 14% of total transport fuel demand.

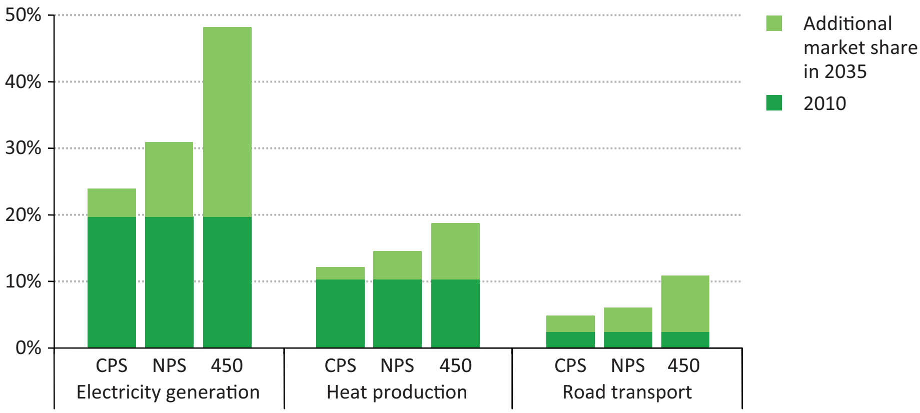
Table 7.2 ▷ World renewable energy use by type and scenario

		New Policies		Current Policies		450 Scenario	
	2010	2020	2035	2020	2035	2020	2035
Traditional biomass (Mtoe)	**751**	**761**	**687**	**764**	**697**	**748**	**653**
Share of total biomass	*59%*	*50%*	*37%*	*51%*	*40%*	*48%*	*29%*
Electricity generation (TWh)	**4 206**	**6 999**	**11 342**	**6 648**	**9 627**	**7 443**	**15 293**
Bioenergy	331	696	1 487	668	1 212	750	2 033
Hydro	3 431	4 513	5 677	4 390	5 350	4 658	6 263
Wind	342	1 272	2 681	1 148	2 151	1 442	4 281
Geothermal	68	131	315	118	217	150	449
Solar PV	32	332	846	282	524	376	1 371
Concentrating solar power	2	50	278	39	141	61	815
Marine	1	5	57	3	32	6	82
Share of total generation	*20%*	*25%*	*31%*	*23%*	*24%*	*28%*	*48%*
Heat demand (Mtoe)	**337**	**447**	**604**	**429**	**537**	**461**	**715**
Industry	207	263	324	258	308	263	345
Buildings* and agriculture	131	184	280	170	229	198	370
Share of total production	*10%*	*12%*	*14%*	*11%*	*12%*	*13%*	*19%*
Biofuels** (mboe/d)	**1.3**	**2.4**	**4.5**	**2.1**	**3.7**	**2.8**	**8.2**
Road transport	1.3	2.4	4.4	2.1	3.6	2.8	6.8
Aviation	-	-	0.1	-	0.1	-	0.8
Other***	-	-	0.0	-	0.0	-	0.6
Share of total transport	*2%*	*4%*	*6%*	*4%*	*5%*	*5%*	*14%*

* Excludes traditional biomass. ** Expressed in energy-equivalent volumes of gasoline and diesel. *** Other includes international bunkers.

In all scenarios, the share of renewables in electricity generation is higher than in heat production or road transport throughout the *Outlook* period (Figure 7.1). In the New Policies Scenario, renewables collectively become the world's second-largest source of electricity generation by 2015 (roughly half that of coal) and by 2035 they approach coal as the primary source of electricity. Between 2010 and 2020, generation from renewables grows 5.2% per year, compared with 3.9% per year between 2000 and 2010.

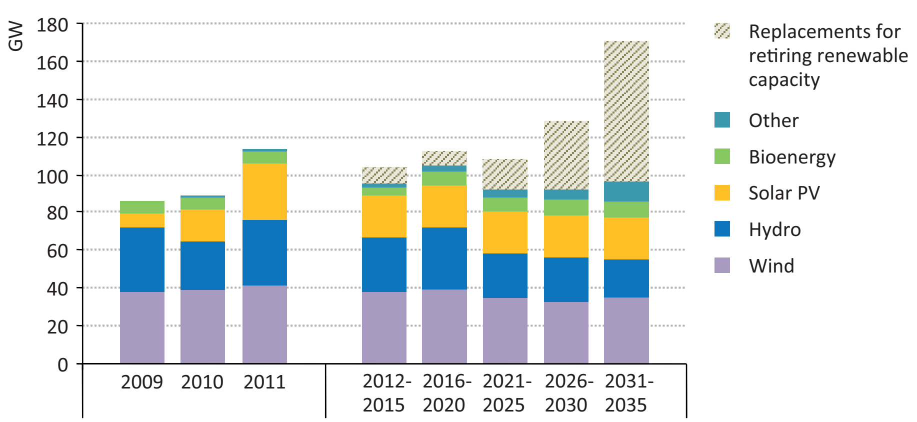
Figure 7.1 ▷ **Share of renewables by category and scenario**



Note: CPS = Current Policies Scenario; NPS = New Policies Scenario; 450 = 450 Scenario.

The global installed capacity of renewable energy sources for electricity production increases from 1 465 GW in 2011 to 3 770 GW in 2035. A total of just over 3 000 GW of renewables capacity, including replacement of older installations, is built from 2012 to 2035 – more than half of total gross capacity additions in the power sector. Replacement for retiring assets amount to 700 GW of capacity over the *Outlook* period, of which 55% is wind, 18% is solar PV, and 15% is hydro. By the end of the *Outlook* period, renewable energy capacity additions exceed 170 GW per year (Figure 7.2).

Figure 7.2 ▷ **World average annual renewables-based capacity additions by type in the New Policies Scenario**



Notes: Net additions plus replacement of retired capacity equals gross capacity additions. Other includes geothermal, concentrating solar power and marine energy.

In 2010, total renewables-based electricity generation was higher in non-OECD countries than in the OECD (Table 7.3). In the New Policies Scenario, total output grows most rapidly in non-OECD countries, though the share of renewables in total generation reaches a higher level in the OECD by the end of the *Outlook* period. In 2035, half of the world's renewables-based electricity comes from hydropower, almost a quarter from wind, 13% from bioenergy and 7.5% from solar PV. Renewables account for 47% of global incremental generation between 2010 and 2035. In the OECD, wind power accounts for about half of the total incremental generation, with the remainder from other renewables, as generation from fossil fuels declines. This leads to a significant change in the electricity mix in the OECD: by 2035, renewables provide one-third of total generation. In non-OECD countries, just over a third of incremental electricity generation is from renewables, taking the total share of renewables generation to 30%. In these countries, hydropower maintains a dominant position, though its share of total generation falls from 20% in 2010 to 17% in 2035, as solar PV and wind power see strong growth.

Table 7.3 ▷ Renewables-based electricity generation by region in the New Policies Scenario (TWh)

	Renewable electricity generation							Share of total generation	
	1990	2010	2015	2020	2025	2030	2035	2010	2035
OECD	**1 339**	**1 960**	**2 493**	**2 963**	**3 444**	**3 936**	**4 436**	**18%**	**33%**
Americas	718	896	1 105	1 297	1 504	1 724	1 953	17%	29%
United States	379	454	600	750	909	1 074	1 238	10%	23%
Europe	472	887	1 138	1 351	1 545	1 734	1 937	24%	44%
Asia Oceania	149	177	250	315	396	477	546	9%	24%
Japan	102	116	161	199	247	292	325	10%	27%
Non-OECD	**977**	**2 245**	**3 038**	**4 037**	**4 904**	**5 851**	**6 906**	**21%**	**30%**
E. Europe/Eurasia	266	309	315	347	391	446	516	18%	22%
Russia	166	170	176	195	224	260	305	16%	21%
Asia	281	1 090	1 688	2 445	3 039	3 663	4 320	17%	27%
China	127	779	1 223	1 789	2 112	2 400	2 689	18%	27%
India	72	136	213	318	466	644	826	14%	25%
Middle East	12	18	28	46	72	119	208	2%	12%
Africa	57	110	141	198	275	374	495	17%	36%
Latin America	361	718	866	1 000	1 127	1 248	1 367	67%	73%
Brazil	211	437	514	585	646	701	754	85%	79%
World	**2 316**	**4 206**	**5 531**	**6 999**	**8 348**	**9 786**	**11 342**	**20%**	**31%**
European Union	310	687	922	1 113	1 285	1 450	1 626	21%	43%

Globally, the production of heat from modern renewables continues to be dominated by bioenergy throughout the projection period. Incentives and obligations for renewables in electricity generation increase the use of bioenergy in combined heat and power production, particularly in OECD countries. Global bioenergy use, excluding traditional biomass, for heat production grows from 294 Mtoe in 2010 to 480 Mtoe in 2035. Solar heat, mainly used in buildings, grows at 5.5% per year from 19 Mtoe to 73 Mtoe over 2010-2035. The largest share of the growth is in China, followed by the European Union and the United States. Geothermal heat, also used mainly in buildings, grows at 7.8% per year from 3 Mtoe in 2010 to 19 Mtoe in 2035.

