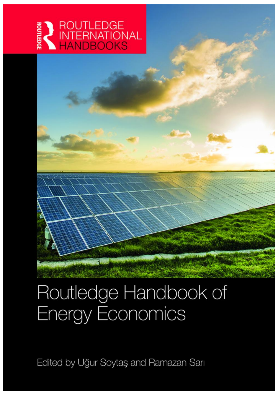


# Routledge Handbook of Energy Economics

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# Economics of renewable energy

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# 4

# Economics of renewable energy

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## 1 Types of renewable energy and their applications

*Renewable energy* refers to the energy that is generated from natural resources that are continuously replenished. This includes solar, wind, hydro, biomass, geothermal, and ocean (tidal) energy. Renewable energy has been in use since ages, as early as humans started using it for heating and lighting purposes. It is currently being used prominently in four areas: power generation (centralized), decentralized generation (off-grid energy services in rural areas), space and water heating/cooling, and transportation. A variety of technologies have been developed to generate and use energy from the renewable resources. Renewables supplied 23.8% of the global power generation in 2016 (IEA, 2018c). Renewables represented almost two-thirds of new net electricity capacity additions in 2016, with almost 165 gigawatts (GW) coming online (IEA, 2017b) Overall renewable power capacity, including hydro, had reached 2,195 GW by 2017, of which hydropower contributed 1,081 GW (REN21, 2018). Prominent renewable energy technologies and their shares in the total renewable energy are briefly described below.

### *1.1 Wind power*

Wind turbines are used to convert wind energy into electricity with utility scale single turbines crossing 9 MW, though most of commercially used turbines are up to 5 MW. The power available from the wind depends on the wind speed and duration of the wind. Therefore, wind turbines are put up at high altitudes, and offshore of late, where wind speeds are higher. The wind speed and duration of wind determine the amount of power generated and variability of the generation. Whereas hydro energy has been used for power generation for a long time, wind grew fastest in the early stage of focus on renewable power to address the issue of climate change and installed wind power capacity increased from 47 GW in 2004 to 539 GW by the end 2017 (WWEA, 2018). Wind-generated electricity met nearly 4% of global electricity demand in 2015. WWEA (2014) also estimated total worldwide potential for wind at 94.9 TW, excluding offshore in most cases, indicating that the identified wind potential was almost double of the whole world's energy demand assuming on average 2,000 full load hours.

Top five wind power countries at the end of 2017 were China, the United States, Germany, India, and Spain.

## 1.2 Hydropower

Hydropower is electricity generated using the energy of moving water. This source of energy has been used for centuries – to grind wheat into flour using water wheel for example – but its major use is as source for generating electricity. In 2016 hydropower generated more than 15% of the world's total electricity and 65% of all renewable electricity (IEA, 2018c). The largest among renewable power, hydropower capacity (including pump hydro) had reached 1,114 GW by 2017 (REN21, 2018).

There are three types of hydropower plants:

- Large hydroelectric dams and reservoirs: Historically, hydroelectric power was generated by constructing large reservoirs, which is still popular in many developing countries. With an installed capacity of 22,500 MW, the Three Gorges Dam in China is the biggest such plant.
- Small hydropower plants: Typically plants not exceeding 50 MW capacity, built on small rivers or a series of plants on a big river to manage impacts on the local community.
- Run-of-river plants: As the title indicates, these plants have little or no water storage, minimizing the impact on the local community.

## 1.3 Solar energy

A number of technologies have evolved to use solar energy; these include already commercially viable technologies such as photovoltaics and solar heating, and other technologies under different stages of development such as concentrated solar power (CSP), concentrator photovoltaics (CPV), and artificial photosynthesis. In addition to this, in buildings, active and passive solar architecture helps harness solar energy.

A photovoltaic (PV) system uses the scientific phenomenon known as photoelectric effect to convert sunlight into electrical energy. PV is the most popular and widely used solar energy technology to produce electricity. Concentrated solar power (CSP) systems use lenses or mirrors and tracking systems and convert a large area of sunlight into a small beam.

The third-largest among renewable power (behind hydro and wind), global solar PV capacity and CSP systems capacity in 2017 were 402 GW and 4.9 GW, respectively.

## 1.4 Geothermal energy

Geothermal energy is thermal energy from the Earth. Originating from processes during earth formation and subsequent radioactive decay of minerals below the surface of earth, it is extracted for a variety of uses, including for electricity generation, water and space heating, and space cooling, depending on temperature gradation. Temperature at the core of earth can be very high (over 5,000°C), from where it conducts to the surrounding rocks and upwards. Thus, below the surface of earth, water gets heated to high temperatures, converting it to steam, which is used for generating electricity. Hot springs, used for bathing and cooking, are also examples of low grade geothermal energy.

