# Renewable energy outlook

## Basking in the sun?

### Highlights

- The share of renewables in primary energy use in the New Policies Scenario rises to 18% in 2035, from 13% in 2011, resulting from rapidly increasing demand for modern renewables to generate power, produce heat and make transport fuels. Limiting this rapid growth is the continued shift away from the use of traditional biomass in developing countries in favour of modern energy services.
- Power generation from renewables increases by over 7 000 TWh from 2011 to 2035, making up almost half of the increase in total generation. Renewables become the second-largest source of electricity before 2015 and approach coal as the primary source by 2035, with continued growth of hydropower and bioenergy, plus rapid expansion of wind and solar PV. Almost two-thirds of the increase in power generation from renewables is in non-OECD countries. The increase in China is more than that in the European Union, United States and Japan combined.
- Consumption of biofuels increases from 1.3 mboe/d in 2011 to 4.1 mboe/d in 2035, to meet 8% of road-transport fuel demand in 2035. The United States, Brazil, European Union and China make up more than 80% of all biofuels demand. Advanced biofuels, helping to address sustainability concerns about conventional biofuels, gain market share after 2020, reaching 20% of biofuels supply in 2035.
- Cumulative investment of $6.5 trillion is required in renewable energy technologies from 2013 to 2035, only 5% of which is for biofuels. Renewables account for 62% of investment in new power plants through to 2035. In addition, investments in new transmission and distribution lines of $260 billion are needed for the integration of renewables. Increasing generation from wind and solar PV has impacts on power markets and system operation, which can reduce the profitability of other generators, but also stimulate changes in market design.
- Renewable energy technologies are becoming more competitive compared to wholesale electricity prices, but their continued growth hinges on subsidies to facilitate deployment and drive further cost reductions. Subsidies to renewables reached $101 billion in 2012, up 11% relative to 2011. Almost 60% of these were paid in the European Union. Global subsidies to renewables increase to over $220 billion by 2035. Wind becomes competitive in a growing number of regions, as does solar PV, but only in a limited number of markets.
- Along with reducing $CO_2$ emissions, deploying renewables delivers co-benefits, including reduction of other pollutants, enhancing energy security, lowering fossil-fuel import bills and fostering economic development. The challenge is to design creative renewable support schemes that are effective and cost-efficient, but also take into consideration existing and planned infrastructure in order to minimise adverse effects.

## Recent developments

Renewables are steadily becoming a greater part of the global energy mix, in particular in the power sector and in regions that have put in place measures to promote their deployment. Double-digit growth rates have been observed in the last decade for some renewable energy technologies and renewables are projected to continue to grow strongly over the *Outlook* period to 2035, provided that the necessary support measures are kept in place. However, the situation is nuanced across the three main energy uses: electricity, heat and transport. Electricity generation from renewable sources is growing rapidly for most technologies; while renewable energy use for heat is growing more slowly and remains under-exploited. After a period of rapid expansion, the rate of growth of biofuels use has recently slowed, due largely to adverse weather conditions that reduced harvests and increased feedstock prices, as well as sustainability concerns. Investment in renewable power generation has also been rising steadily but it fell, for the first time, in 2012. In part, this reflects falling unit costs; but it is perhaps also a sign that the prospects for renewables are becoming more complex.

In Europe, rapid expansion of renewable power generation, particularly wind and solar, has occurred in recent years, driven by the requirements of the European Union's Renewable Energy Directive and national targets. However, low rates of power demand growth and a difficult economic situation raise doubts about the timelines of future investments and policymakers in several countries have started to express concerns about the affordability of high shares of certain types of renewable power generation. These concerns relate, particularly, to higher than anticipated rates of deployment of solar photovoltaic (PV) systems, driven, in some countries, by generous and unlimited subsidy schemes and rapidly falling PV system cost. For example, Spain acted in 2010 to adjust over-generous renewables subsidies and, more recently, a moratorium has been put on further subsidies to renewables. Difficulties about integrating high levels of variable renewables into the electricity system are also emerging in some European countries.

In the United States, the market for renewables has been growing strongly, in large part due to the continuation of stimulus policies directed at renewable energy, such as the provision of cash grants (instead of a tax credit) of up to 30% of investment costs for eligible renewable energy projects (US Treasury 1603 Program). This programme expired at the end of 2012, but many projects were able to pre-qualify and will receive this support if completed by the end of 2016. An investment tax credit and production tax credits also provided support for renewables in the United States, despite uncertainty over the future of the programmes. Indeed, doubts about their renewal at the end of 2012 led to high growth in that year; as developers pressed to complete projects in time to receive support. (Uncertainty surrounding future policy support measures has often caused "boom and bust" cycles for capacity additions of renewables). Renewable portfolio standards, currently in effect in 30 states and the District of Columbia, continue to provide an important incentive to boost deployment. Along with blending mandates, annually increasing volume requirements under the Renewable Fuels Standard (RFS) have been a major driver for higher consumption of biofuels each year since its enactment in 2005.

With rapidly growing power demand and concerns over energy security and local pollution, deployment of renewables has been accelerating and is expected to continue to do so in non-OECD countries. In China, the energy development plan, published in January 2013 as part of the 12th Five-Year Plan, sets ambitious renewables targets with mandatory 2015 targets for non-fossil energy use, energy intensity, carbon intensity and particulate emissions. India's 12th Five-Year Plan foresees an increase in grid-connected renewable generation capacity of 11 GW from large hydropower and 30 GW from other renewable sources by 2017. Major increases in renewables capacity are planned in the coming years in Brazil, led by hydropower, bioenergy and onshore wind (see Chapter 10). Tendering schemes in South Africa, the United Arab Emirates and Morocco are prompting investment in wind, solar PV and concentrating solar power (CSP), and many other countries with rising power demand are also embarking on large-scale deployment (IEA, 2013a).



After global biofuels production more than doubled between 2006 and 2010, driven by supportive policies in Brazil, the United States and the European Union, growth in 2011 and 2012 stagnated, despite high oil prices. A combination of physical and policy-related issues was to blame. Ethanol output in Brazil and the United States was affected by poor sugarcane and corn harvests, leading to a lack of feedstock supply and high prices. In Europe, high feedstock prices and poor margins, as well as strong competition from non-European producers, posed challenges for biodiesel producers. Provision for the blending of more than 10% ethanol in the gasoline pool in the United States has raised technical and economic challenges, while doubts about the sustainability of biofuels production in the European Union have led to a proposal to limit the use of food-crop derived biofuels to 6% of transport fuel. The production of advanced biofuels – which offer the prospect of requiring less land, improving greenhouse-gas balances and lower competition between food and fuel – has been expanding, but only slowly.

The portion of modern renewable energy for heat in total final heat demand has risen only slowly and is currently just above 10%. Most of this contribution comes from bioenergy, although solar thermal and geothermal are playing an increasing part as they become progressively more cost competitive in a number of markets and circumstances. However, these technologies face distinct market and institutional challenges to deployment, with renewable heat receiving much less policy attention than electricity from renewables or biofuels. To date, only 35 countries have policy frameworks supportive of renewable heat (mostly within the European Union stemming from the Renewables Directive).

## Renewables outlook by scenario

There is a rapid increase in the use of renewable energy in each of the three scenarios presented in this *Outlook* (Table 6.1). This is primarily the result of the creation of an environment, through policy, in which costs can be driven down so that renewable energy technologies become more competitive with other energy sources. In a limited, but growing, number of cases, they become fully competitive.

Reflecting differences in the assumed level of policy action across the scenarios, the share of renewables in total primary energy demand in 2035 varies markedly, from 26% in the

450 Scenario, to 18% in the New Policies Scenario and 15% in the Current Policies Scenario. By comparison, renewables met 13% of the world's primary energy demand in 2011. Because renewables include both traditional and modern forms, its growth is the net result of two opposing trends. Dominant is a dramatic rise in demand for modern renewable energy (albeit from fairly low levels). The other is a shift away from the use of traditional biomass – mostly fuel wood, charcoal, animal dung and agricultural residues used for heating and cooking – in favour of modern forms, such as gas, electricity and liquefied petroleum gas (LPG). Reducing traditional biomass brings important health benefits by limiting exposure to local air pollutants (see Chapter 2). In the New Policies Scenario, the share of traditional biomass in total primary energy demand drops from 5.7% in 2011 to 3.9% in 2035, as the reduction of traditional biomass use in Asia more than offsets the population-driven increase in Africa.

**Table 6.1 ▷ World renewable energy use by type and scenario**

| | | New Policies | | Current Policies | | 450 Scenario | |
|---|---|---|---|---|---|---|---|
| | 2011 | 2020 | 2035 | 2020 | 2035 | 2020 | 2035 |
| **Primary energy demand** (Mtoe) | **1 727** | **2 193** | **3 059** | **2 130** | **2 729** | **2 265** | **3 918** |
| United States | 140 | 196 | 331 | 191 | 282 | 215 | 508 |
| Europe | 183 | 259 | 362 | 250 | 326 | 270 | 452 |
| China | 298 | 392 | 509 | 373 | 445 | 405 | 690 |
| Brazil | 116 | 148 | 207 | 146 | 204 | 150 | 225 |
| *Share of global TPED* | *13%* | *15%* | *18%* | *14%* | *15%* | *16%* | *26%* |
| **Electricity generation** (TWh) | **4 482** | **7 196** | **11 612** | **6 844** | **10 022** | **7 528** | **15 483** |
| Bioenergy | 424 | 762 | 1 477 | 734 | 1 250 | 797 | 2 056 |
| Hydro | 3 490 | 4 555 | 5 827 | 4 412 | 5 478 | 4 667 | 6 394 |
| Wind | 434 | 1 326 | 2 774 | 1 195 | 2 251 | 1 441 | 4 337 |
| Geothermal | 69 | 128 | 299 | 114 | 217 | 142 | 436 |
| Solar PV | 61 | 379 | 951 | 352 | 680 | 422 | 1 389 |
| Concentrating solar power | 2 | 43 | 245 | 35 | 122 | 56 | 806 |
| Marine | 1 | 3 | 39 | 3 | 24 | 3 | 64 |
| *Share of total generation* | *20%* | *26%* | *31%* | *24%* | *25%* | *28%* | *48%* |
| **Heat demand***(Mtoe) | **343** | **438** | **602** | **432** | **551** | **446** | **704** |
| Industry | 209 | 253 | 316 | 255 | 308 | 248 | 328 |
| Buildings* and agriculture | 135 | 184 | 286 | 177 | 243 | 198 | 376 |
| *Share of total final demand* | *8%* | *10%* | *12%* | *9%* | *11%* | *10%* | *16%* |
| **Biofuels** (mboe/d)** | **1.3** | **2.1** | **4.1** | **1.9** | **3.3** | **2.6** | **7.7** |
| Road transport | 1.3 | 2.1 | 4.1 | 1.9 | 3.2 | 2.6 | 6.8 |
| Aviation*** | - | - | 0.1 | - | 0.1 | - | 0.9 |
| *Share of total transport* | *2%* | *4%* | *6%* | *3%* | *4%* | *5%* | *15%* |
| **Traditional biomass** (Mtoe) | **744** | **730** | **680** | **732** | **689** | **718** | **647** |
| *Share of total bioenergy* | *57%* | *49%* | *37%* | *50%* | *40%* | *47%* | *29%* |
| *Share of renewable energy demand* | *43%* | *33%* | *22%* | *34%* | *25%* | *32%* | *17%* |

* Excludes traditional biomass. ** Expressed in energy-equivalent volumes of gasoline and diesel.
*** Includes international bunkers. Note: Mtoe = million tonnes of oil equivalent; TPED = total primary energy demand; TWh = terawatt-hour; mboe/d = million barrels of oil equivalent per day.