Outlook by type in the New Policies Scenario

Focus on bioenergy

Demand

Global primary energy demand for bioenergy,[4] excluding traditional biomass, more than doubles from 526 Mtoe in 2010 to nearly 1 200 Mtoe by 2035, growing at an average rate of 3.3% per year. The industrial sector is the largest consumer of bioenergy in 2010 at 196 Mtoe, increasing to over 300 Mtoe in 2035. However, the power sector accounts for a larger share of bioenergy consumption in 2035 (Figure 7.3). Together, these two sectors account for about two-thirds of the additional consumption of bioenergy. Bioenergy consumption to produce biofuels increases by 250% from 2010-2035, reaching almost 210 Mtoe by 2035. The use of traditional biomass declines over time as access to modern fuels increases around the world (see Chapter 18).

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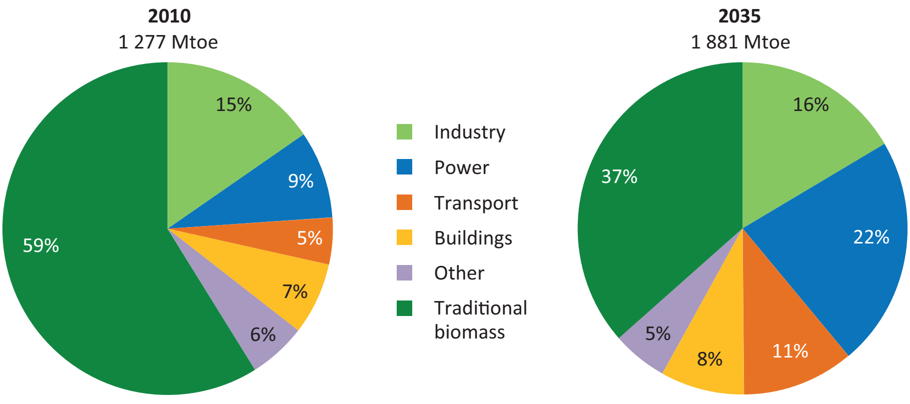
Figure 7.3 ▷ World bioenergy use by sector and use of traditional biomass in the New Policies Scenario, 2010 and 2035



Excluding demand for traditional biomass, primary energy demand for bioenergy is largest in the European Union, rising from 130 Mtoe in 2010 to about 230 Mtoe by 2035, with industrial and residential heat accounting for nearly half of this demand. The United States has the second-highest demand, reaching about 210 Mtoe by 2035, driven mainly by

4. The term bioenergy refers to the energy content in solid, liquid and gaseous products derived from biomass feedstocks and biogas. This includes biofuels for transport and products (*e.g.* wood chips, pellets, black liquor) to produce electricity and heat. Municipal solid waste and industrial waste are also included. Refer to Annex C for further descriptions.

increases in the transport and power sectors. Brazil is also projected to have a thriving biofuel industry over the projection period, bioenergy primary demand reaching about 140 Mtoe in 2035. Bioenergy demand, excluding traditional biomass, in both China and India reaches about half that of the European Union by 2035.

From 2000 to 2010, global electricity generation from bioenergy grew by 6.9% per year, with larger increases in the OECD than in non-OECD countries. The increase in absolute terms was about half that of wind power but more than five times that of solar PV. By 2010, generation from bioenergy reached 331 TWh globally, accounting for over 40% of global non-hydro renewables generation. In the New Policies Scenario, bioenergy generation soars to 1 487 TWh in 2035. Currently, the European Union, United States, Brazil and Japan generate the most electricity from bioenergy. Over the projection period, China surges well ahead of all other regions, generating 325 TWh by 2035. The United States and the European Union generate 259 TWh and 272 TWh from bioenergy respectively in 2035, with India the only other region generating more than 100 TWh.

Bioenergy is also used to produce heat in combined heat and power facilities (such as in industrial co-generation) or stand-alone boilers (in the industrial, residential and services sectors). Global bioenergy consumption for heat in the final consumption sectors grows in the New Policies Scenario from 294 Mtoe in 2010 to about 480 Mtoe in 2035, with industrial demand maintaining its share of about two-thirds of total bioenergy demand for heat throughout the projection period. Opportunities for expanding bioenergy for heat production in non-OECD countries are larger than in the OECD because of their rapid energy demand growth.

The growth of demand for bioenergy for power generation and heat production is driven largely by government policy. In regions that establish a carbon price, some proven bioenergy power generation technologies become competitive with fossil fuel-based power plants during the projection period, particularly combined heat and power, co-firing with coal and waste to energy. Policy interventions, including renewable energy standards and subsidies, contribute to the growth in the demand for bioenergy for power and heat.

In the New Policies Scenario, biofuels increasingly displace oil in transport and start making inroads in aviation over the *Outlook* period. Ethanol continues to be the main biofuel, accounting for about three-quarters of biofuels supply throughout the *Outlook* period, as consumption rises from 1.0 mboe/d in 2010 to 3.4 mboe/d in 2035 (Table 7.4). This increase is due largely by blending mandates for passenger light-duty vehicles (PLDVs). Biodiesel supply increases from 0.3 mboe/d in 2010 to 1.1 mboe/d in 2035. Biodiesel holds potential, particularly in heavy freight transport, where options to replace oil are much more limited than for PLDVs (see Chapter 3); but its use is less widely supported by policy at present and the development of advanced biodiesel is making only slow progress.

The United States remains the largest market for biofuels, with demand rising from 0.6 mboe/d in 2010 to 1.7 mboe/d by 2035. Correspondingly, the share of biofuels in road transport grows from 5% to 19% over the same periods. These increases are driven by both supply- and demand-side policies: a production target of 136 billion litres of biofuel by 2022 and blending mandates contained in the Renewable Fuel Standard.

Table 7.4 ▷ Ethanol and biodiesel consumption by region in the New Policies Scenario (mboe/d)

	Ethanol		Biodiesel		Total biofuels		Share of road transport	
	2010	2035	2010	2035	2010	2035	2010	2035
OECD	**0.6**	**1.7**	**0.2**	**0.8**	**0.8**	**2.5**	**4%**	**13%**
Americas	0.6	1.5	0.0	0.2	0.6	1.7	4%	15%
United States	0.6	1.4	0.0	0.2	0.6	1.7	5%	19%
Europe	0.0	0.2	0.2	0.5	0.2	0.7	4%	13%
Non-OECD	**0.4**	**1.7**	**0.1**	**0.3**	**0.5**	**2.0**	**3%**	**6%**
E. Europe/Eurasia	0.0	0.0	0.0	0.0	0.0	0.1	1%	2%
Asia	0.0	0.7	0.0	0.1	0.1	0.8	1%	4%
China	0.0	0.5	0.0	0.0	0.0	0.5	1%	5%
India	0.0	0.2	0.0	0.0	0.0	0.2	0%	5%
Latin America	0.3	0.9	0.1	0.1	0.4	1.0	12%	22%
Brazil	0.3	0.8	0.0	0.1	0.3	0.9	22%	37%
World	**1.0**	**3.4**	**0.3**	**1.1**	**1.3**	**4.5**	**3%**	**8%**
European Union	0.0	0.2	0.2	0.6	0.2	0.8	4%	16%

Brazil maintains the highest share of renewables in transport in the world through to 2035, reaching about one-third by 2035, following wider adoption of flex-fuel vehicles that can use either gasoline or ethanol. In the European Union, biofuels meet 10% of road transport fuel demand by 2020 (in line with the target set in the renewable directive) and 16% by 2035 – up from 4% in 2010. The United States, European Union and Brazil together accounted for about 90% of global biofuel consumption in 2010, but new markets are expected to emerge over the *Outlook* period, notably China and India, where biofuels meet around 5% of road transport fuel demand in 2035.

Generally, blending rates are expected to increase over time, although not without first overcoming additional challenges. For example, a recent regulation in Germany to move from 5% ethanol blended with gasoline (E5) to 10% (E10) has been met with resistance by consumers, who are concerned about the impact on their car engines. In the United States, the recent decision by the EPA to allow retailers to sell 15% ethanol blended with gasoline (E15) has been met with similar criticism. Across all regions, ethanol remains the main type of biofuel to 2035, although passenger vehicle efficiency improvements – which reduce the overall fuel consumption of the car – have a moderating impact on ethanol demand. This is less of an issue for biodiesel demand, as efficiency improvements in trucks – the main users of biodiesel – are less significant (see Chapter 3).

Growth in biofuels will largely continue to depend on policy support. The limited potential for greenhouse-gas emission savings from some conventional biofuels has raised questions about the benefits of including biofuels in climate mitigation policies, though their potential to reduce oil imports provides another important justification for support in some cases. We assume that the European Union meets its 2020 target by allowing only biofuels that substantially reduce emissions, relative to fossil fuels, to be blended with oil-based fuels. Such restrictions are already in place in the United States, where emissions thresholds have been defined in advance for various types of biofuels.