Low temperature geothermal energy is also used for heating and cooling buildings, and in other refrigeration and industrial uses. Geothermal heat pumps (GHP) are used for this purpose. GHP helps reduce electricity demand for heating and cooling from buildings, which otherwise contribute to the peak in the system.

Worldwide geothermal power capacity was 12.8 GW in 2017.

## *1.5 Bioenergy*

Bioenergy is primarily derived from biomass, which often refers to plants or plant-derived materials. Biomass is used directly through combustion to produce heat as well as indirectly through conversion to biofuels. Biomass resources include wood and wood waste, crops and crop residues, dung and all other type of organic waste from plants and animals (IEA, 2018a).

Biomass can be converted to other usable forms of energy; into gaseous fuels like methane or transportation fuels like ethanol and biodiesel. Methane is generated by landfills and also from agricultural and human waste. Some crops like corn and sugarcane are used to produce ethanol, and biodiesel is produced from a variety of agricultural produce that contain fats/oils. Second-generation biofuels that use plants and other organic material, which is not used for human consumption, are under advanced stage of research and development. Biomass is also used for electricity generation – wood residues, agricultural waste (sugar cane residue, rice husks), and animal husbandry residues are used as feedstock in boilers that produce steam for electricity generation.

Conversion of biomass to biofuel is achieved using *thermal, chemical*, and *biochemical* methods. Biofuels include bioethanol, biodiesel, biogas, landfill gas, and synthetic gas. Bioenergy production and use from renewable biomass resources, though carbon neutral, is associated with other harmful pollutants.

Modern bioenergy refers to the relatively efficient use of biomass heat in industry processes, space and water heating, district heating, electricity and transport. More than 50% of biomass energy relates to the traditional use of biomass in developing countries for cooking and heating, using inefficient open fires or simple cookstoves.

Bioenergy power capacity was estimated at 122 GW in 2017.

Existing technologies are getting better and new technologies are emerging. Some of the emerging technologies are indicated in Box 4.1.

### Box 4.1 Emerging technologies

Several other renewable energy technologies are under development, and include the following:

*Enhanced geothermal system (EGS)*: Generates energy without the need for natural convective hydrothermal resources. EGS technologies enhance and/or create geothermal resources in the hot dry rock (HDR) through "hydraulic stimulation".

*Cellulosic ethanol*: Also referred as one of the second-generation biofuel, ethanol is produced from plant cellulose instead from the oil seed, which has alternate uses.

*Ocean energy (or marine energy)*: This refers to the energy from ocean waves, tides, and ocean thermal (due to temperature differences across water layers).

*Other technologies under different stage of development*: These include concentrated photovoltaics (CPV) systems, that employ concentrated sunlight onto photovoltaic surfaces to generate electricity; floating solar arrays in which PV systems float on the surface of water reservoirs, lakes, or canals; artificial photosynthesis in which solar electromagnetic energy is stored in chemical bonds by splitting water to produce hydrogen and then using carbon dioxide to make methanol; algae fuels that produce liquid fuels from oil-rich varieties of algae.

Modern forms of renewable energy are primarily displacing conventional energy in the areas of electricity generation, water and space heating and cooling, transport, and off-grid energy services, especially in rural areas. The major applications of renewable energy are briefly described below.

## 1.6 Electricity generation

Renewable power commissioned in 2017 reached a record 157 gigawatts (GW), far exceeding the 70 GW of net fossil fuel generating capacity. Of this solar alone at 98 GW crossed total fossil fuel capacity added, balance coming from other renewables, namely, wind, solar, biomass and waste-to-energy, geothermal, marine and small hydro. Installed capacity for solar PV and wind reached 402 GW and 539 GW, respectively, by the end 2017. Total renewable power capacity reached 2,195 GW (1,081 GW excluding hydro) and share of renewable electricity rose to 12% of total electricity generated in 2017, avoiding around 1.8 gigatonnes of carbon dioxide emissions (Frankfurt School-UNEP Centre, 2018). Overall, renewables accounted for an estimated 70% of net additions to global power generation capacity, up from 63% in 2016.

Renewables-based stand-alone and off-grid single home or mini-grid systems represented about 6% of new electricity connections worldwide between 2012 and 2016 (REN21, 2018).

## 1.7 Heating

Renewables' contribution to heating is currently limited but developments in some countries indicate that increased use of renewables is possible. Renewable energy share in heating and cooling in 2016 was 68.6% in Sweden, primarily from use of biomass, and the share of renewable energy (including recycled heat) in district heating reached 90% in 2017. Denmark has recently incorporated solar thermal also into its district heating systems. Bioenergy was used in Brazil to meet around 50% of its industrial heat demand in 2017. Geothermal energy directly for heating and geothermal heat pumps, which provide both heating and cooling, has also been introduced in this area.