## Renewables outlook by use in the New Policies Scenario

Renewables contribute an increasing share to total primary energy in the New Policies Scenario and reach 18% in 2035, with the share increasing for all uses and in almost all regions (Figure 6.1). Demand for modern renewable energy – including hydropower, wind, solar, geothermal, marine and bioenergy – rises almost two-and-a-half times, from 983 million tonnes of oil equivalent (Mtoe) in 2011 to almost 2 400 Mtoe in 2035. Its share of total primary energy demand increases from 8% to 14%. A rapid uptake of hydropower occurs mainly in non-OECD countries, where significant resources remain untapped and offer a cost-effective means of meeting fast-growing electricity demand. For most other technologies, the growth is driven by continued support, although other factors, such as falling technology costs and, in some regions, rising fossil fuel prices and carbon pricing also contribute. Traditional biomass remains an important energy source in parts of the world that continue to lack access to clean cooking facilities, although at the global level its use drops from 744 Mtoe in 2011 to 680 Mtoe in 2035.

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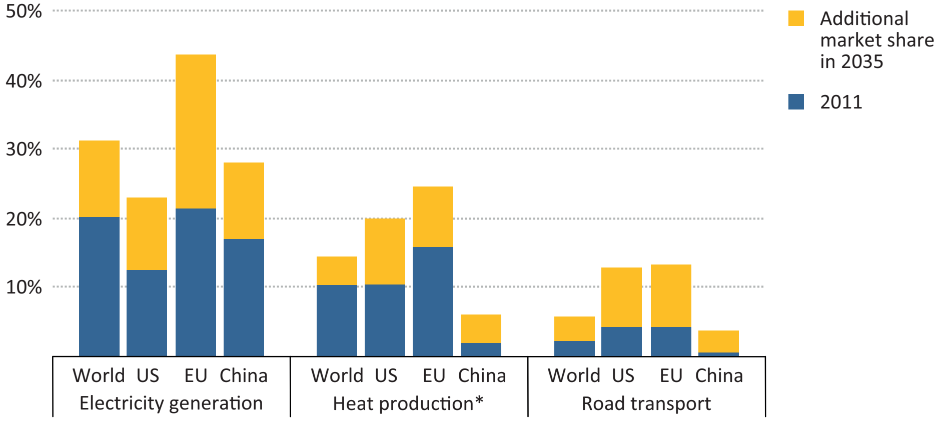
**Figure 6.1 ▷ Renewable energy share in total primary energy demand by category and region in the New Policies Scenario, 2011 and 2035**




* Excludes traditional biomass. Note: US = United States; EU = European Union.

### *Power generation*

In the New Policies Scenario, renewables power generation expands by over 7 000 terawatt-hours (TWh) between 2011 and 2035. This is equivalent to around one-third of current global power generation, and almost half of the projected increase in total power generation to 2035 (see Chapter 5). The share of renewables in the global power mix rises from 20% in 2011 to 31% in 2035 (Table 6.2). Collectively, renewables become the world's second-largest source of power generation before 2015 and approach coal as the primary source by the end of the period. There is rapid expansion of wind and solar PV, coupled with steady increases in both hydropower and bioenergy.

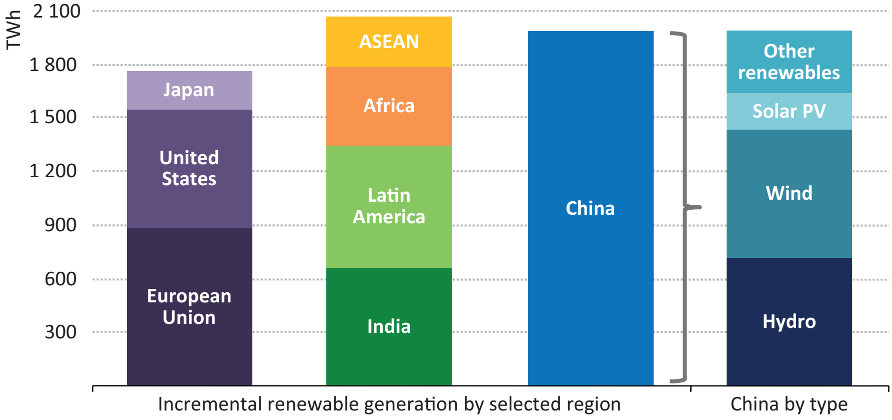
**Table 6.2 ▷ Renewables-based electricity generation by region in the New Policies Scenario** (TWh)

| | Renewables generation | | | | Share of total generation | | Share of variable renewables* in total generation | |
|---|---|---|---|---|---|---|---|---|
| | 2011 | 2020 | 2030 | 2035 | 2011 | 2035 | 2011 | 2035 |
| **OECD** | **2 116** | **2 994** | **3 943** | **4 434** | **19.6%** | **33.8%** | **3.6%** | **14.2%** |
| Americas | 1 014 | 1 313 | 1 733 | 1 965 | 19.0% | 29.6% | 2.6% | 11.0% |
| United States | 544 | 740 | 1 039 | 1 211 | 12.6% | 23.0% | 2.9% | 10.7% |
| Europe | 900 | 1 353 | 1 710 | 1 889 | 24.9% | 45.2% | 6.3% | 21.0% |
| Asia Oceania | 203 | 329 | 500 | 581 | 10.9% | 25.5% | 1.1% | 10.9% |
| Japan | 133 | 213 | 304 | 343 | 12.7% | 28.2% | 0.9% | 11.4% |
| **Non-OECD** | **2 365** | **4 202** | **6 099** | **7 178** | **20.9%** | **29.9%** | **1.0%** | **7.8%** |
| E. Europe/Eurasia | 290 | 357 | 457 | 528 | 16.9% | 21.8% | 0.2% | 2.3% |
| Russia | 169 | 200 | 265 | 312 | 16.1% | 20.5% | 0.0% | 1.1% |
| Asia | 1 173 | 2 569 | 3 787 | 4 423 | 16.9% | 27.2% | 1.4% | 9.1% |
| China | 814 | 1 888 | 2 515 | 2 804 | 17.1% | 28.0% | 1.5% | 9.9% |
| India | 183 | 350 | 666 | 850 | 17.4% | 25.2% | 2.3% | 10.4% |
| Middle East | 21 | 48 | 141 | 226 | 2.4% | 12.9% | 0.0% | 6.8% |
| Africa | 116 | 205 | 403 | 550 | 16.8% | 36.0% | 0.4% | 5.6% |
| Latin America | 765 | 1 023 | 1 312 | 1 451 | 69.0% | 71.0% | 0.4% | 6.2% |
| Brazil | 463 | 614 | 782 | 862 | 87.1% | 79.5% | 0.5% | 8.9% |
| **World** | **4 482** | **7 196** | **10 042** | **11 612** | **20.3%** | **31.3%** | **2.2%** | **10.0%** |
| European Union | 696 | 1 113 | 1 427 | 1 580 | 21.4% | 43.8% | 6.9% | 23.1% |

* Variable renewables include solar PV and wind power.

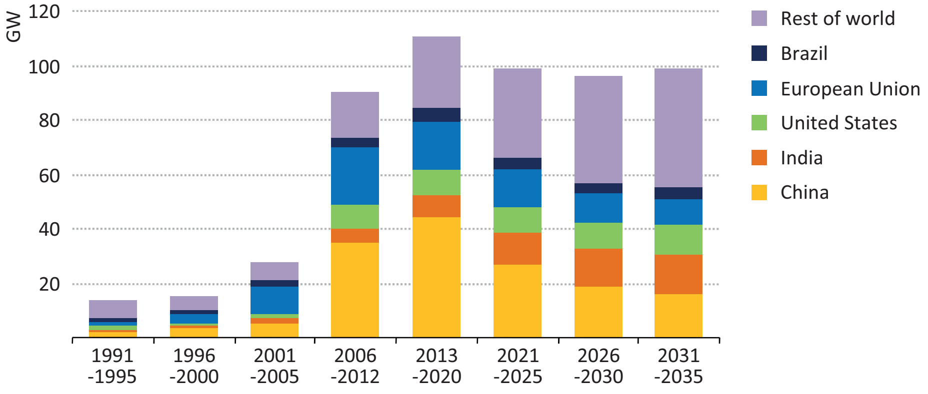
Two-thirds of the increase in power generation from renewables occurs in non-OECD regions, with these countries accounting for 62% of total renewables generation in 2035, up from 53% in 2011. China alone accounts for 28%, or 1 990 TWh, of the total growth in generation from renewables, more than the European Union, United States and Japan combined (Figure 6.2). Considerable growth is also seen in Latin America, India, Africa and Southeast Asia, mainly driven by policy interventions. The increase in the United States, which contributes over 70% of the increase in its total generation over the period, comes despite strong competition from natural gas and also thanks to the decline in coal-fired generation. It is driven by federal tax credits and state-level renewable energy standards, which are assumed to continue also beyond 2020. In the European Union, the increase in generation from renewables far exceeds the increase in total generation, as output falls from coal-fired and nuclear plants. In Japan, mainly in response to the generous support policies recently put in place, electricity generation from renewables increases by 160%, its share increasing from 13% in 2011 to 28% in 2035. Policy action is also the main driver of growth in India, where ambitious targets have been set to scale-up renewable energy capacity in order to overcome electricity shortages and increase access. There is an eleven-fold increase in generation from renewables in the Middle East, reflecting the region's considerable solar and wind resources and growing recognition of their potential importance in satisfying rapid growth in power demand, while freeing up oil and natural gas for export.

**Figure 6.2 ▷ Incremental electricity generation from renewables in selected regions, 2011-2035**




More than 3 100 gigawatts (GW) of renewables capacity are added over the period, equivalent to almost three times the present total installed capacity of the United States. After taking account of the retirement of older installations, this results in installed capacity of renewables increasing by a factor of around 2.5, from almost 1 600 GW in 2012 to nearly 4 000 GW by 2035. Annual capacity additions rise steadily over the period, with a brief downturn around 2020, when rapid expansion of hydropower in China slows as higher-quality sites become scarcer (Figure 6.3). Including the replacement for retiring capacity, annual gross capacity additions are around 180 GW by the end of the projection period, compared with over 115 GW in 2012.

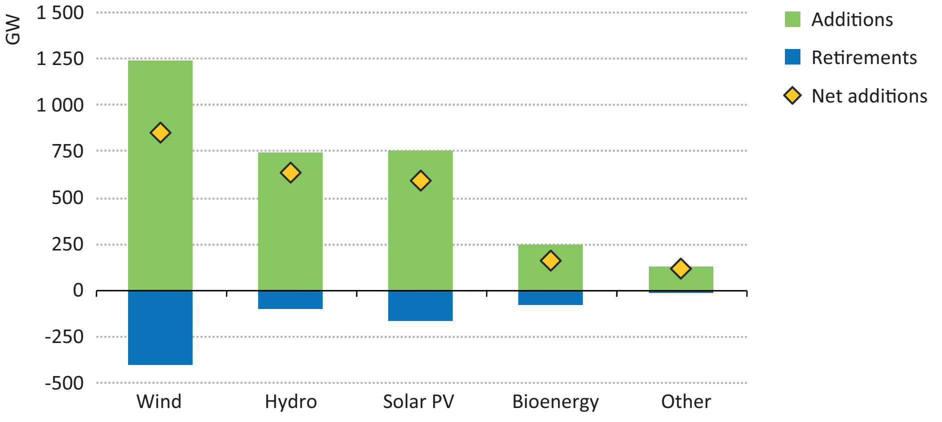
**Figure 6.3 ▷ Average annual increases in renewables-based capacity* by region in the New Policies Scenario**




* Excludes capacity that directly replaces retired capacity of the same technology type.

Renewable energy technologies make up more than 50% of gross capacity additions in the power sector, pushing their share of installed power capacity from 28% in 2012 to 40% in 2035. Wind, with gross capacity additions of almost 1 250 GW, makes the largest contribution to the growth, followed by solar PV (750 GW) and hydro (740 GW) (Figure 6.4).