The pace of development of advanced biofuel technologies also adds uncertainty to biofuels prospects, as targets and accompanying measures are largely absent to date. The United States is currently the only country in the world to have a clear target for the amount of advanced biofuels to be produced. Financial support will be essential to attract investment in technologies to produce advanced biofuels, which are assumed to become commercially available (though not yet competitive with conventional fuels) around 2020 in the New Policies Scenario. By 2035, advanced biofuels make up 18% of total biofuel production. They are mostly used in OECD countries, where they account for 27% of all biofuel use by 2035.

Supply and Trade

Our assessment indicates that global bioenergy resources are more than sufficient to meet projected demand in the New Policies Scenario without competing with food production. In 2035, primary energy demand for bioenergy is nearly 1 900 Mtoe, while we estimate the potential supply to be an order of magnitude higher, similar to other estimates (IPCC, 2011; IEA, 2011a; IIASA, 2012). Potential bioenergy resources are not evenly distributed across regions. Some of the regions with the largest resource potentials are Latin America (especially Brazil), the United States and China. Government policies will be needed to minimise or avoid direct and indirect land use change as a result of expanding biomass feedstock production (Box 7.3).

The global bioenergy supply potential is the aggregate of the supply potentials for several types of feedstocks. Energy crops – those grown specifically for energy purposes, including sugar and starch feedstocks for ethanol (corn, sugarcane and sugar beet), vegetable-oil feedstocks for biodiesel (rapeseed, soybean and oil palm fruit) and lignocellulosic material (switchgrass, poplar and miscanthus) for advanced biofuels – make up the vast majority of this potential.[5] Residues – the leftover materials from harvesting crops and forestry activities, such as corn stover, bagasse from sugarcane and scraps from logging – have the potential to provide over 600 Mtoe of bioenergy, depending largely on the sustainable portion that must remain in the field to replenish soils and maintain future crop yields. Forestry products, grown specifically for energy purposes, contribute somewhat less to the overall bioenergy supply potential.

5. In this assessment, land demand for food crops is given priority and such land is subtracted from total available land before considering use for energy crops.

Box 7.1 ▷ Improvements to the World Energy Model: the bioenergy supply and trade module

A new module was added to the IEA's World Energy Model this year to analyse the supply and trade of bioenergy.[6] It includes 25 regions with detailed representation of bioenergy supply potentials and conversion technology costs for the power sector and biofuel production. In order to meet demand for bioenergy in each sector and region, domestic resources are given priority (after taking account of existing trade) and compete with each other on the basis of conversion costs (including feedstock prices). Regional resources are treated as "bioenergy available for energy purposes", where agricultural demands are met before supplying the energy sector. If domestic bioenergy resources cannot satisfy all demands in a given region, supplementary supplies are obtained on the global market. Regions with available resources beyond food and domestic energy needs supply the global market. The model uses a global trade matrix for ethanol, biodiesel and solid biomass pellets to match unsatisfied demand with available supply on a least-cost basis, including transportation costs. The transition from conventional to advanced biofuels occurs in the model as the economics improve through technological advances and learning, and policies raise demand.

In the New Policies Scenario, all sources of solid biomass supply increase to meet significantly higher demand in the power and transport sectors, however, the shares provided by different feedstocks change over time. Energy crops (sugar-, starch- or oil-based and lignocellulosic crops) provide the largest share of supply until late in the projection period, when residues (forestry and agricultural) provide a slightly larger share (Figure 7.4). This is due to bioenergy demand in the power sector far surpassing demand for biofuels and technology development enabling residues to make inroads as a feedstock for advanced biofuels. By 2035 in the New Policies Scenario, about one-third of the estimated maximum sustainable potential for residues is consumed. The supply of bioenergy from forestry products grows substantially over time, continuing to provide about 10% of solid biomass supply through 2035. In total, solid biomass feedstocks meet about three-quarters of demand for bioenergy in the power and transport sectors throughout the *Outlook*, with the remaining portion met by biogas and waste products.

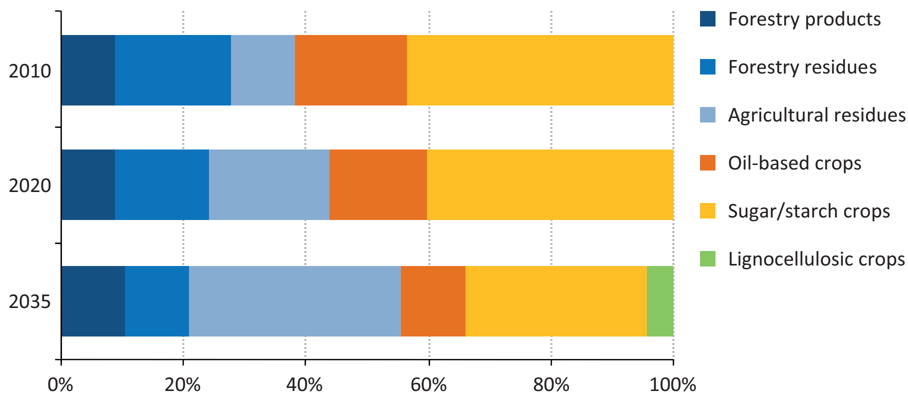
International trade of biofuels and solid biomass for power generation, usually in the form of pellets, accounted for about 7% of demand in the power and transport sectors in 2010.[7] In the New Policies Scenario, trade expands to over 10% of supply, as policy goals exceed some regions' capacity to meet demand with domestic resources, particularly in the European Union and India (Figure 7.5). An increasing share of supply for bioenergy in the

6. For more information on the World Energy Model and this module, see *www.worldenergyoutlook.org.*

7. Biomass pellets, a high-density uniform product, can be made from residues and other feedstocks to facilitate transport over long distances and increase performance in certain applications, such as co-firing.

power sector is met from imports, with inter-regional trade increasing from 6 Mtoe in 2010 to about 40 Mtoe in 2035, or about one-tenth of bioenergy supply in the power sector. The European Union and Japan are projected to be the largest pellet importers, with the United States, Canada and Russia expected to be the major pellet exporters. While playing limited roles in the world market, China, the European Union, India and Brazil also produce large amounts of bioenergy for domestic use in the power sector.

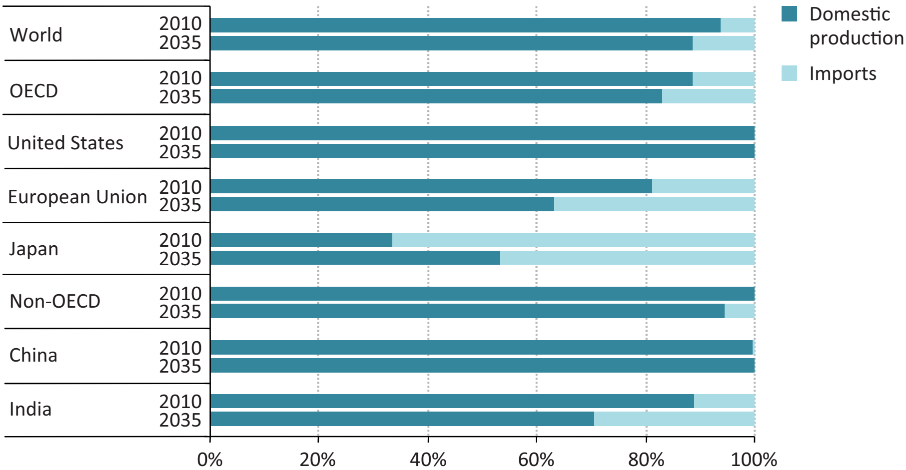
Figure 7.4 ▷ Share of solid biomass supply for biofuels and power generation by feedstock in the New Policies Scenario



Trade of biofuels expands rapidly through the *Outlook* period, from 0.2 mboe/d in 2011 to about 0.9 mboe/d in 2035, or about one-fifth of total biofuel demand. In the New Policies Scenario, the European Union and India are far and away the largest importers of biofuels through 2035. Brazil is set to be the largest exporter of biofuels (mainly ethanol) in the world, with exports approaching 0.2 mboe/d in 2035. Other Latin American countries combined supply a similar volume of biofuels (with more emphasis on biodiesel) to the world market. Indonesia, the ASEAN region, and other non-OECD developing countries in Asia are also set to become large biofuels exporters. Brazil and the United States continue to be the largest producers of biofuels, though nearly all of US production is consumed domestically by the end of the period. China becomes a major biofuels producer over time as production increases sharply to meet growing domestic demand.