Global solar water heating capacity reached 472 GW in 2017, with more than 70% of the capacity in China. Besides modern renewables that provided 10.3% of total global energy consumption for heat in 2015, another 16.4% was supplied by traditional biomass, predominantly for cooking and heating in the developing world (REN21, 2018).

## 1.8 Transportation

Production of bioethanol and biodiesel, used as fuel for vehicles as a substitute for gasoline and diesel, reached 106 and 31 and billion liters, respectively, in 2017. Growth was moderate in case of ethanol, and there was no growth in case of biodiesel over 2016 on account of concerns related to impact on agriculture and environment from increased use of these two fuels in transport (food-feed-fuel issue).

Electric vehicles (EV) are however gaining momentum in the transport, which also helps integration of variable production of electricity from renewables into the grid, as variable production can be absorbed through battery banks that vehicles and charging stations use. Fully electric passenger cars, scooters, and bicycles are becoming common place in countries such as Norway and China. More than 200 million two- and three-wheeled EVs were on the world's roads in 2016, and more than 30 million are being added each year. Electric passenger cars passed the three million mark in 2017 (REN21, 2018). Electricity use in other transport mediums is also planned in many countries, which may further increase renewables' contribution to transport.

### *1.9 Distributed Renewables for Energy Access (DREA)*

More than one billion people do not have access to electricity, and about 2.8 billion people do not have clean cooking facilities. The majority of these are in rural areas in Asia and Africa. DREA systems, including off-grid solar systems and renewable-based mini-grids, are increasingly being supported to provide energy access along with support to diffusion of clean cook stoves. There are several support programs for decentralized renewables in Africa; African Development Bank (AfDB), for example, has recently initiated a USD 12 billion plan under its new electrification program that aims to provide decentralized solar technologies to 75 million households and businesses between 2017 and 2022 in Africa (Ford, 2017). A variety of business models are being tested and used to provide energy access – the pay-as-you-go (PAYG) business model for example has been used widely. Off-grid solar systems, and in particular those commercialized through the pay-as-you-go (PAYG) business model, were the most significant technology in the sector, providing electricity access to more than 360 million people worldwide (REN21, 2018).

## 2 Cost of renewable energy and trends

The cost of renewable energy has fallen substantially over the last two decades. Still the contribution of renewables to the world's energy mix is a rather modest one. According to IEA statistics (IEA, 2018c), all forms of renewable energy account for a mere 13.7% of total primary energy supply. Biofuels and waste (which is classified as renewable) dominate the renewables segment (69.5% of total renewables), solar and wind energy are still hardly noticeable on a global scale. In electricity production, however, renewables account for 23.8%, largely as a result of hydropower generation.

Between 1990 and 2016, total worldwide energy demand increased at an average annual rate of 1.7%, hardly outpaced by renewables which increased by 2% annually on average. Solar PV and wind energy were the fastest growing forms of renewable energy, with average annual growth rates of 37.3% and 23.6%, respectively (Figure 4.1). The use of solid biofuels and charcoal increased by just 1.1%, dragging the average growth of all renewables to 2.0%.

In 2016, the regional shares of renewables in total primary energy demand ranged from 0.4% in the Middle East to 49.5% in Africa. In OECD countries renewables provided 9.9% to total energy demand (IEA, 2018c). Between 1973 and 2016, the share of renewables in global energy demand increased by 1%, however total energy demand more than doubled over that time span. According to IEA projections, global energy demand over the period to 2040 is projected to increase under all scenarios considered, with fossil fuel shares ranging from 79% under the "Current Policies" scenario to 61% in the "Sustainable Development" scenario (IEA, 2017c).

The market penetration of any (new) technology depends on its economic competitiveness. In the case of renewable energy this competitiveness is largely driven by (generation) cost and the regulatory environment. In many cases, the cost of renewables have fallen dramatically and are likely to continue their decline over the coming decades. In Germany, for example, onshore wind power at good locations is already cost competitive with new coal and gas combined cycle power plants (Kost et al., 2018).