**Figure 6.4 ▷ Cumulative global renewables-based capacity additions and retirements by technology in the New Policies Scenario, 2013-2035**




Electricity generation from bioenergy more than triples over the projection period, with China, United States and the European Union accounting for over half of the growth. Its share of total generation doubles from 2% to 4%. The share of hydropower in total power generation stays stable throughout the *Outlook* period, at about 16%. Hydropower remains the leading source of renewables-based power, although its share of renewable electricity generation falls from almost 80% today to around half in 2035, as the scope for further additions is gradually reduced and other renewable technologies are deployed at a faster rate. Hydropower output rises from almost 3 500 TWh in 2011 to 5 800 TWh in 2035, based on an increase in installed capacity from 1 060 GW to 1 730 GW over the same period. The expansion is concentrated in non-OECD countries. China accounts for almost 25% of the increase in generation, its capacity rising from 246 GW in 2012 to 430 GW in 2035. China added 16 GW of new hydropower capacity in 2012 and further strong growth is projected until around 2020, when growth slows as China gets closer to utilising its full potential. Brazil also continues to rely heavily on hydropower to meet electricity demand, adding around 70 GW of capacity over the projection period, to reach an installed capacity of 151 GW in 2035 (see Chapter 10). In the OECD, generation from hydropower increases by a modest 16%, with the growth focused in North America and the European Union.

## *Biofuels*

Consumption of biofuels is projected to rise from 1.3 million barrels of oil equivalent per day (mboe/d) in 2011 to 2.1 mboe/d in 2020, and 4.1 mboe/d in 2035 (Table 6.3). By 2035, biofuels meet 8% of total road-transport fuel demand, up from 3% today. Ethanol remains the dominant biofuel, making up about three-quarters of global biofuels use throughout the period. Consumption of biodiesel in road transport more than triples over the *Outlook* period, to 1.1 mboe/d in 2035. Combined, the United States, Brazil, the European Union, China and India account for about 90% of world biofuels demand throughout the *Outlook* period, with government policies driving the expansion in these regions. These projections are similar to those made in *WEO-2012,* despite a drop in investment in the sector last year and a temporary slowdown in production growth, due primarily to poor harvests in the United States and Brazil. Continued policy support and a return to normal harvests put biofuels consumption back on track over the long term. In addition to the use of biofuels in road transport, its use in aviation begins to make inroads over the projection period.

**Table 6.3 ▷ Ethanol and biodiesel consumption in road transport by region in the New Policies Scenario** (mboe/d)

| | Ethanol | | Biodiesel | | Biofuels total | | Share of road transport energy use | |
|---|---|---|---|---|---|---|---|---|
| | 2011 | 2035 | 2011 | 2035 | 2011 | 2035 | 2011 | 2035 |
| **OECD** | **0.7** | **1.5** | **0.2** | **0.8** | **0.9** | **2.3** | **4%** | **12%** |
| Americas | 0.6 | 1.3 | 0.1 | 0.3 | 0.7 | 1.6 | 4% | 13% |
| United States | 0.6 | 1.2 | 0.1 | 0.3 | 0.7 | 1.5 | 5% | 15% |
| Europe | 0.0 | 0.2 | 0.2 | 0.5 | 0.2 | 0.7 | 4% | 12% |
| **Non-OECD** | **0.3** | **1.4** | **0.1** | **0.4** | **0.4** | **1.8** | **2%** | **5%** |
| E. Europe/Eurasia | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0% | 2% |
| Asia | 0.0 | 0.7 | 0.0 | 0.1 | 0.1 | 0.8 | 1% | 4% |
| China | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.4 | 1% | 4% |
| India | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.2 | 0% | 4% |
| Latin America | 0.3 | 0.8 | 0.1 | 0.2 | 0.4 | 1.0 | 10% | 20% |
| Brazil | 0.2 | 0.6 | 0.0 | 0.2 | 0.3 | 0.8 | 19% | 30% |
| **World** | **1.0** | **2.9** | **0.4** | **1.1** | **1.3** | **4.1** | **3%** | **8%** |
| European Union | 0.0 | 0.2 | 0.2 | 0.5 | 0.2 | 0.7 | 5% | 15% |

The United States remains the largest biofuels market, spurred on by the Renewable Fuel Standard (RFS) through 2022 and assumed continuation of support thereafter, with consumption increasing from around 0.7 mboe/d to 1.5 mboe/d in 2035, by which time biofuels meet 15% of road-transport energy needs. Driven by blending mandates and strong competition between ethanol and gasoline, Brazil remains the second-largest market and continues to have a larger share of biofuels in its transport fuel consumption than any other country. In 2035, biofuels meet 30% of Brazilian road-transport fuel demand up from 19% today. Supported by the Renewable Energy Directive and continued policy support, biofuels use in the European Union more than triples over the period to 0.7 mboe/d in 2035, representing 15% of road-transport energy consumption. In China, government plans for expansion lead to demand for biofuels reaching 0.4 mboe/d in 2035, many times the current level. India established an ambitious National Mission policy on biofuels in 2009, but the infancy of the ethanol industry and difficulty in meeting current targets constrains future demand growth in the projections.

The outlook for biofuels is highly sensitive to possible changes in government subsidies and blending mandates, which remain the main stimulus for biofuels use. Over the past year much uncertainty has developed about how biofuel policies in several key markets will evolve. At the time of writing, discussions in the European Union were continuing on the possible introduction of a 6% cap on the amount of conventional biofuels that can be counted towards the level of renewable energy in transport mandated in the Renewable Energy Directive. These discussions are driven by sustainability issues, including concern that feedstock production for biofuels contributes to deforestation or pre-empts land that could be used to grow food. The European Union has also placed temporary anti-dumping duties on biofuel imports from the United States, Argentina and Indonesia, with material impact on trade in biofuels, so clouding the picture for future trade. In the United States, a review of the federal RFS is underway, which could significantly alter the long-term outlook for ethanol, amid widespread concerns that the supply targets for 2022 are not achievable. One key concern is the amount of ethanol that can be consumed by vehicles on the road (often referred to as the "blend wall"), due to strong resistance from various parts of the industry to blending levels higher than 10% (E10) and logistical barriers to supplying the current flex-fuel vehicle fleet with high-ethanol content fuels, such as E85. A second concern is whether domestic production of cellulosic biofuels can meet official volume goals, as cellulosic biofuel supply targets have had to be lowered in the past few years. On the other hand, Brazil has made policy changes over the last year pointing to higher growth for biofuels, including restoring the ethanol blending mandate to 25%, after reducing it to 20% in late 2011 due to poor sugarcane harvests.

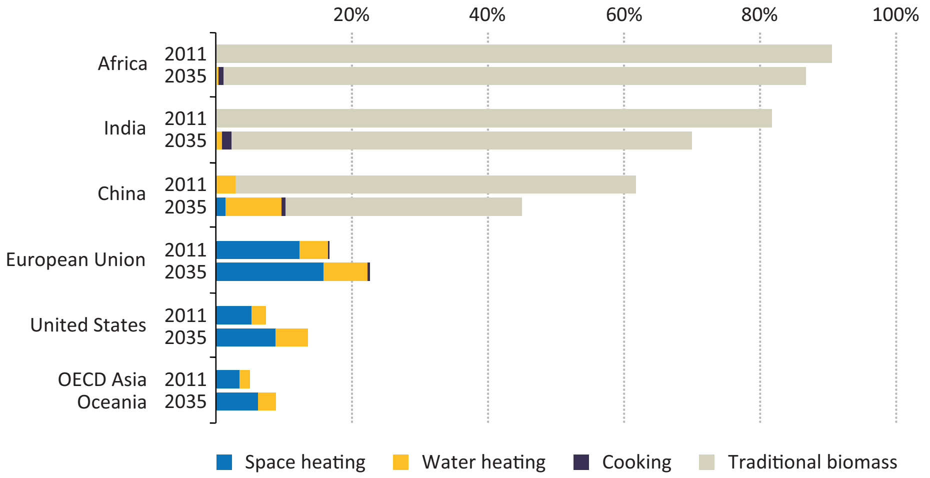
Advanced biofuels offer the prospect of increasing biofuels supply while reducing or eliminating sustainability concerns for biofuels. Cellulosic ethanol is a promising advanced biofuel that can be derived from a variety of feedstocks, including bagasse and agricultural residues, as well as dedicated energy crops. Much work on advanced biodiesel at present is concentrated on the use of feedstocks with far higher yields than conventional feedstock, including palm oil, rapeseed and jatropha. But all the feedstocks depend on conversion technologies that are mainly in the research and development, pilot or demonstration phases. If developed successfully, they hold the promise of achieving lower overall unit costs and imposing lower land requirements than conventional biofuels. While a few commercial-scale units and about 100 plants at pilot or demonstration scale already exist, widespread deployment will require lower costs which further technological progress could bring (IEA 2013b). Because of the lack of commercial scale production of advanced biofuels, the supply mandate for cellulosic biofuels under the RFS in the United States was reduced again in 2013. In the New Policies Scenario, advanced biofuels become available at commercial scale around 2020, with their share of total biofuels supply rising from below 1% today to almost 20% in 2035, led by the United States, Europe, China and Brazil.

## *Heat*

Heat is the largest energy service demand worldwide, typically used for process applications in industry, and for space and water heating, and cooking in the buildings sector. The energy use required to meet this service demand accounts for around half of total final energy consumption. Currently, most of the contribution of renewables to heat production comes from biomass used in traditional ways for cooking and heating in developing countries (Figure 6.5). The use of traditional biomass for heat amounted to 744 Mtoe in 2011 and made up 18% of total global energy use for heat. Such use is often unsustainable because of the low efficiency with which the fuels are converted, the emissions produced (leading to potential health problems) and the difficulty in maintaining supply. More modern and efficient technologies utilising renewable energy – (non-traditional) bioenergy, geothermal and solar thermal in particular – are playing an increasing role in heat supply and met 8% of total global demand for heat in 2011.



**Figure 6.5 ▷ Share of renewables in heat production in the residential sector for selected regions in the New Policy Scenario**




In the residential sector, more than 40% of the heat supplied globally today by modern renewables is consumed in Europe, mainly in the form of bioenergy for space heating. The United States and China account for 14% and 11% of modern renewable use for heat respectively. Recent growth in China has outpaced all other regions. In the last five years, China accounted for almost 40% of global growth in the use of modern renewable energy for heat in the residential sector, driven by the rapid deployment of solar water heaters, which are increasingly cost competitive with conventional fuels (Eisentraut and Brown, 2013), and household biogas systems. In industry, 70% of renewable energy use for heat is in the light industry sector such as food, tobacco and machinery. Almost all of it is bioenergy, which accounts for 11% (136 Mtoe) of global light industry's total energy demand.

Global modern renewable energy use for heat production increases by 75% in the New Policies Scenario, reaching 600 Mtoe in 2035. By the end of the period, modern renewables meet 12% of total heat demand, compared with 8% in 2011. The use of traditional biomass for heat production falls some 10%, to 680 Mtoe in 2035. It continues to be the main source of heat in the residential sector in many developing countries, although in others the switch to modern energy services is made possible by rising incomes, ongoing urbanisation and programmes to foster access to modern energy sources. Demand for modern renewables for heat in the residential sector almost doubles, growing from 88 Mtoe in 2011 to 165 Mtoe by 2035. Most of the growth occurs in China and Europe, with modern bioenergy remaining the dominant source even though solar and geothermal both grow at much faster rates, largely driven by the use of solar thermal heaters in China.

## Focus on power generation from variable renewables

Unlike dispatchable power generation technologies, which may be ramped up or down to match demand, the output from solar PV and wind power is tied to the availability of the resource.[1] Since their availability varies over time, they are often referred to as variable renewables, to distinguish them from the dispatchable power plants (fossil fuel-fired, hydropower with reservoir storage, geothermal and bioenergy). Wind and solar PV power are not the only variable renewables – others include run-of-river hydropower (without reservoir storage) and concentrating solar power (without storage) – but PV and wind power are the focus of this section as they have experienced particularly strong growth in recent years and this is expected to continue.

The characteristics of variable renewables have direct implications for their integration into power systems (IEA, forthcoming 2014a). The relevant properties include:

- **Variability:** power generation from wind and solar is bound to the variations of the wind speed and levels of solar irradiance.
- **Resource location**: good wind and solar resources may be located far from load centres. This is particularly true for wind power, both onshore and offshore, but less so for solar PV, as the resource is more evenly distributed.
- **Modularity:** wind turbines and solar PV systems have capacities that are typically on the order of tens of kilowatts (kW) to megawatts (MW), much smaller than conventional power plants that have capacities on the order of hundreds of MW.
- **Uncertainty**: the accuracy of forecasting wind speeds and solar irradiance levels diminishes the earlier the prediction is made for a particular period, though forecasting capabilities for the relevant time-frames for power system operation (*i.e.* next hours to day-ahead) are improving.