The projected growth in bioenergy trade is in line with recent trends. Solid biomass trade, in the form of wood pellets, increased six-fold between 2000 and 2010, with European Union countries accounting for two-thirds of the trade in 2010 (Lamers, 2012). Ethanol and biodiesel were traded mainly between European Union countries in 2011 (REN21, 2012). Ethanol imports to the European Union from countries outside the region are currently limited, but imports of biodiesel are more important, coming mainly from Latin America and Indonesia. Another emerging trend that is set to continue is the growing supply gap for ethanol in Asia (F.O. Licht, 2012). The United States is a major importer of ethanol from Brazil and other countries in Latin America, though it is also an exporter – net imports represent less than 1% of its total ethanol consumption.

Figure 7.5 ▷ **Share of bioenergy demand for biofuels and power generation from domestic production and imports, 2010 and 2035**



Notes: Trade within *WEO* regions is excluded. Aggregates present averages of the relevant *WEO* regions.

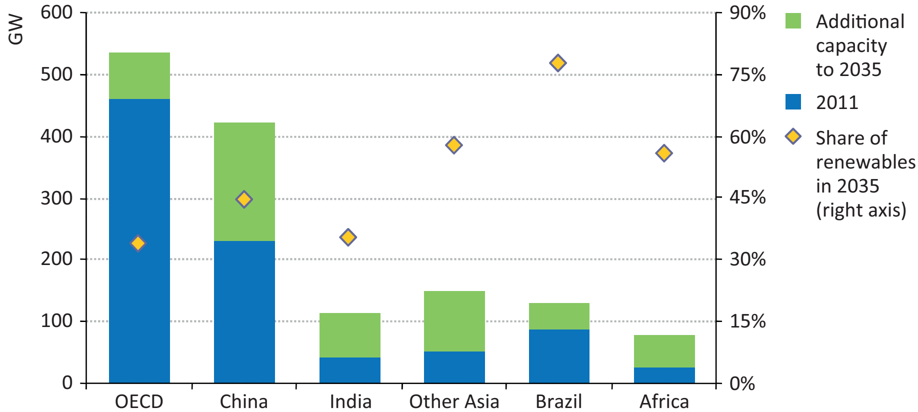
Economic and technical factors tend to limit demand for internationally traded bioenergy. Import and export tariffs, which apply mainly to biofuels, are one factor currently limiting ethanol and biodiesel trade. Lack of infrastructure for handling and transporting biomass, such as processing facilities, port infrastructure or ships, is another important barrier, which could prevent imports and exports increasing fast enough to meet demand. Technical standards need to be developed further, as well as sustainability criteria and certification schemes.

Hydropower

Hydro is currently the largest renewable source for power generation in the world, producing 3 431 TWh and meeting 16% of global electricity needs in 2010. It remains so over the projection period in the New Policies Scenario, with generation reaching 5 677 TWh in 2035, its share in total electricity generation dropping marginally to 15%. Projected growth in hydropower production in OECD countries – where the best resources have already been exploited – is limited. Nearly 90% of the increase in production between 2010 and 2035 is in non-OECD countries, where the remaining potential is higher and electricity demand growth is strongest. Most incremental hydro output is in Asia and Latin America, notably China, India and Brazil.

Global hydropower capacity is projected to increase from 1 067 GW in 2011 to over 1 680 GW in 2035. China's capacity almost doubles, to 420 GW, bringing its total installed hydropower capacity in 2035 close to that of the entire OECD in 2011 (Figure 7.6). Capacity jumps from 42 GW to 115 GW in India, from 89 GW to over 130 GW in Brazil and Africa continues to develop some of its vast hydro potential (Box 7.2).

Figure 7.6 ▷ Installed hydropower capacity in selected regions in the New Policies Scenario



Box 7.2 ▷ Hydropower prospects in Africa

In 2010, 27 GW of installed hydropower capacity in Africa generated 105 TWh, supplying 16% of the continent's electricity. However, only a small fraction of Africa's hydropower potential has been developed (UNEP, 2010; IPCC, 2011). The technical potential has been estimated to exceed 1 800 TWh, located largely in the Republic of Congo, Ethiopia and Cameroon (WEC, 2010). In the New Policies Scenario, hydropower capacity rises to almost 80 GW by 2035, including several projects currently under construction, accounting for over 20% of the continent's total electricity generation.

Several challenges threaten the development of hydropower in Africa, particularly the availability of funding. Political and market risks, as well as local environmental considerations are barriers to securing the large initial investments required. However, opportunities for funding are enhanced by several international programmes, including the Clean Development Mechanism under the Kyoto protocol and a recent G20 initiative promoting investment in developing countries, which identified the Grand Inga project on the Congo River as a possible candidate for funding. Africa's energy needs are huge: 590 million of its people still lack access to electricity (see Chapter 18). Hydropower, both large and small scale, is an abundant source of clean energy that can make a major contribution to providing energy for all.

Wind power

Wind power is set to continue to expand rapidly as it becomes more cost-competitive with conventional sources of electricity generation, driven to a large degree by supportive government policies. In the New Policies Scenario, incremental electricity output from wind is greater than that of any other renewable source. Global generation from wind increases dramatically from 342 TWh in 2010 to around 2 680 TWh in 2035, pushing up its share in total electricity generation from 1.6% to 7.3%. Wind achieves the highest level of market penetration in the European Union, where it accounts for almost one-fifth of electricity generated in 2035, compared with less than 5% in 2010. Growth is also strong in the United States, China and India, in each of which wind reaches a share of 6-8% of electricity supply by 2035.

Wind power capacity worldwide increases from 238 GW in 2011 to almost 1 100 GW in 2035 (Table 7.5). Onshore wind makes up four-fifths of this growth. Offshore wind capacity expands rapidly, from 4 GW in 2011 to 175 GW by 2035, its deployment being underpinned by government support. There are still significant uncertainties about the achievement of cost savings on the required scale through deployment. Despite the cost reductions per unit of electricity produced by 2035, offshore wind costs remain well above wholesale electricity prices in most countries. By then, the European Union and China combined account for two-thirds of installed offshore wind capacity. The growing role of wind (and other variable renewables) underlines the importance of upgrading networks and adding flexible capacity into the power mix in order to maintain the overall reliability of supply.

7

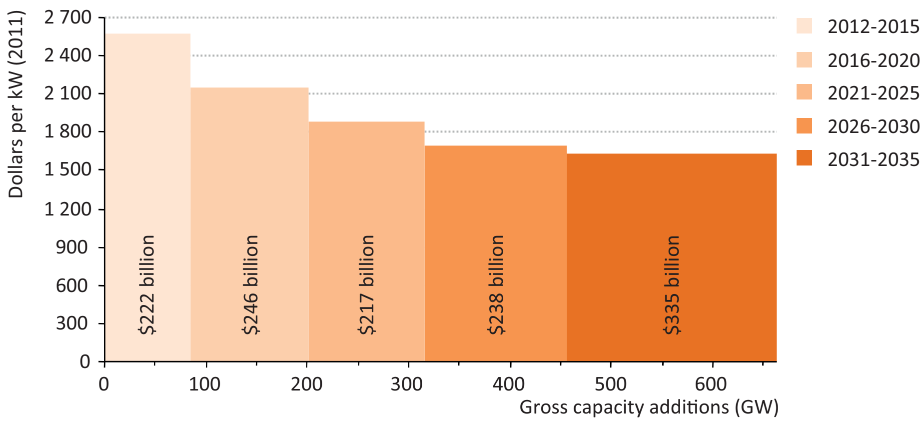
Table 7.5 ▹ Installed onshore and offshore wind power capacity by region in the New Policies Scenario (GW)

	Wind Onshore			Wind Offshore			Total Wind		
	2011	2020	2035	2011	2020	2035	2011	2020	2035
OECD	**150**	**285**	**441**	**4**	**31**	**113**	**154**	**315**	**555**
Americas	53	107	175	-	4	26	53	112	202
United States	47	90	143	-	3	18	47	93	161
Europe	91	161	231	4	24	72	95	184	304
Asia Oceania	6	16	34	0	3	14	6	19	49
Japan	3	8	16	0	2	9	3	9	25
Non-OECD	**84**	**262**	**482**	**0**	**9**	**62**	**85**	**271**	**544**
E. Europe/Eurasia	2	6	16	-	0	3	2	6	19
Asia	79	239	411	0	9	53	79	248	464
China	62	191	280	0	9	46	62	200	326
India	16	44	93	-	-	5	16	44	97
Middle East	0	2	21	-	-	2	0	2	23
Africa	1	4	15	-	-	1	1	4	16
Latin America	2	11	19	-	-	3	2	11	22
World	**234**	**546**	**923**	**4**	**40**	**175**	**238**	**586**	**1 098**
European Union	90	159	218	4	23	70	94	182	288

Solar photovoltaics

Solar PV produced only a small fraction of the world's total electricity in 2010, but installed solar PV capacity has grown rapidly in recent years and is expected to continue to do so in the future. In the New Policies Scenario, electricity generation from solar PV in 2035 is over 26-fold that of 2010, increasing from 32 TWh to 846 TWh. Its share in total generation rises to just over 2% in 2035. Installed solar PV capacity increases from 67 GW in 2011 to just over 600 GW in 2035, thanks to continuing cost reductions and government support (Figure 7.7).