1. Electricity generation from (non-dispatchable) variable renewables, such as wind and solar, is weather dependent and can only be adjusted to demand within the limits of the resource availability.

- **Low operating costs:** once installed, wind and solar power systems generate electricity at very low operating costs, as no fuel costs are incurred.
- **Non-synchronous generation:** power systems are run at one synchronous frequency: most generators turn at exactly the same rate (commonly 50 Hz or 60 Hz), synchronized through the power grid. Wind and solar generators are mostly non-synchronous, that is, not operating at the frequency of the system.

The extent to which these properties of variable renewables pose challenges for system integration largely depends on site-specific factors, such as the correlation between the availability of wind and solar generation with power demand; the flexibility of the other units in the system; available storage and interconnection capacity and the share of variable renewables in the overall generation mix. The speed at which renewables capacity is introduced is also important, as this influences the ability of the system to adapt through the normal investment cycle. Effective policy and regulatory design for variable renewables needs to co-ordinate the rollout of their capacity with the availability of flexible dispatchable capacity, grid maintenance and upgrades, storage infrastructure, efficient market operation design, as well as public and political acceptance.



### *Wind power*

Generating power from wind turbines varies with the wind speed. Although there are seasonal patterns in some regions, the hourly and daily variations in wind speed have a less predictable, stochastic pattern. Geographically, good wind sites are typically located close to the sea, in flat open spaces and/or on hills or ridgelines, but the suitability of a site also depends on the distance to load centres and site accessibility.

For onshore wind turbines, capacity factors – the ratio of the average output over a given time period to maximum output – typically range from 20% to 35% on an annual basis; excellent sites can reach 45% or above. The power output from new installations is increasing, as turbines with larger rotor diameters and higher hub heights (the distance between the ground and the centre of the rotor) can take advantage of the increased wind speeds at higher altitudes. Moreover, wind projects are increasingly being tailored to the characteristics of the site by varying the height, rotor diameter and blade type. Wind turbines that are able to operate at low wind speeds offer the advantage of a steadier generation profile, reducing the variability imposed upon the power system, but likely reducing annual generation.

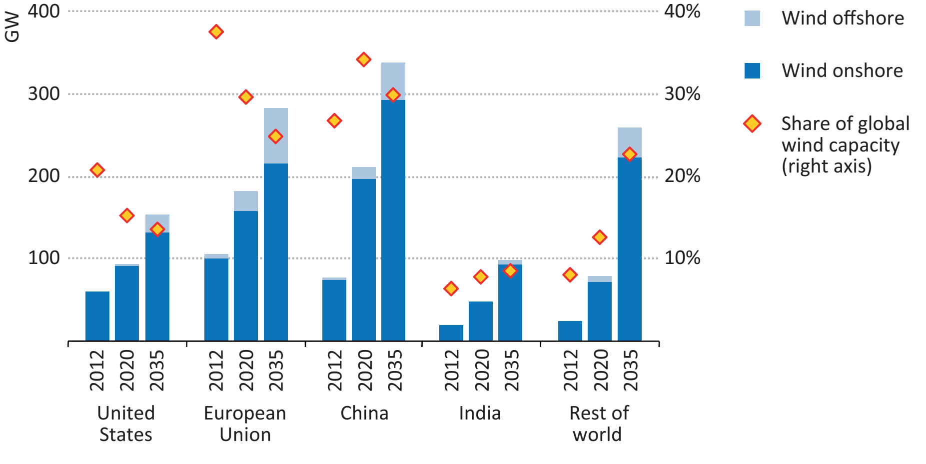
Wind turbines located offshore can take advantage of stronger and more consistent sea breezes. Wind speeds tend to increase with increasing distance from the shore, but so too does the seafloor depth, requiring more complex foundation structures. Capacity factors are generally higher ranging from 30% to 45% or more, as distance from the shore or hub height increases. However, offshore wind turbines are more expensive to install because of the high costs associated with the foundations and offshore grid connections. Bottlenecks can also occur due to a shortage of specialised installation vessels.

### *Recent trends and projections*

After experiencing growth of around 25% per year over the past decade, wind power made up 2.3% of global power generation in 2012. Globally, wind capacity rose by 44 GW in 2012, a record year, to 282 GW. This is almost five times the capacity in place in 2005. New installations were concentrated in China (adding 13 GW in 2012) and the United States and the European Union (both adding 12 GW). There was a surge in installations in the United States, as developers sought to secure production tax credits, which were set to expire at the end of 2012. Additions in China were 5 GW lower than in 2011 due to bottlenecks for connections to the grid. Out of this total, offshore wind saw a 32% increase in global installed capacity in 2012, a rise of 1.3 GW to 5.4 GW, the highest annual capacity addition to date. Some 90% of this was added in the European Union, mainly in the United Kingdom, Germany, Belgium and Denmark.

In the New Policies Scenario, electricity generation from wind (onshore and offshore) is projected to increase at an annual average rate of 6% between 2011 and 2035. Wind generation approaches 2 800 TWh in 2035, when its share of global power supply is 7.5%, and total capacity reaches 1 130 GW. Around 80% of the capacity additions are onshore, although offshore wind installations gradually increase in importance. While today the European Union has the largest share of global wind capacity, China has the largest share in 2035 (Figure 6.6).

**Figure 6.6 ▷ Installed wind power capacity by region in the New Policies Scenario**




## *Solar photovoltaics*

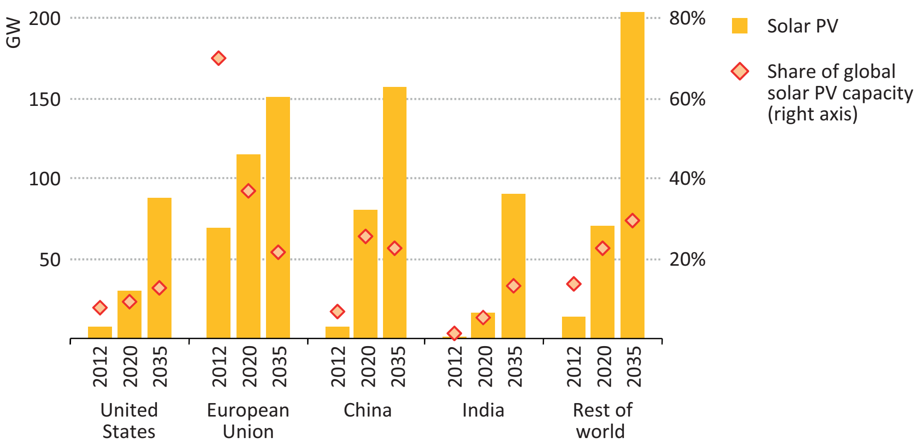
Power generation from solar PV installations varies with the level of solar irradiation they receive. Geographically, solar irradiation increases with proximity to tropical regions and is more uniformly distributed than wind. Seasonal and daily patterns in output from solar PV systems can be fairly well forecast – on a clear day, solar generation follows a bell shape, reaching its maximum around midday – but there remains an element of unpredictability, such as the extent of cloud cover or interference through snow, sand or dust cover.

Capacity factors vary widely, but generally lie within 10% and 20%, or above. The last ten years brought important technology progress, with significant cost reductions. Newer technologies, such as thin film technologies, are gaining growing market shares and bring further potential for cost reductions. Systems which include sun tracking systems can reduce variability, as can an array of panels with differing orientations, but in both cases costs are increased.

### *Recent trends and projections*

Solar PV generation expanded by 50% per year worldwide over the last decade, reaching almost 100 TWh in 2012. In this year, total installed capacity of solar PV increased by 43%, or 29.4 GW, representing 15% of the total growth in global power generation capacity. Germany alone, under the impetus of strong government support, accounted for more than one-quarter of the increase with 7.6 GW of additions. Other countries with major additions include Italy (3.6 GW), China (3.5 GW), United States (3.3 GW), Japan (2.0 GW) and India (1.1 GW). In each country, the growth was driven by government support programmes and subsidies.

**Figure 6.7 ▷ Installed solar PV capacity by region in the New Policies Scenario**




In the New Policies Scenario, electricity produced from solar PV rises to 950 TWh in 2035, as its share of global electricity generation increases from 0.4% to 2.6%. This is underpinned by a seven-fold increase in installed solar PV capacity over the *Outlook* period, reaching 690 GW in 2035 (Figure 6.7). Generation from solar PV increases faster than installed capacity due to technical improvements and deployment in regions with high quality resources. Solar PV on buildings accounts for the majority of installations, its share declining over the *Outlook* period as large-scale facilities operated by utilities gain market share. Driven by big increases in China (150 GW) and India (90 GW), non-OECD regions account for almost 60% of the increase in global solar PV capacity. Large increases also occur in the European Union and the United States (both around 80 GW), and Japan (50 GW). Through ongoing reductions, generation costs become comparable to retail electricity prices in several countries, but growth of solar PV will continue to be closely linked to the provision of government subsidies as, over the course of the *Outlook* period, solar PV is expected to become competitive in only a limited number of circumstances when compared to the average wholesale electricity price (Spotlight).

## *Implications for electricity systems and markets*

The impact of a growing component of variable renewables on the power system depends on the timing and co-ordination of renewables capacity additions, the investment cycles in the power system and the rate of deployment of measures to facilitate their integration into the system. The main impacts of location constraints and modularity are on the transmission and distribution network, while variability and uncertainty impact the way other power plants in the mix are operated.

### *Implications for grids*

The location of good variable renewable resources can be remote from demand centres, making transmission grid extensions necessary. Early and integrated planning of transmission corridors is necessary to maximise use of good resources and reduce public opposition. In some locations, transmission corridors will have to cross state or national borders, requiring co-operation between transmission system operators and regulators.

The transmission system costs involved to connect and integrate variable renewables depend on the distance to be covered, the status of development of the existing grids and the amount of capacity of variable renewables to be integrated. Costs range between $100 and $250 per kW of added variable renewables capacity (Dena, 2010; EnerNex, 2011; NREL, 2010). In total, about $170 billion or some 10% of the global investment in transmission grids in the New Policies Scenario is required to extend the grid to accommodate the growth in renewables. The amount varies significantly by region. In Europe and Japan, high levels of deployment mean that the integration of renewables accounts for a share of overall transmission investment of about 25% and 20% respectively. The comparable figure is about 10% in the United States, China and India.

The modularity of variable renewables can also have significant impacts on distribution grid needs. Bypassing the high-voltage transmission grids that transport power from large conventional power plants, wind and solar generators are typically connected at the distribution level (wind at mid-voltage and solar mainly at low-voltage). At low levels of installed wind and solar capacity, their generation can be consumed close to the production site (especially for solar PV) and may reduce the strain on distribution grids. At higher levels, the capacity of the distribution grid may need to be raised to accommodate increasing volumes of electricity sold back to the grid by distributed generators. Voltage transformers can be an initial bottleneck; a need to upgrade line capacities may follow.

The amount of investment to upgrade distribution grids also depends on their current condition. If these grids are in need of refurbishment, the additional costs may be low. In France and Germany, for example, each kilowatt of new variable renewables capacity will add an estimated $100 to $300 to the costs of the distribution grids (Lödl, *et al.*, 2010; Dena, 2012; CRE, 2012). In the New Policies Scenario, total investment in distribution grids to accommodate variable renewables amounts to over $90 billion globally, or about 2% of total distribution investment. Bringing together transmission and distribution (T&D) costs attributable to variable renewables, the additional investment is about $260 billion, or some 4% of total T&D investment over the *Outlook* period.

### *Implications for dispatchable power plants*

In the absence of a widespread uptake of the measures available to alleviate the challenges posed by variables renewables (Box 6.1), an increase in generation from wind and solar power has implications for the operation and use of dispatchable plants as well as for investment in such plants.



**Box 6.1 ▷ Reducing the challenges posed by variable renewables**

A number of operational and infrastructure measures can be taken to address the challenges posed by variable renewables. These include:

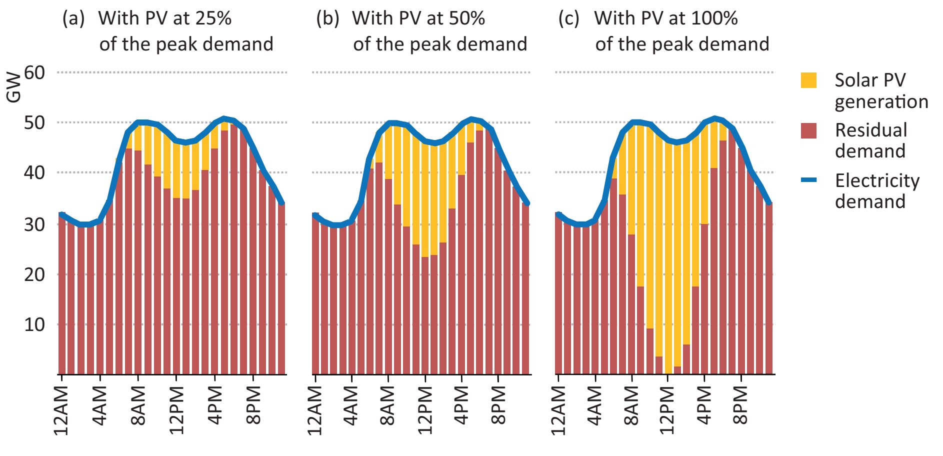
- Adapting the operation of power systems. This can include the application of advanced forecasting techniques, and adapting the market and power plant dispatch rules, for example reducing the time between the commitment of power plants to generate electricity and real-time operation.
- Extending the transmission grid to capture remote resources and increase cross-border trade, so as to reduce the effects of variations in solar irradiation and wind speed on the system. This can be especially effective for wind (Schaber, *et al.*, 2012).
- Promoting demand-side integration. Modifying electricity demand according to the variable supply could reduce the system impacts of wind and solar and also avoid the need for other integration measures.
- Investing in storage (such as pumped hydro storage, compressed air, hydrogen or batteries). If deployed on a small scale (such as batteries for solar PV), storage can help to sustain reliance on local generation and defer grid investment (IEA, 2014b).
- Balancing fluctuations from variable renewable output with flexible forms of generation, such as gas turbines.
- Curtailing extreme wind and solar power generation peaks, when variable renewables output is very high compared to electricity demand, to reduce the ramping up and down of power output from other sources (Baritaud, 2012).

While all measures may be advantageous individually, co-ordination between the integration measures is needed to maximise their benefits.

Electricity demand varies considerably during the course of a day, but it generally follows a predictable profile. For example, on a weekday demand may peak in the early evening as people arrive home and be lowest during the early hours of the morning when most people are asleep. However, generation from wind and solar power is tied to the availability of their resources and is often not well matched with the electricity demand profile. The pattern of the remaining electricity demand, after variable renewables production has been taken into account, also called residual electricity demand, can differ markedly from the total electricity demand (Figure 6.8). The variability of wind and solar generation alters the peaks and troughs in the residual demand profile which requires the dispatchable plants to adjust their output level accordingly. However, where variable renewables generation is well correlated with electricity demand (*e.g.* solar PV coinciding with air conditioning loads at midday) their generation pattern – up to a certain level of deployment – may be advantageous to the system by smoothing the demand profile.

The greater the variability of residual demand, the greater the flexibility of dispatchable power plants must be to be able to respond to changes not only of demand but also to supply side changes. This can raise their operational costs (through not running at optimal efficiency) and increase the wear-and-tear of power plant components. These "balancing costs" vary from system to system, depending on the presence of storage, the flexibility of the power plant fleet and also the quality of wind and solar resources and forecasts.

**Figure 6.8 ▷ Indicative hourly electricity demand and residual electricity demand with expanding deployment of solar PV**

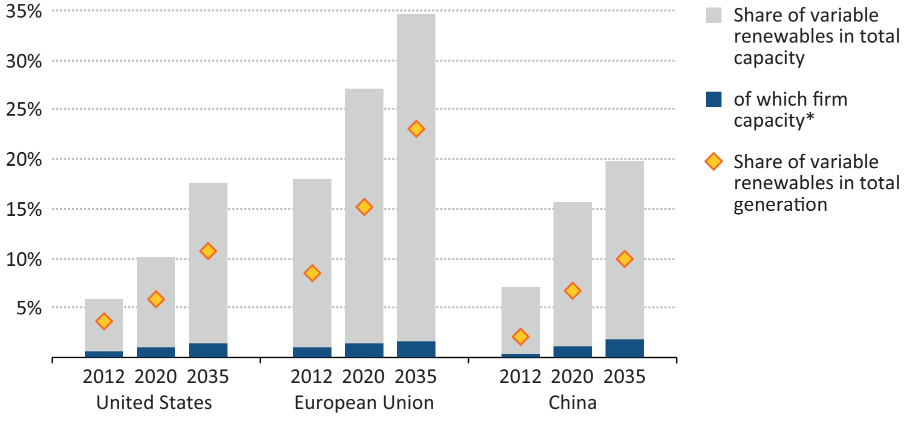



In regions where the electricity generation of variable renewables increases faster than demand, utilisation of existing plants is reduced. In the New Policies Scenario, total wind capacity increases by around 850 GW and solar PV by almost 600 GW in the period to 2035 with about 40% of this increase occurring before 2020 (in the 450 Scenario wind and solar capacity increases by 1 400 GW and some 900 GW until 2035, respectively [Box 6.2]). Until 2020, many of the existing dispatchable power plants will continue to be needed, but will likely experience less use, especially in regions that see major expansions of wind and solar generation, such as Europe. In countries with fast-growing power demand, such as China, this effect is less pronounced.

Despite the increasing capacity of wind and solar, their variable and uncertain generation profile mean that the need for dispatchable capacity is not reduced significantly. The reason is that the share of installed wind and solar capacity that can be confidently relied upon at times of high demand is much lower than for dispatchable plants. This share is referred to as "capacity credit". It depends on the respective correlation of wind and solar supply with the load profile and the level of penetration of variable renewables.[2] For example, in the European Union, it typically falls between 5% and 10% for wind and 0% to 5% for solar PV.

In the New Policies Scenario, wind and solar account for about 19% of global installed power capacity in 2035, reaching almost 35% in the European Union (Figure 6.9). However, globally they contribute only about 2% to firm capacity (capacity that can be relied upon to generate electricity at any given time). The provision of sufficient dispatchable capacity can entail additional costs. Assuming that additional gas turbines are used to meet this requirement, these adequacy costs are estimated to range from between $3-5 for each megawatt-hour (MWh) of additional generation from variable renewables (IEA, 2011). Since the use of other power plants declines with increasing levels of variable renewables, the capacity mix gradually shifts to less capital-intensive power plant types, such as gas-fired power plants, for which profitability at low utilisation rates is easier to achieve.

**Figure 6.9 ▷ Shares of wind and solar power capacity and generation in the New Policies scenario**




* Firm capacity of wind and solar is computed based on the capacity credit.

2. For solar, the capacity credit can be higher in systems where peaks in electricity demand are driven by demand for air conditioning, for example. Through interconnection over larger geographic areas, smoothing can be achieved, and the capacity credit can also be raised.

**Box 6.2 ▷ Variable renewables in the 450 Scenario**

The stronger deployment of renewable energy technologies is one of the key features of the 450 Scenario. By 2035, their share of global power generation increases to 48%, compared to 31% in the New Policies Scenario. The global share of wind and solar power generation in the 450 Scenario increases to 18% in 2035 (compared to 10% in the New Policies Scenario), with important implications for the power system. Total wind and solar capacity reaches 2 700 GW, which corresponds to 50% of peak demand in 2035. At a regional level, the capacity of variable renewables compared to peak load can be considerably higher; for example, in Europe it is more than 90% of peak demand and in China and Japan about 60% of peak demand. This means that the likelihood of momentary regional excess supply increases, when wind and solar generate electricity at their full capacity. In that case, there would be an important challenge for stable operation of the system, due to the non-synchronous generation of wind and solar power. A solution, such as keeping online a share of thermal generators at all times, would have to be considered. The commercial viability of these other power plants is a challenge, since they would operate at a very low utilisation rate. Moreover, additional investments would be required in T&D grids, as well as in other integration measures.

### *Implications for market price formation*

In most liberalised electricity markets, spot wholesale prices are largely determined by the operational costs of the most expensive generating unit used. Whenever low marginal cost power from wind and solar is fed into the system, generators with high operating costs, at the upper end of the merit order,[3] are needed less and the wholesale electricity price is, in consequence, lowered. Electricity end-users might benefit from this decrease depending on how much of the cost subsidies to renewables is passed through to them (see Chapter 8). The merit order effect may also reduce profit margins for all power generators, to the point that some generators become unprofitable. This has been observed recently, for example, in some European markets, and has put in question whether some utilities will be able to recover the investment costs of dispatchable plants under current market conditions. This could potentially jeopardise the reliability of power supply if the situation worsens.

Market reforms have been introduced or are under consideration in several countries where there is concern that price signals resulting from this effect may not be sufficient to stimulate timely and sufficient investment in new dispatchable power plants or to maintain older plants in operation. The options include different forms of capacity remuneration or regulatory obligation to maintain strategic reserve capacity or to allow hourly wholesale prices to increase unconstrained during times of scarcity (for example, when peak demand periods coincide with limited generation from variable renewables). Discussion of these issues remains open. One possibility is to incorporate measures which can reduce capacity needs, such as storage or demand-side management.

3. The merit order ranks the different generating units that are available in a power market in terms of their marginal cost of generation. It is often used to determine which units will be used to supply expected demand, with the cheapest units being used first.

## Competitiveness and unit costs

The cost of producing electricity from solar PV and wind has fallen dramatically over the last decade, leading to debate about whether they are now competitive, without subsidies, with the costs of power generated from fossil fuels. When measuring the competitiveness of different renewable energy technologies, it is important to distinguish between generating power for sale and power produced by households for auto-consumption.[4] The latter typically involves solar PV.

### *Competitiveness of variable renewables as a wholesale power generation source*

For electricity produced to sell on wholesale markets, it is usually considered that breakeven is achieved when the levelised cost of electricity (LCOE)[5] of a technology does not exceed the average wholesale electricity price received for generation over its lifetime. Variable renewables, however, have limited or no means to adjust their power output across the day to maximise their revenues. At increasing rates of penetration in the power mix, the price that they would receive in the market is likely to decrease over time, due to the so-called merit order effect (Hirth, 2013; Mills and Wyser, 2012).

One consequence of decreasing prices over time is that the support needed would be higher than currently calculated in the New Policies Scenario, where the benchmark is the average annual wholesale price. If the reference price considered for the calculations of the wind and solar PV subsidies were to be lower than the annual average by 10%, the subsidies for wind and solar PV would be 12% higher. With a price 20% lower, they would be 25% higher. For the end-user, the higher cost of subsidies would, at least in part, be compensated by the lower wholesale prices.

### *Competitiveness of solar PV for households*

For household auto-consumers, the break-even point for solar PV has typically been considered to be when the cost to the consumer reaches "grid parity" or "socket parity", that is, the point at which the levelised cost of electricity (excluding subsidies) falls to the average retail price for electricity. However, this approach has shortcomings and we question whether it is the appropriate metric to evaluate the competitiveness of solar PV in households. An alternate approach, that takes account of other relevant costs, is to measure competiveness on the basis of "cost parity". This is the break-even point for the costs incurred, on the one hand, by a household with a solar PV system and, on the other hand, by a corresponding household that is solely reliant on the grid (Spotlight).

The distinction between grid parity and cost parity has important real-world implications. In most markets, the fixed costs are only partially recovered through a fixed component in the electricity bills and the remaining part (often larger) is recovered through the

4. Auto-consumers are defined as those households which generate principally for their own consumption, with any excess being sold to the grid.

5. The levelised cost of electricity represents the average cost of producing electricity from a given technology, including all fixed and variable costs, expressed in terms of the present value equivalent.

variable component. From the single household perspective, under such an electricity tariff structure, it might, therefore, be economically attractive to invest in PV, where grid parity is reached. This could lead to a significant additional amount of PV installations.