Figure 7.7 ▷ Solar PV gross capacity additions, average unit cost, and resulting investment requirements in the New Policies Scenario



Notes: Gross capacity additions, which include replacements, are shown. In 2035, total global installed capacity of solar photovoltaics reaches some 600 GW. Total investment in each period is indicated vertically on each of the columns (capacity addition times cost per GW). Unit investment costs represent the weighted average of costs throughout all regions, for both large and rooftop installations.

This extremely rapid expansion is in line with recent experience – global solar PV capacity was just 1 GW in 2000. Over the course of 2011, solar PV capacity increased by about 30 GW, a 75% increase. Around 60% of the additions were in Germany and Italy, the world leaders in solar PV, with 25 GW and 13 GW of installed capacity respectively at the end of 2011. The European Union accounts for over three-quarters of global solar PV capacity in 2011. Over the *Outlook* period, EU capacity increases to some 146 GW, accounting for 5% of its electricity generation in 2035 (up from 1% in 2010). In the United States, capacity increases from 4 GW in 2011 to 68 GW in 2035. Other countries with large amounts of solar PV capacity in 2035 are China (113 GW), India (85 GW) and Japan (54 GW).

Investment in solar PV installations has been encouraged in recent years by substantial falls in solar PV costs, which resulted largely from widespread deployment and substantial oversupply (Spotlight). Between the first quarter of 2010 and the first quarter of 2012, solar PV generating costs fell by 44% (Frankfurt School UNEP Collaborating Centre and Bloomberg New Energy Finance, 2012). Solar PV costs continue to fall over the projection period, although at lower rates as the oversupply situation is corrected.

The increase in solar PV installations in European Union countries is thanks largely to feed-in tariffs, which considerably reduce project risk as returns are guaranteed, typically for periods of 10-20 years. These tariffs have been very generous in some cases and were not adjusted quickly enough to reflect the rapidly falling costs of solar PV. As a result, the returns offered were closer to those typically associated with high-risk investments and led to massive investment in solar PV installations. In some countries, governments responded quickly by reducing feed-in tariffs to levels that better reflected costs. As the costs of feed-in tariffs are passed on to consumers in most cases, it is essential to design incentives which attract sufficient investment while yet permitting adjustment of subsidies for new capacity additions as technology costs fall, to avoid unnecessary increases in electricity prices and maintain public acceptance.

S P O T L I G H T

Beyond the solar PV bubble

Solar PV cell manufacturing capacity has grown rapidly in response to booming global demand, initially in OECD countries, where demand first matured, and then in China, which expanded manufacturing capacity massively to support exports. In recent years, manufacturing capacity has expanded much more quickly than actual demand for solar PV panels. By 2011, estimated solar cell production capacity was around 20 GW higher than production, two-thirds higher than the new capacity installed worldwide that year. Since 2008, there has also been a very sharp fall in the cost of purified silicon, a key input for manufacture. Along with cost reductions from technological learning, these two factors have driven down the cost of PV systems sharply (IEA, 2011b).

Installers of solar PV systems and final electricity consumers have benefited greatly from falling solar PV prices, but solar PV manufacturers around the world, and particularly those in the United States and Europe, have suffered large financial losses. A wave of consolidation has been triggered within the industry, with a view to reducing costs and becoming more competitive. Several large companies have already gone bankrupt, such as Germany's Q-Cells – the largest solar cell manufacturer in Europe – in April 2012. Trade tensions have arisen between the United States, Europe and China, resulting in the imposition of import tariffs by the United States in 2012 on solar panels from China.

Difficulties are likely to persist in the short term, while the imbalance between supply and demand endures. How quickly the balance is restored depends largely on the rate of growth of demand for solar PV. China represents a large potential market, but its demand for solar PV in the short term is uncertain. In the New Policies Scenario, the oversupply continues over the short term.

Other renewables for electricity and heat

In the New Policies Scenario, electricity generation from concentrating solar power (CSP) plants soars from 1.6 TWh to about 280 TWh and capacity from 1.3 GW to 72 GW between 2010 and 2035. The majority of new projects in the near term are in the United States and Spain, but there are also developments in a number of other regions in the later years of the *Outlook* period, including North Africa, the European Union, India, Australia and South Africa. In 2035, CSP capacity is highest in China, followed by the Middle East. Most plants currently in operation or under construction are based on parabolic trough technology, the most mature of the CSP technologies. Further technology improvements and significant cost reductions are necessary to make CSP plants competitive on a large scale. The average capacity factor of CSP plants increases over the period, because of increasing use of CSP technologies with thermal storage.

Global geothermal electricity generation increases from 68 TWh to more than 300 TWh and capacity from 11 GW to over 40 GW between 2010 and 2035. Most of these projected increases occur in the United States, Japan and in Asia (Philippines and Indonesia). African countries, particularly North Africa, also increase their use of geothermal for electricity generation.

Electricity generation from marine energy, which includes tidal and wave power, increases from less than 1 TWh to almost 60 TWh between 2010 and 2035, with capacity growing from less than 1 GW to 15 GW. Tidal power is limited to select sites due to economic considerations, requiring a large tidal range and proximity to existing transmission lines to be considered viable. Wave power has notable potential to contribute to meeting electricity demand, but the relevant technologies are still in their infancy, requiring significant improvements to reduce costs.

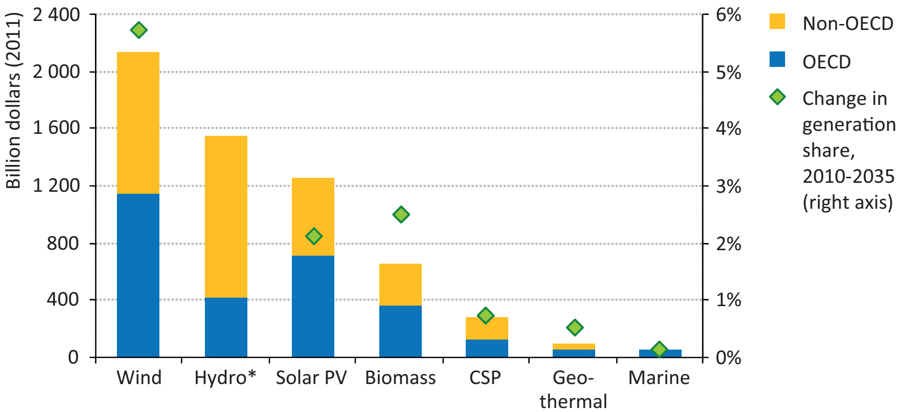
Solar heat, used mainly in buildings to provide hot water, grows from 19 Mtoe to over 70 Mtoe worldwide between 2010 and 2035. China accounted for 68% of global solar heating capacity in 2011 (REN21, 2012). The country's use of solar heat is projected to expand substantially during the *Outlook* period, at about 30 Mtoe in 2035. US production also increases strongly, from 1.4 Mtoe to about 7 Mtoe. Geothermal heat is used mainly in buildings in the European Union and United States. In the New Policies Scenario, final consumption of geothermal heat increases from 3 Mtoe to almost 20 Mtoe between 2010 and 2035, coming mainly from the European Union, United States, China and Japan.

Costs of renewables

Investment

The projected increase in global renewables-based electricity generation capacity in the New Policies Scenario requires cumulative investment of $6.0 trillion (in year-2011 dollars), with annual investment increasing to over $300 billion by 2035. Renewables account for 62% of total investment in power generation capacity from 2012-2035, reaching almost 70% in 2035. Investment in wind power is higher than for any other source, at $2.1 trillion, representing 35% of total investment in renewables capacity (Figure 7.8). Investment in hydropower totals $1.5 trillion and solar PV $1.3 trillion over the projection period. OECD countries invest more than non-OECD in all sources, except hydropower and CSP. OECD countries invest $2.9 trillion in total renewables capacity, of which almost two-thirds goes to wind power and solar PV, while non-OECD countries invest $3.1 trillion, with over one-third going to hydro.

Figure 7.8 ▷ **Cumulative investment in renewables-based electricity generation by region and type in the New Policies Scenario, 2012-2035**



* The share of hydropower in total generation declines by half a percentage point in 2010-2035, starting from a share of 16% in 2010. All other renewable technologies start from a share of less than 2% in 2010.

To accommodate more renewables-based capacity, often in remote locations to capture the best renewable energy sources, additional transmission lines will need to be built and some existing transmission and distribution networks reinforced. Those additional investments are estimated at just below $230 billion from 2012-2035, or 3.2% of the total investment in electricity networks (see Chapter 6). This share is significantly higher for transmission lines, accounting for almost 10%. In the European Union and Japan, where the deployment of renewables continues to grow strongly, this share increases to around one-quarter. Extensive deployment of distributed renewables, such as solar PV in buildings, can reduce future transmission investment needs, though it would require additional investment in the reinforcement of distribution networks to accommodate electricity flowing from residential customers to the grid.