However, from a system perspective, this creates a free-rider effect, where households with PV systems do not pay fully for their share of the system's fixed costs, shifting the burden to households without PV systems. This could concentrate fixed costs on fewer households, raising the retail prices against which the competitiveness of PV systems is measured according to grid parity. These system level issues require thorough assessment and attention from policymakers, regulators and retailers, who may need to consider the use of time-based metering and pricing, and tariffs adjusted to user profiles to ensure both the full recovery and fair allocation of system costs.

SPOTLIGHT

## Is residential solar PV already competitive?

A fall of over 40% in the price of solar panels since 2010 has led some parties to make the case that electricity generated from residential solar PV installations has become – or is fast becoming – competitive with electricity generated from fossil fuels. These arguments have often been based on the concept of "grid parity". But is grid parity the right criterion to measure the full competitiveness of residential PV, after which it can stand on its own without the need for subsidies?

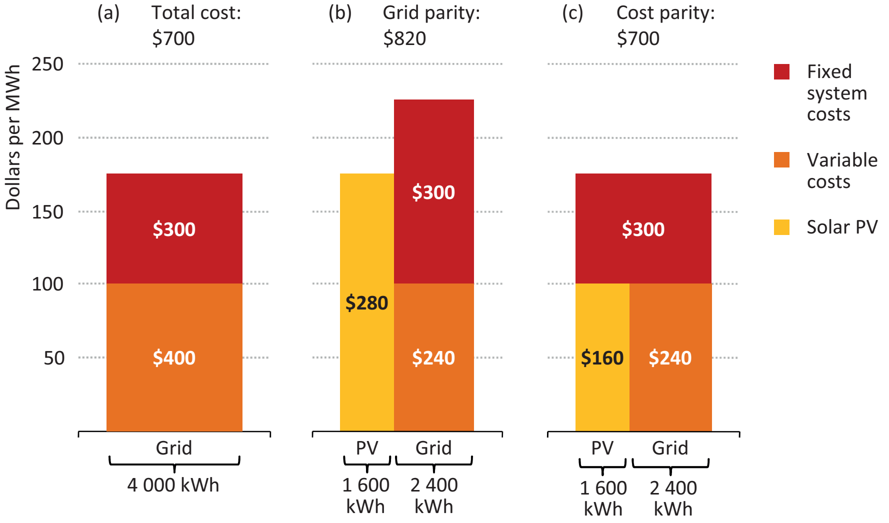
The short answer is no, at least for households that remain connected to the grid. The reason is that fixed system costs are not included in the calculations of grid parity. The fixed costs of a power system include costs such as the construction and maintenance of the transmission and distribution grids, metering and billing. From a system perspective, these costs always need to be recovered. When allowance is made for these costs, the cost of generation from solar PV systems would have to fall below grid parity to become competitive.

Take an example, in which residential solar PV has just reached grid parity. In the first case, the household does not install solar PV. It pays $300 per year in fixed charges (assuming all fixed costs are passed through) and another $400 per year for the 4 MWh it consumes, to give an average retail price of $175/MWh (Figure 6.10a).

In the second case, the household installs a solar PV system which produces 1.6 MWh for consumption on site, for a total cost of $280 (equal to 1.6 MWh × $175/MWh). It additionally purchases 2.4 MWh from the grid at cost of $540 per year (including fixed charges of $300, plus $240 for the energy consumed). This means that, at grid parity, the consumer pays a total of $820 per year for electricity when installing the solar PV system, higher than without it (Figure 6.10b).

A more accurate means of gauging the break-even point of solar PV is to consider "cost parity", which measures the point at which a household that installs a solar PV system incurs the same overall costs as it would if solely reliant on the grid. Using the example, the cost of the PV system would have to drop to $160 (1.6 MWh × $100/MWh), well below some current notions of grid parity, for it to make economic sense (Figure 6.10c). This is equal to the variable cost that the PV system is displacing.

**Figure 6.10 ▷ Indicative breakeven costs of residential solar PV using the "grid parity" and "cost parity" approaches**



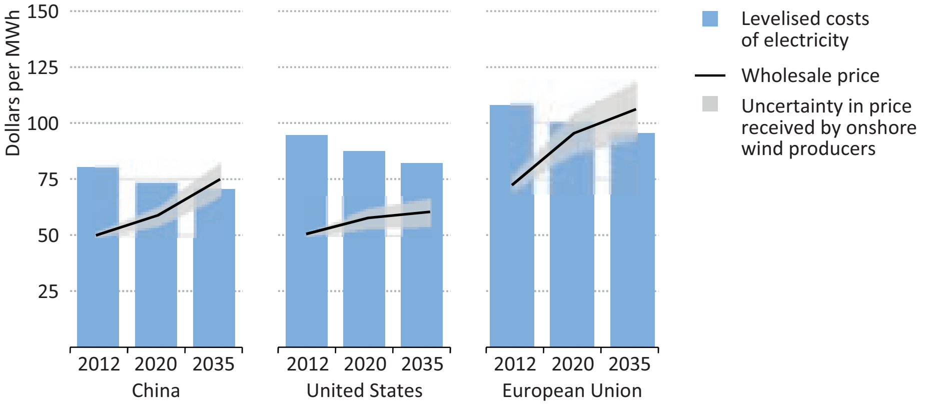

There are several other factors that could influence the competitiveness of solar PV. For example, the calculations would change if the household with the PV system did not consume all its generation on site but sold the excess to the grid. In that case, for the PV generator to be fully competitive, the electricity would have to be sold at the actual wholesale market prices, *i.e.* the same price that other suppliers receive at that time. Any higher price for electricity sales, if fixed by regulation, would result in windfall profits for the PV generator. Also, if the renewables integration costs were passed on to the seller, it would make competitiveness harder to achieve. On the other side, potential savings through reduced infrastructure needs could lower costs.

### *Unit costs*

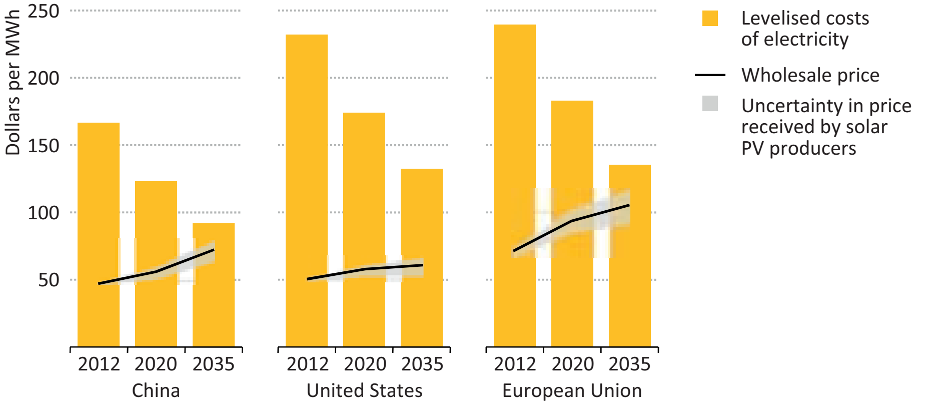
Generating costs for solar PV and wind power vary significantly across regions, according to local cost factors and the quality of the resources available (Figure 6.11). The evolution of these costs is largely determined by two factors: reductions in capital costs and technological advancements to harness more of the resource. Although increased deployment of wind and solar PV leads to prime sites becoming increasingly scarce within each region, which will tend to reduce capacity factors, at the global level this effect is expected to be more than offset by technological improvements and deployment in regions with untapped high-quality resources. Average capacity factors for wind onshore rise from 21% in 2012 to 26% in 2035, and for large-scale PV from 11% to 17% over the same period.

**Figure 6.11 ▷ Renewable electricity production costs relative to the wholesale prices for selected technologies and regions in the New Policies Scenario**

(a) Onshore wind




(b) Large-scale solar PV




Notes: The cost of production is the average levelised cost of electricity at deployed sites over the *Outlook* period, based on a weighted average cost of capital, assumed at 8% for OECD countries and 7% for non-OECD countries. Wholesale electricity prices are taken as the averages projected for respective regions in the New Policies Scenario. In the mid-term, they include the recovery of investment costs for new capacity. The pricing methodology can be found at *www.worldenergyoutlook.org*.

The global average investment cost of onshore wind was about $1 700/kW in 2012. Average costs for offshore wind turbines are still hard to quantify, due to the small number of projects in operation, but they are estimated to range from $3 000/kW to $4 500/kW. In the New Policies Scenario, the global average investment costs for onshore wind decrease by about 10%, partly due to learning effects and economies of scale, as well as a shift of new installations towards non-OECD countries and related lower investment costs. Investment costs for offshore wind decline by around one-third, with increased deployment.

Due to stepped up deployment and overcapacity in manufacturing, the price of solar PV systems dropped more than 40% between 2010 and end-2012. Demand for new capacity was around 30 GW while production capacity was about 55 GW in 2012. Much of the growth in production facilities occurred in China, raising concerns that subsidies were enabling Chinese manufacturers to flood the European market with panels sold below cost. An agreement has been reached, prescribing a cap of 7 GW per year and a minimum price for exports from China to the European Union and it is expected to run until end 2015. Assuming that learning and economies of scale lead to an average cost decrease of about 20% each time capacity doubles (Frauenhofer ISE, 2012), about half of the price decrease over the last two years has been due to overcapacity. As this temporary situation is resolved, market prices will tend to return to the long-term trend. Investments costs at the end of 2012 showed large regional differences. They ranged from some $1 800-5 500/kW for residential rooftop systems and $1 500-3 000/kW for large installations, with China on the low side of the range, and the United States and Japan towards the higher side. In the New Policies Scenario, by the end of the *Outlook* period, the cost for both types declines by around 40%.



## Bioenergy

### *Demand*

Total global demand for bioenergy across all sectors increases from 1 300 Mtoe in 2011 to about 1 850 Mtoe in 2035, about two-thirds of the primary energy demand for natural gas today.[6] The largest proportion of demand for bioenergy is in the buildings sector (including traditional biomass) throughout the *Outlook* period, though this declines in both absolute terms and share over time, largely as a result of relatively high levels of demand in non-OECD countries. Demand for bioenergy in the power sector increases most in absolute terms from 2011 to 2035, by about 280 Mtoe, especially due to significant expansion in non-OECD countries such as China, India and Brazil. This growth is mainly driven by policies to reduce air pollution, boost productive use of domestic agricultural residues and speed deployment of renewables. Also driven by government support policies, demand for biofuels in the transport sector grows at the fastest rate over the *Outlook* period. It more than doubles in OECD countries and increases five-fold in non-OECD countries. Biofuels increase to more than 10% of total bioenergy demand (Figure 6.12).

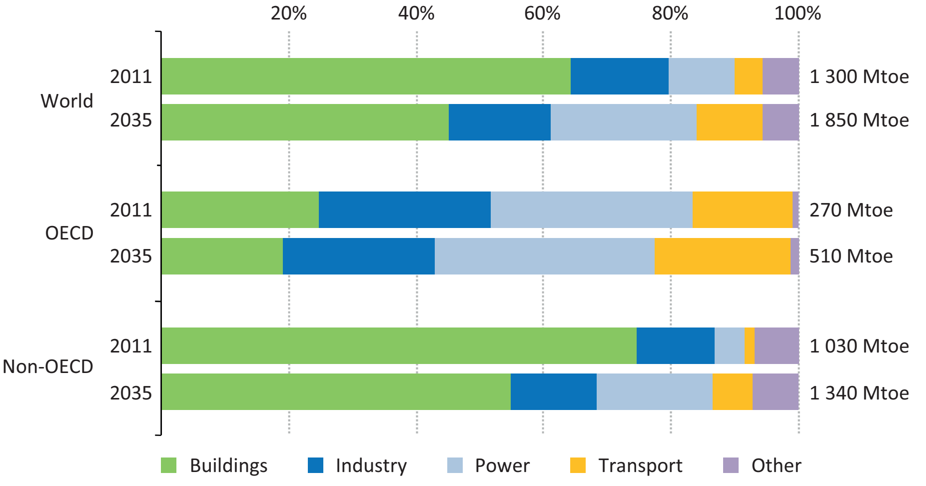
### *Production and Trade*

To meet strong demand growth in the New Policies Scenario, the supply of all types of modern biomass will increase substantially, including biogas and municipal waste. Globally, the potential supply of biomass exceeds the demand in 2035 by an order of magnitude, without competing with food supply or displacing current forestry activities, although land

6. Global biomass use in the "other energy sector" in 2011 was reported at 65 Mtoe. In several cases, biomass use in biofuels production was understated, and it is estimated that there were some 50 Mtoe of unreported biomass use. If this amount would be included, it would result in an additional 200 Mtoe in 2035, or about 12% of global primary biomass demand.

use implications need to be carefully considered (IEA, 2012).[7] On the one hand, for some regions, it will be difficult for the domestic supply of various biomass feedstocks to keep pace with growing demand. For example, the European Union has taken strong measures to support the use of bioenergy in several sectors, including power and transportation, but already imports large volumes of both biomass pellets and biofuels and will continue to do so. India is another region that, despite having large supply potential for many feedstocks, particularly agricultural residues, struggles to ramp up the collection of feedstocks to meet the strong growth in domestic demand for bioenergy, for both power sector applications and biofuels production. The challenge to meet the growing demand domestically will be especially difficult where markets already exist for waste products from agricultural and forestry activities. On the other hand, a few regions have ample supplies to meet both domestic demand and international demand. Brazil, Canada and the United States stand out in this group.