The projected demand for biofuels in the New Policies Scenario calls for a total of around $360 billion to be invested in bio-refineries worldwide. Almost two-thirds of this sum goes to conventional ethanol plants. Just over one-fifth of the total, $78 billion, goes to advanced biofuels (ethanol and biodiesel). Investment in conventional biodiesel amounts to $43 billion (12% of the total) and in aviation fuels around $12 billion (3%). Most biofuels investment is in OECD countries, where much of global demand is concentrated.

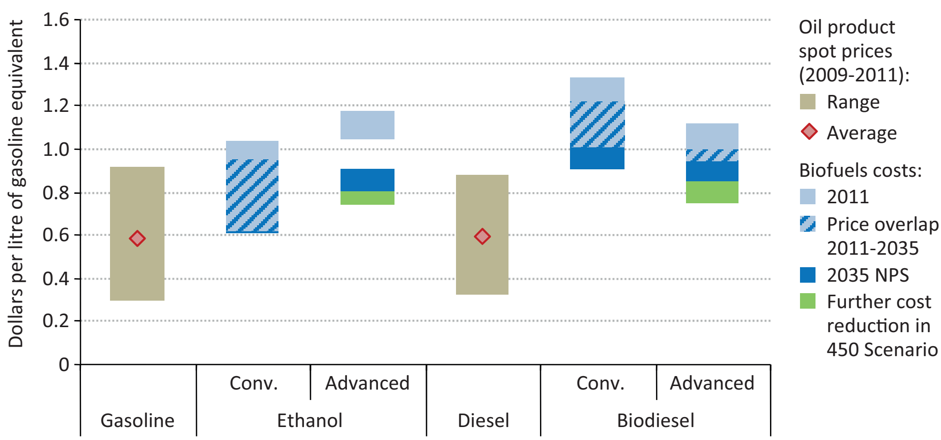
Production costs

In the electricity sector, the fall in investment costs (on a per-kilowatt basis) of many renewable energy technologies in recent years has resulted in lower production costs. However, based on these costs, most renewable technologies are not yet competitive with fossil fuel-based technologies. Solar PV generating costs have declined the most of any renewable energy technology over the past two decades, especially in the last few years (Spotlight) and are expected to achieve the largest reduction of any generating technology over the *Outlook* period as well, falling by between 40% and 60% in most regions compared to costs in 2011. However, this is not enough to decrease average solar PV generation costs below the wholesale price in any of the *WEO* regions during the projection period.

The cost of onshore wind power has also declined over time to where it is competitive with fossil fuel-based generation today in a few countries, and close in several others. Its costs are expected to continue to fall in the future, as a result of technological progress and economies of scale. Between 2011 and 2035, the levelised cost of energy generation from wind falls below wholesale prices in the European Union around 2020 and in China in the early 2030s, at which point it becomes competitive in the market without government support.[8] However, wind does not become competitive in the United States, as wholesale prices remain at low levels due to low gas prices and the absence of a CO_2 price.

The electricity production costs for offshore wind, CSP and marine fall throughout the *Outlook* period, but remain well above a competitive level. Those of bioenergy power plants, by contrast, see little reduction over time, as the technologies are already mature and their costs depend greatly on biomass feedstock prices, which are not expected to decrease through 2035.

Figure 7.9 ▷ Indicative biofuels production costs and spot oil prices



Notes: NPS = New Policies Scenario; Conv. = Conventional. The range of gasoline and diesel spot prices is taken from the monthly average spot price in the United States, Singapore and Rotterdam from 2009 to 2011. Biofuels costs are not adjusted for subsidies; cost variations can be even larger than depicted here, depending on feedstock and region.

8. The quality of available resources can vary widely across a region, resulting in differences in the generation costs of renewables. For example, sites with sub-optimal wind quality characteristics reduce wind turbine capacity factors, increasing the levelised costs of energy generation. Within a region, the best sites may become competitive earlier, with others becoming competitive later.

The costs to produce biofuels are higher than conventional fossil fuels, with a few exceptions, *e.g.* Brazil (Figure 7.9). Biofuel costs vary greatly by region, depending mainly on the feedstock, technology, land characteristics and climatic factors. In Brazil, ethanol derived from sugarcane is often cheaper to produce than gasoline due to favourable soil and climate conditions for the high yield crop. Ethanol produced from corn or sugar beets, such as in the United States and Europe, is generally more expensive. Biodiesel produced from soybeans and rapeseed, the most common feedstocks, currently cost significantly more than conventional diesel. Over the *Outlook* period, while the investment costs for conventional biofuel production processes are expected to fall, biofuel feedstock costs are not expected to decrease significantly, resulting in only small reductions in conventional biofuel production costs by 2035. Advanced biofuel technologies have higher potential cost reductions, decreasing by 10-20% between 2010 and 2035 in the New Policies Scenario. Increasing oil prices over the *Outlook* period help conventional and advanced biofuels to become more competitive.

Subsidies to renewables

To foster the deployment of renewable energy, governments use subsidies to lower the cost of renewables or raise their revenues, helping them compete with fossil fuel technologies. The justification is that imperfections in the market fail to factor in externalities (such as environmental costs attributable to other fuels) or deny nascent technologies the opportunity to mature without support. The ultimate goal is to help renewable energy technologies to achieve sufficient cost reductions to enable them to compete on their own merits with conventional technologies. At that point, any support should, accordingly, cease to be awarded to additional capacity.

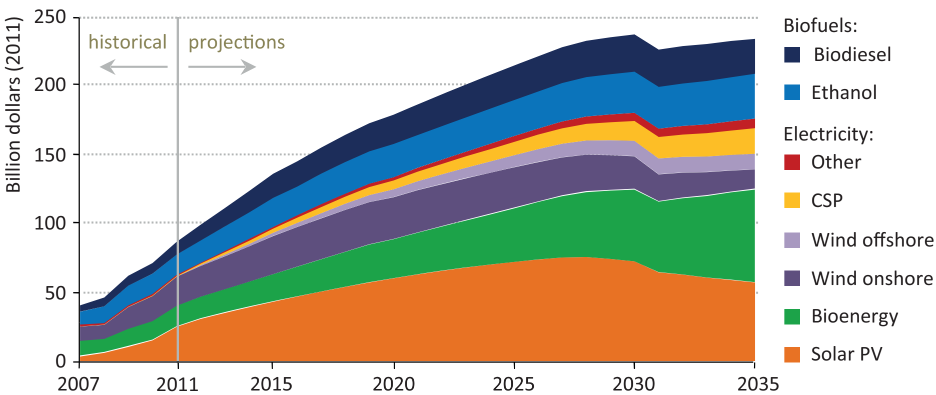
Most of the current support mechanisms for renewables apply to electricity produced by capacity installed in a specific year, and for a fixed duration, which is typically 20 years. As cost reductions for renewable technologies are achieved, the level of support provided for new capacity installations needs to decline to avoid excessive and unnecessary increases in the cost of energy services. This structure means that even after the costs for new capacity of a renewable technology become competitive with fossil-fuel technologies, the payments related to the capacity installed in previous years will continue for the fixed duration.

Subsidies to renewables are generally paid to producers. They can be direct or indirect. Direct support includes tax credits for production and investment, price premiums and preferential buy-back rates (or feed-in tariffs). Indirect subsidies arise from mandates, quotas and portfolio standards, which support the uptake of renewables at higher costs to the economy or the consumer. The costs may be met either through government budgets (for example, tax credits) or by end-users collectively.

To ensure sustained deployment of renewables, it is critical to maintain investors' confidence through consistent policies. Repeated expirations of the production tax credit for wind power over the past fifteen years in the United States demonstrate the effects of inconsistent policies, as the wind industry has experienced boom and bust cycles over this period. Governments need to monitor market developments closely, set clear rules for calculating subsidies and make a credible commitment not to enact retrospective changes.

In 2011, renewables excluding large hydro received an estimated $88 billion in subsidies in various forms, up 24% from 2010, of which $64 billion went to electricity and the remainder to biofuels (Figure 7.10). Solar PV received more than any other renewable energy technology for electricity generation ($25 billion), followed by wind ($21 billion) and bioenergy ($15 billion). In the New Policies Scenario, total subsidies to renewables grow to about $185 billion in 2020 and reach almost $240 billion per year by 2035.[9] Support provided to bioenergy for power generation continues to grow over time, reaching $69 billion in 2035, exceeding that received by any other technology. The amount received by solar PV grows rapidly in the medium term, reaching $77 billion in 2027, before falling to $58 billion in 2035, as retired installations are replaced by new, less expensive capacity. Onshore wind power receives more support each year until around 2020, before falling to $14 billion by 2035, as this technology becomes increasingly competitive. Biofuels receive $24 billion in 2011, increasing to $46 billion in 2020 and $59 billion in 2035, with the vast majority going to conventional biofuels in 2035.

Figure 7.10 ▷ Global renewable energy subsidies by source in the New Policies Scenario



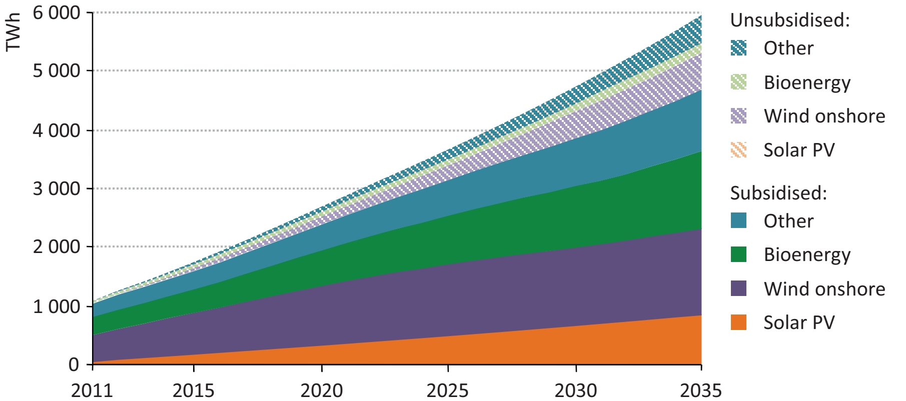
Notes: Other includes geothermal, marine and small hydro. CSP = Concentrating solar power.

While subsidies to renewables in the power sector increase in total, they decline on a per-unit basis as the costs of renewable energy technologies fall and electricity prices increase, mainly due to higher fossil fuel prices and the introduction – in some regions –

9. Projected subsidies to renewables are calculated by taking the difference between the average cost of electricity generated by the renewable energy technology and the regional wholesale electricity price. This level of subsidy is paid for each unit of electricity generated by the installed capacity over its lifetime. For biofuels, they are calculated by multiplying the volumes consumed by the difference of their cost to the reference price of the comparable oil-based products.

of a carbon price. They fall significantly for solar PV through 2035, due to continued cost reductions. However, outside of limited niche applications, solar PV continues to require subsidies through 2035. As onshore wind becomes more competitive, growing amounts of unsubsidised electricity are generated (Figure 7.11). Offshore wind, CSP and marine continue to require support through 2035. Subsidies per unit of biofuel also decline over time, with technological advances lowering the costs while oil prices increase.

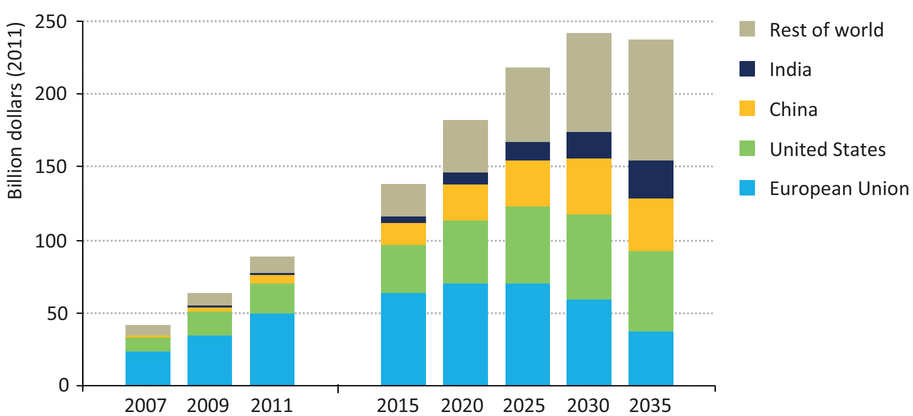
Figure 7.11 ▹ Subsidised and unsubsidised renewables-based electricity generation by type in the New Policies Scenario



Note: Other includes concentrating solar power, geothermal, marine energy, small hydro and wind offshore.

In 2011, the European Union provided the highest level of total renewable energy support in the world, almost $50 billion, followed by the United States at $21 billion (Figure 7.12). Subsidies to biofuels were also the highest in the European Union, at $11 billion, the bulk of them going to biodiesel. In the United States, $8 billion in 2011 went to biofuels, mainly targeting ethanol.

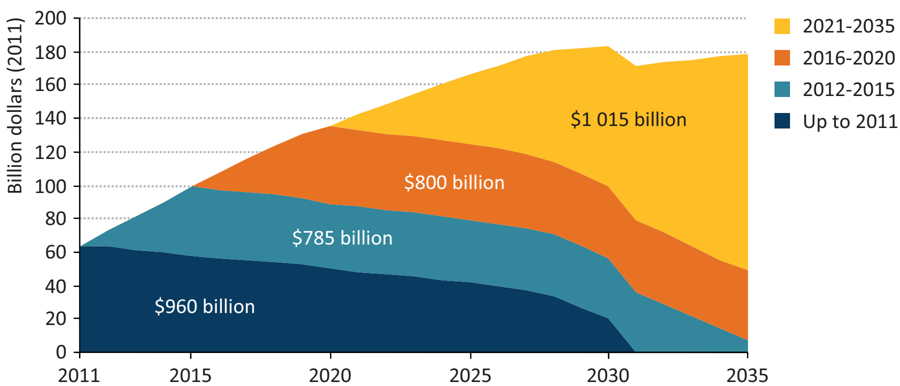
Figure 7.12 ▹ Global subsidies to renewables-based electricity generation and biofuels by region in the New Policies Scenario



In the New Policies Scenario, subsidies to renewable energy in the European Union reach a plateau of around $70 billion in the 2020s, before declining to about half that level by 2035, as commitments to support higher cost capacity recently installed expire. In the United States, they increase until around 2030, peaking at $58 billion. In China, subsidies for renewables stabilise at above $35 billion during the late 2020s, while they keep increasing in India, reaching about $26 billion by the end of the projection period.

Subsidies to renewables-based electricity amount to a total of $3.5 trillion over 2012-2035. Of this, the capacity installed up to 2011 receives almost $1.0 trillion, continuing to receive payments until the early 2030s (Figure 7.13). The capacity added through to 2020 – mostly due to current targets – receives an additional $1.6 trillion. The remainder is paid for capacity built after 2020, with a part of the cost being paid beyond the time horizon of this *Outlook* for all the capacity built after 2015. Despite lower unit costs for most renewables over time, they are deployed in such large amounts after 2020 that they account for close to $1.0 trillion in subsidies from 2020 to 2035.

Figure 7.13 ▷ Subsidy lock-in of renewables-based electricity generation in the New Policies Scenario



Note: Generation refers to all subsidised renewables-based electricity generation (excluding large hydro).

Integration of variable renewables into the electricity system

Electricity suppliers have always had to deal with weather-related demand volatility and often with capacity restrictions – for example, hydropower can be limited in dry years with low water inflows. However, the availability of wind and solar power is more sensitive to short-term changes in weather conditions, as wind conditions and cloud cover can change significantly in a matter of hours in a manner that is difficult to predict. Handling the natural variability of these and other renewable energy sources to ensure security of supply will become increasingly important as their share of overall capacity expands.

Several options exist or are being developed that can contribute to better management of the variability of the electricity system, including increasing interconnections, electricity storage, demand response and smart grids. Smart grids employ advanced technologies to monitor and manage the transmission of electricity from the generation point to the end-user, and can facilitate the integration of grids spanning large areas, allowing for a more efficient use of remotely located renewable resources. Demand response measures, shifting end-user demand to achieve a better distribution of load, can also help accommodate variable renewables. Electricity storage technologies can help smooth the supply of energy over short periods (minutes to hours), as well as allowing electricity produced during low demand periods (typically over periods of hours) to be available during times of peak demand. Improved forecasting techniques, over periods of minutes or hours, would also allow for better utilisation of variable renewable energy sources.

Until these measures are deployed on a larger scale, flexible capacity, with readily controllable electricity generation, will be required to accommodate variable renewables. It is important for flexible capacity to be able to start up quickly, ramp up to maximum output rapidly and operate at partial levels of output. Reservoir-based hydropower generally offers the best combination of these attributes, but costs and geography are limiting factors. Low investment costs, a wide range of available capacities and rapidly adjustable output often make gas-fired power plants the next best choice for flexible capacity. New coal-fired power plant designs can also provide considerable operational flexibility.