**Figure 6.12 ▷ World bioenergy use by sector in the New Policies Scenario**




Note: Buildings includes the use of traditional biomass.

The demand for bioenergy for power generation and heat increases from 136 Mtoe in 2011 to 420 Mtoe in 2035. Over 90%, of world demand is met from domestic resources throughout the *Outlook* period. To meet the remaining demand, some regions will increasingly turn to international supplies of solid biomass for power generation, most commonly in the form of biomass pellets.[8] In total, inter-regional trade of solid biomass for power generation increases from a few percent of biomass consumption to generate electricity to upwards of 8% by 2035.

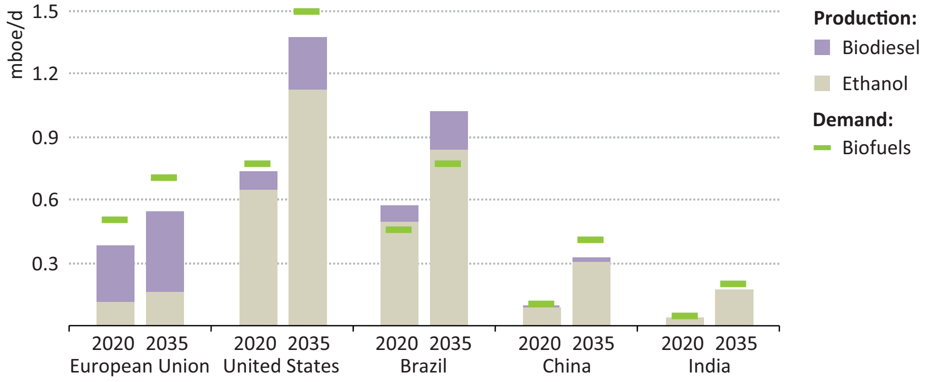
7. This technical potential, based on conservative technological improvements, is an evaluation of available supply of forestry products, energy crops, and residues from forestry and agricultural activities. For more information, please see www.*worldenergyoutlook.org*.

8. A processed product that has a relatively high energy density is fairly uniform and easier to transport than untreated biomass feedstocks.

The European Union is the largest importer of biomass for power generation by 2035, importing about 6.7 Mtoe. At current biomass pellet prices of $170 per tonne (Govan, 2012), the cost of these imports, largely coming from the United States, Canada and Russia, would reach almost $3 billion. Other regions may also become important players in this market, including countries in Latin America and Africa. In Japan, policy support pushes demand for biomass for power generation and heat well beyond available domestic resources, driving up biomass imports to up to 4.4 Mtoe in 2035, coming mainly from Australia and the United States. Korea and India also look set to become significant importers of solid biomass for power generation. In India, demand for solid biomass in power generation reaches 37 Mtoe, almost triple current levels, requiring some 100 million tonnes of dry biomass feedstocks. While a similar order of magnitude of agricultural residues is available, it will be difficult to collect and transport a high proportion of these to power plants at reasonable costs. As for many fuels in the power sector, China will become the largest consumer of biomass for power generation and heat by 2035. It also has one of the highest supply potentials, through a combination of agricultural and forestry residues, as well as forestry products. In the New Policies Scenario in 2035, China is a net exporter of biomass to other regions in Asia, though, as has happened for other fuels such as coal, a small shift in China's supply and demand balance could have a large impact on global trade.



**Figure 6.13 ▷ Biofuels demand and production in selected regions**




The international market for biofuels increases from 0.2 mboe/d in 2012 to about 0.7 mboe/d in 2035, providing a broadly constant share of total biofuels demand over time. The European Union is the largest net importer of biofuels in 2035, with over 20% of its biofuels demand, about 0.2 mboe/d (Figure 6.13), met through imports from many different countries, including Brazil, the United States and several countries in Asia and Latin America. These trade patterns re-emerge despite recent action by the European Union to impose anti-dumping duties on biofuel imports from Argentina, Indonesia and the United States, and the need for exporters to Europe to first meet sustainability criteria, verifying reductions in greenhouse-gas emissions and demonstrating limited direct and indirect environmental impacts. Furthermore, a cap for conventional biofuels of 6% (at the time of writing) in the transport sector is under discussion in the European Union, which could have important impacts on the global picture. The United States is both a major importer and exporter of biofuels throughout the *Outlook* period, importing sugarcane-based ethanol from Brazil to help meet rising targets for advanced biofuels under the Renewable Fuel Standard and exporting to the European Union to help meet blending targets there. The United States also continues to export lower volumes of ethanol to Canada and Mexico. Brazil is the main supplier for international biofuel markets, especially for fuel ethanol, and it is by far the largest exporter by the end of the *Outlook* period, providing about 0.2 mboe/d to the international market by 2035, about 40% of global biofuels trade.

China and India are both expected to increase their biofuels consumption several times over by 2035, making it difficult for domestic supply to keep up (Figure 6.13). By 2035, both require some imports to meet demand. They are expected to come mainly from Brazil, but also from Indonesia and other countries in Asia. The assumed development of advanced biofuels at commercial scale after 2020 affects the biofuels market in several ways. First, it creates a single market for biomass feedstocks for the power and transport sectors. For some regions, this limits available supply for one or both of these sectors. For example, in India available supplies of residues become relatively scarce by the end of the *Outlook* period due to demand from multiple sectors. The development of advanced biofuels also allows some regions to reduce their reliance on imports of biofuels, as they are able to tap alternative feedstocks to produce biofuels. For example, the European Union is able to limit imports of biofuels after 2025 due to a rise in domestically produced advanced biofuels.

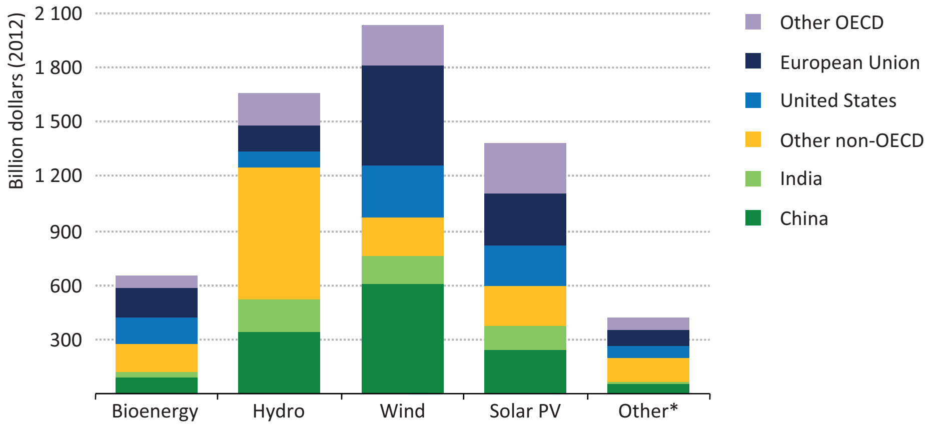
## Investment

Cumulative investment of $6.5 trillion (in year-2012 dollars) is required in renewable energy between 2013 and 2035 in the New Policies Scenario. This corresponds to $280 billion per year on average. Annual investments increase over the period, reaching almost $370 billion in 2035.[9] Renewables for power generation account for more than 95% of the total, with the remainder for biofuels.

Projected investment for renewables in the power sector amounts to $6.2 trillion between 2013 and 2035 (Figure 6.14). Renewables account for 62% of investment in new power plants over the projection period, providing just over half of total capacity additions. Wind power accounts for one-third of the total investment in renewables capacity, followed by hydropower (27%) and solar PV (23%). Investment for renewables in non-OECD countries are $3.3 trillion, higher than the $2.9 trillion required in OECD countries at. Additional global investment of $260 billion (4% of total grid infrastructure investment) is needed to upgrade transmission and distribution networks to accommodate more renewables-based capacity. Investment to meet the expansion of biofuels supply amounts to $330 billion over 2013-2035, or $14 billion per year on average. Conventional production of ethanol requires the bulk of the total (60%), followed by conventional biodiesel (14%) and the remainder for advanced biofuels. OECD countries account for around 60% of total investment.

9. Investments for renewables used for heat are included in the buildings sector investments (see Chapter 7).

**Figure 6.14** ▷ **Cumulative investment in renewables-based power generation capacity, 2013-2035**




* Other includes geothermal, marine and solar CSP.

## Subsidies

Renewable energy subsidies take a variety of forms, including blending mandates, quotas, portfolio obligations, tax credits and feed-in tariffs, which all offer a higher return than market prices, to offset higher costs. With schemes like feed-in tariffs, blending mandates or portfolios and quota obligations, this remuneration is paid by the end-users (though some schemes, such as tax credits are funded from government budgets). Many forms of support mechanisms are specific to electricity produced by renewables capacity installed in a particular year, and have a fixed duration, typically twenty years. Subsidies for biofuels predominately take the form of blending mandates.

Hydropower and geothermal, have long been economic in many locations. Newer technologies, such as wind and solar, are often an attractive option for generating electricity in remote, isolated areas with limited or no existing grid infrastructure, but they require policy support to foster their deployment in most countries. The costs of generation from onshore wind are getting closer to the average wholesale price level in many countries – and are already there in some, such as New Zealand, Brazil, Ireland and parts of the United States. Reductions in production costs for conventional biofuels have not been as pronounced and these costs remain vulnerable to high feedstock prices and weather conditions. Outside Brazil and some parts of the United States, conventional biofuels generally still cost more than oil-based gasoline or diesel. Advanced biofuels remain even more costly, although there are promising signs that significant cost reductions in the production process are on the horizon.

In addition to playing a crucial role in driving down the costs of renewable energy technologies, subsidies to renewables can have important co-benefits (Box 6.3). But support schemes for renewables need to be carefully designed to ensure their efficiency and effectiveness. They should be predictable and transparent and, where possible, provide for competition between technologies best suited to meet short- and long-term objectives. They need to be accompanied by ambitious, yet credible, targets and offer support differentiated according to the maturity of each technology. As cost reductions are achieved, the level of support provided for new installations needs to decline to avoid unnecessary increases in the cost of energy services.

### Box 6.3 ▹ Multiple benefits of renewables

The contribution of renewable energy to global energy needs has continued to grow in recent years, stimulated by policy initiatives in an increasing number of countries. The benefits of renewables within a national energy portfolio can be summarised as:

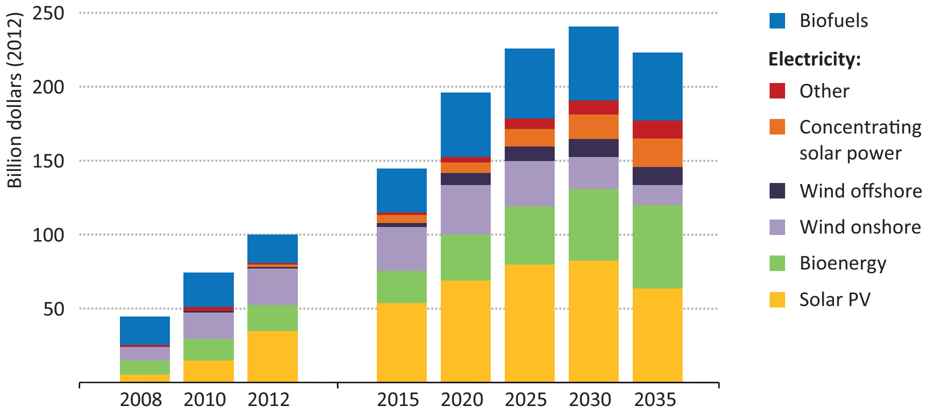
- **Energy security and diversity**: renewable energy technologies can contribute to energy security by providing more diversity in energy supply. They can also reduce the need for fossil fuels, in turn, reducing fuel import bills.
- **Environment**: the deployment of renewables in the New Policies Scenario saves some 4.1 gigatonnes (Gt) of $CO_2$ emissions in 2035 compared with the 2010 fuel mix at the same level of total generation (IEA, 2012). Renewables also help reduce local air pollution and emissions of other pollutants, such as sulphur dioxide and nitrogen oxides.
- **Economic benefits**: the development and deployment of renewables can form part of comprehensive strategies aimed at more sustainable economic growth (often called "green growth"). Renewable energy has featured strongly in economic recovery packages put in place in response to the global economic downturn.
- **Energy access and affordability**: renewables can play an important role in providing electricity access modern energy services to the 1.3 billion people currently without access to electricity and the 2.6 billion that still rely on traditional use of biomass. Mini-grid and off-grid solutions, including solar PV, are often less costly than grid extension to rural areas (see Chapter 2).

Based on a survey of established national policies, renewables are estimated to have received $101 billion in subsidies in 2012, 11% higher than 2011.[10] This includes $82 billion to renewables for electricity generation and $19 billion to biofuels for transport. The rise in 2012 was primarily due to the increase in solar PV capacity, increased generation from capacity installed towards the end of 2011 and the increase of onshore wind capacity. The level of renewables subsidies is less than one-fifth of the fossil-fuel consumption subsidies in the same year (see Chapter 2). However, the geographical distribution is very different, with OECD countries paying about 85% of the renewables subsidies. Subsidies were most generous in the European Union ($57 billion) almost 60% of the total, the United States ($21 billion) and China ($7 billion). Ranked by generating technology, subsidies for solar PV ($35 billion) were the highest, followed by wind ($26 billion) and bioenergy ($17 billion).

10. The subsidy estimates do not include integration costs or subsidies for renewable energy use for heat. See *www.worldenergyoutlook.org* for the methodologies on how renewables subsidies and fossil-fuel consumption subsidies are calculated.

Subsidies to biofuels declined by almost 20% in 2012 from the previous year. This is partly due to reform of taxation levels (or tax incentives) in some of the main subsidising regions, notably the United States and Brazil. In the United States, the US Congress did not extend the ethanol import tariff nor the production tax credit for ethanol, which had been in place for decades. In Brazil, subsidies to biofuels fell by more than half due to lower ethanol supply, following a reduction in the blending mandate, and a decrease in the tax preference provided to ethanol, when gasoline taxes were reduced in the middle of the year. China, too, drastically lowered subsidies for ethanol from $155/tonne to $80/tonne and, although biofuels use increased, the total subsidy level declined.

**Figure 6.15 ▷ Global renewable energy subsidies by source in the New Policies Scenario**



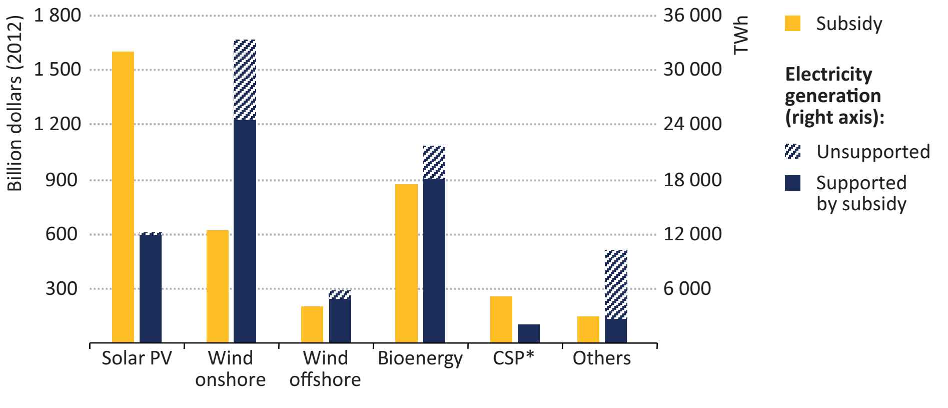

Notes: Other includes geothermal, marine and small hydro.

The New Policies Scenario projects an almost six-fold increase in electricity generation from non-hydro renewables and a tripling of the use of biofuels. Subsidies to renewable energy amount to over $220 billion per year in 2035, after peaking just above $240 billion around 2030 (Figure 6.15). From 2013 to 2035, cumulative subsidies to renewables amount to $4.7 trillion, or around 0.15% of cumulative global GDP. These estimates are calculated by taking the difference between the levelised cost of electricity generated by the renewable energy technology and the regional wholesale electricity price, multiplied by the amount of generation. For biofuels, they are calculated by multiplying the volumes consumed by the difference between their cost and the reference price of the comparable oil-based products.

In total, annual subsidies for renewables for power generation reach $177 billion in 2035. They peak around 2030 and then decline, thanks to increasing wholesale power prices, the decreasing unit costs of most renewable energy technologies, and because older installations are gradually retired, meaning that newer and cheaper units make up a larger share of the installed capacity. Subsidies for onshore wind power peak just after 2020, earlier than those for any other technology, reflecting the increasing competitiveness of this technology. Subsidies for biofuels continue to increase until 2030 to $50 billion, reaching $45 billion in 2035. The bulk of this goes to conventional biofuels, which remain uncompetitive in most locations with conventional gasoline or diesel.

Over the projection period, onshore wind becomes competitive in more and more regions, generating over 33 300 TWh cumulatively, supported by subsidies of some $620 billion (Figure 6.16), corresponding to a low level of subsidy per unit of output ($19/MWh on average over the *Outlook* period, including non-subsidised generation). Solar PV requires $1 600 billion of cumulative subsidies and generates almost 12 200 TWh, meaning a higher average unit subsidy of $131/MWh. Where support policies are committed for many years (typically twenty years for feed-in tariffs), subsidies for older capacity continue to be paid, even after new projects reach competitiveness. For bioenergy, the unit subsidy remains broadly constant through 2035, as costs are not expected to decline significantly. For this reason, and due to a more than three-fold increase in bioenergy generation, subsidies to bioenergy become the second-largest of all by 2035, behind solar PV.

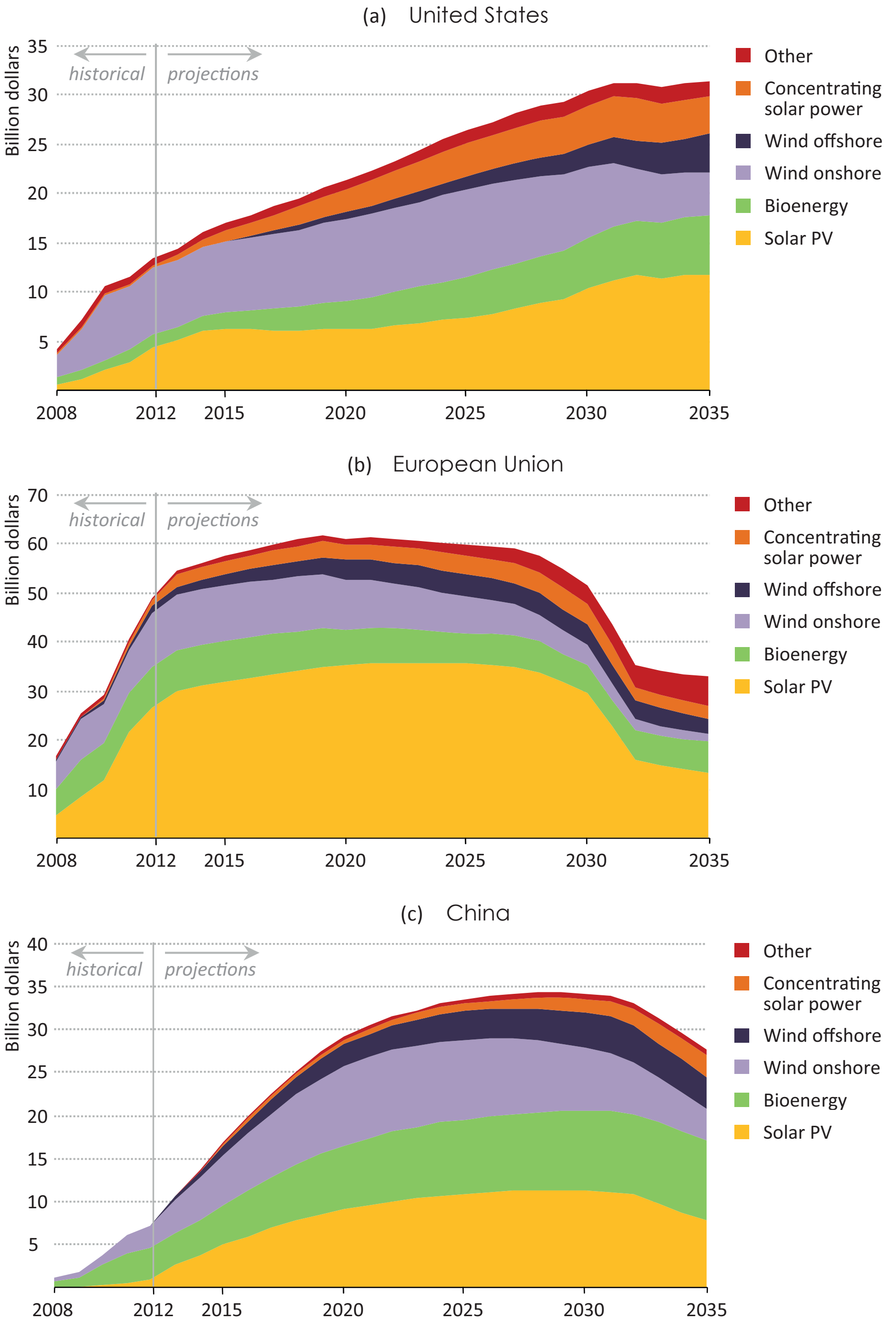
**Figure 6.16 ▷ Global subsidies for renewable electricity generation and generation by source in the New Policies Scenario, 2013-2035**



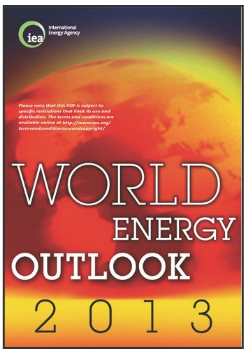

* Concentrating solar power.

Similar to the global trend, total subsidies to electricity from renewables peak over the projection period in the European Union and in China (Figure 6.17). In the European Union, subsidies level off in 2020 at $60 billion per year, before declining to about half that level by 2035, as the subsidies to some 52 GW of PV solar added in the last three years come to an end and wholesale prices increase. The peak in China reaches about $35 billion per year around 2030 and then falls to below $30 billion in 2035. The bulk of the increase is attributable to bioenergy and solar PV. The share of wind decreases from 37% in 2012 to 26% in 2035. In the United States, subsidies increase from $13 billion in 2012 to just above $30 billion in 2035, while generation from non-hydro renewables almost quadruples. Subsidies to onshore wind decrease over the *Outlook* period, as the technology gains in competitiveness, while subsidies to bioenergy increase strongly, due to a three-fold increase in generation and the replacement of a large amount of aging capacity.

**Figure 6.17 ▷ Renewables-based generation subsidies by source and selected region in the New Policies Scenario**




Note: Other includes geothermal, marine and small hydro.



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