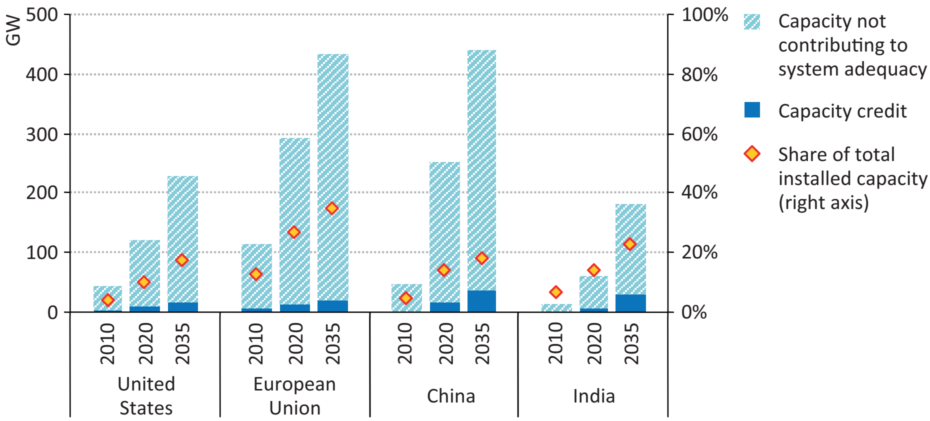
Today, there is adequate flexibility within most power systems to accommodate some further expansion of variable renewables. As larger amounts of variable renewables are deployed, additional capacity will be needed to ensure system adequacy. We estimate the additional global flexible capacity needs in the New Policies Scenario at 300 GW by 2035. In all *WEO* scenarios, natural gas dominates new flexible capacity. As the electricity sector decarbonises, the shares of both renewables and gas are expected to grow. While renewables may compete with gas in some cases, the two can be mutually beneficial, providing low-carbon electricity while maintaining the security of electricity systems.

The additional flexible capacity needed is calculated as the difference between the average annual power output of a variable renewable technology and the level of its output that can be relied on during times of peak demand (its capacity credit). The capacity credit, measuring their contribution to the adequacy of a system, depends on the renewable energy source and is typically lower than the average power output. In 2035, the average capacity credit of wind and solar PV (the two largest variable renewable technologies in terms of installed capacity), taken together, ranges between 5-20% depending on the region (Figure 7.14), against the average power output of 24% of their capacity. The capacity value is relatively low in the European Union, largely because of solar PV installed in countries where solar PV output is minimal or zero when electricity demand is at its peak. However, it is higher in India and Japan, where there is good correlation between peak electricity demand and solar PV output.

The costs of integrating variable renewables can be grouped into three broad categories: adequacy, balancing and grid integration, with total costs typically from $6-$25 per megawatt-hour (MWh) of variable renewable electricity generation. Adequacy costs arise from additional flexible capacity needed at times of peak demand and are on the order of

$3-$5/MWh. Balancing costs cover additional services to match supply and demand on a short-term basis and range from $1-$7/MWh. Grid integration costs add an additional $2-$13/MWh of variable renewables generation, including provision for transmission extensions for renewables located far from demand centres and reinforcements of existing transmission and distribution grids.

Figure 7.14 ▷ Installed wind and solar PV capacity and their contribution to system adequacy in the New Policies Scenario

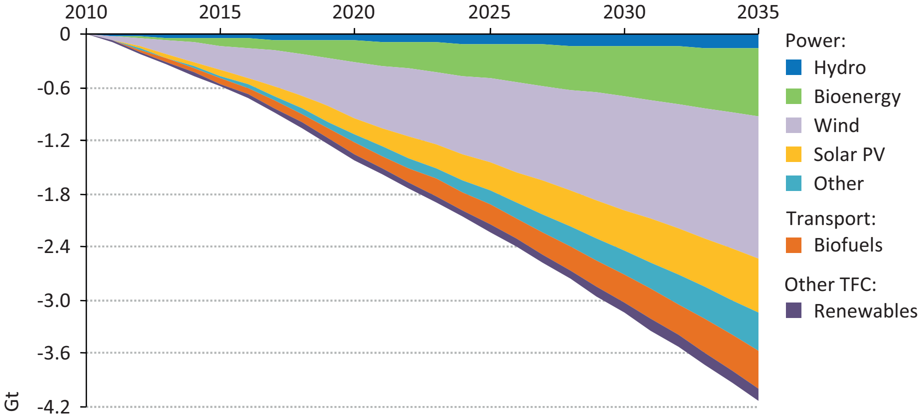


Note: Capacity credit is the amount of capacity that contributes to system adequacy, *i.e.* can be relied upon at times of peak demand.

Benefits of renewables

Several benefits are associated with the deployment of renewable energy technologies, including very low or no greenhouse-gas emissions, making them a key component in any climate change mitigation strategy (IPCC, 2011). In the New Policies Scenario, total CO_2 savings across all sectors from renewables are 4.1 gigatonnes (Gt) in 2035. In the power sector, renewables-based generation reduces emissions when it displaces power generation from the combustion of fossil fuels. Relative to the emissions that would be generated if the growing electricity demand of the New Policies Scenario were to be supplied using the electricity generation mix of 2010, renewables help to reduce CO_2 emissions in the power sector by 3.6 Gt in 2035 (Figure 7.15). These savings represent some 10% of the level of emissions reached in 2035, with more than 40% of the savings coming from increased wind generation. Although hydropower generation increases by about two-thirds over the projection period, its share of total generation declines in many regions, therefore its contribution to CO_2 savings is more limited than other renewables. Heat produced from renewable sources, as in wood pellet or solar heat boilers for example, reduce CO_2 emissions by 150 million tonnes in 2035 by displacing heat from boilers using coal, oil or gas.

Figure 7.15 ▷ **CO_2 emissions savings from greater use of renewables, relative to 2010 fuel mix* in the New Policies Scenario**



* The emissions savings compared with the emissions that would have been generated for the projected level of electricity generation in the New Policies Scenario were there no change in the mix of fuels and technologies and no change in the efficiency of thermal generating plants after 2010.

Notes: Other includes concentrating solar power, geothermal and marine energy. TFC = total final consumption.

Biofuels reduce emissions from oil in the transport sector by an estimated 0.4 Gt in 2035, but only so long as their production does not result in increases in emissions from direct or indirect land-use changes (Box 7.3). This aspect of biofuels has come under close scrutiny in recent years. Sugarcane ethanol and advanced biofuels have the highest potential to reduce emissions (IEA, 2011a). Biofuels have also been criticised for competing with food supply and contributing to deforestation. The negative impacts of biofuels, however, can be minimised or avoided if the right policies are established and enforced.

Renewable energy is largely a domestic source of energy (although some proportion of biofuels and other bioenergy is traded internationally). When it displaces imported fuels, it contributes to greater national energy security and directly reduces import bills, which represent a fairly significant percentage of gross domestic product (GDP) in many importing countries and often contribute to a trade deficit. Biofuels have the potential to reduce these effects significantly. Moreover, greater use of renewables could indirectly put downward pressure on oil and gas prices and reduce price volatility. In the electricity sector, renewables mainly reduce the need to import gas or coal, as oil use is limited in this sector.

The use of fossil fuels gives rise to several pollutants that worsen ambient air quality and have a negative impact on human health. Two of the most important of these pollutants are sulphur dioxide (SO_2) and nitrogen oxides (NO_x); SO_2 coming mainly from burning coal but also from diesel fuel, while NO_x come from burning all types of fossil fuels. They cause a number of environmental problems, such as acid rain and ground-level ozone formation.

Their impact is local and regional. Air pollution is a major problem in several large cities in non-OECD countries (and in some cities in the OECD). Integration of air quality and renewable energy policies can be more effective than separate actions.

Box 7.3 ▷ Indirect land-use change and the European Union's biofuels policy

The European Union's 2009 directive on renewable energy requires that 10% of transport demand in 2020 come from renewable sources, a target largely expected to be met through increased use of biofuels. The directive set sustainability criteria for biofuels, taking into account direct land-use changes, and established thresholds for greenhouse-gas emissions savings from biofuels, starting at 35% and rising to 50% in 2017 and to 60% in 2018. It also mandated the European Commission to review the impact of indirect land use changes on emission savings from biofuels. Direct land-use changes occur when, for example, forests and grasslands are converted to cropland to produce biofuels. Indirect land-use changes (ILUC) may occur when growing crops for biofuels in one area displaces previous agricultural or forest production to other areas. Studies have shown that ILUC can significantly reduce the greenhouse-gas savings potential of biofuels or even lead to increased emissions. Sugar-based ethanol has the highest savings potential and biodiesel some of the lowest (IFPRI and CEPII, 2010). These new findings have made it clear that ILUC emissions need to be taken into account in formulating biofuels policies, alongside other benefits of biofuels, notably reduced oil import dependence. No decision has been taken yet at the European Union level regarding the impact of these findings on future biofuels policy.

Several types of renewable energy technologies for electricity generation require significantly less water for their operation than fossil fuel-based and nuclear power plants. Solar PV and wind power do not use water to produce electricity and require only small amounts for cleaning purposes (see Chapter 17).[10] If the significant use of water during the extraction of fossil fuels and uranium is taken into consideration, the differences in water use are even greater. Use of solar PV and wind power also avoids thermal pollution and contamination that may be caused by the discharge of cooling water for thermal power plants.

10. Bioenergy, concentrating solar and geothermal power plants use water for cooling purposes, at levels close to those of fossil fuel-based and nuclear power plants. Bioenergy also requires water to grow the feedstocks.

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Chapter 7: Renewable energy outlook

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