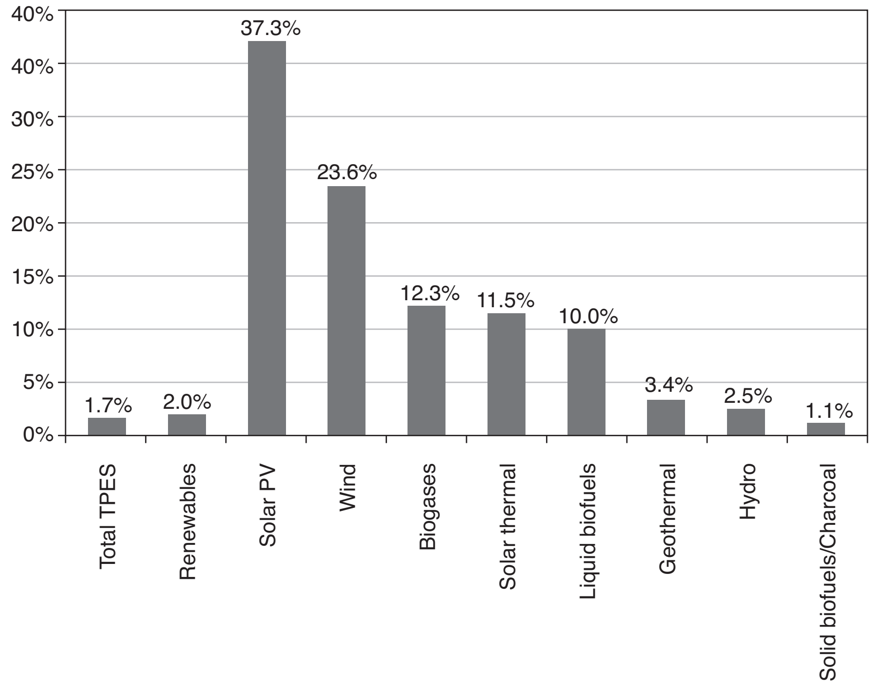


*Figure 4.1* Average annual growth rates of world renewables supply, 1990–2016

*Source*: IEA (2018c).

In order to express the competitiveness of different generating technologies, the concept of levelized cost of electricity (LCOE) is usually adopted. It represents the cost in discounted real monetary units of building and operating a generating plant over an assumed financial life cycle. Capital costs, fuel costs, operation and maintenance costs, financing costs, and an assumed utilization rate are key inputs in the calculation. Incentives such as feed in tariffs and tax breaks also affect the calculation of LCOE. An alternative indicator of economic competitiveness is that of levelized avoided cost of electricity (LACE). It considers avoided cost – "a measure of what it would cost the grid to generate the electricity that would be displaced by a new generation project" (EIA, 2018, p 3).

Global LCOE from utility-scale solar PV projects (weighted by deployment) declined by 70% from 2010 to 2016. By 2040 an additional decline of 60% is expected by the IEA, and the learning curve is quite steep: "The assumed rate at which costs decline for solar PV in the future also varies slightly depending on local conditions, but in general it is around 20% for each doubling of cumulative installed capacity" (IEA, 2017c). Figure 4.2 show past and projected evolution of global average generation cost for utility-scale solar PV and EV battery technologies, and Figure 4.3 provides information on levelized cost of electricity generation for selected technologies in the European Union and India. Figures 4.4 and 4.5 show levelized cost for solar PV and wind technologies and conventional baseload technologies, depending on the cost of capital. The numbers clearly show that – without taking into account external costs of conventional technologies – most forms of renewables are still at a competitive disadvantage.

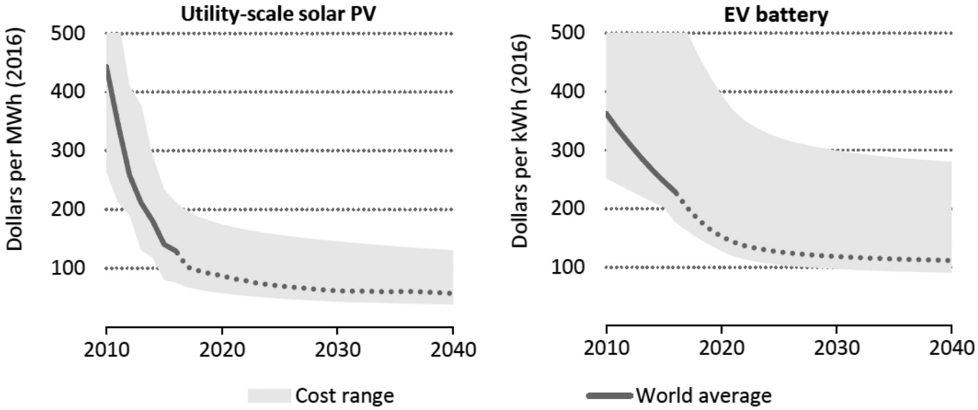


*Figure 4.2* Global average costs for utility-scale solar PV and EV battery

*Source*: IEA (2017c).

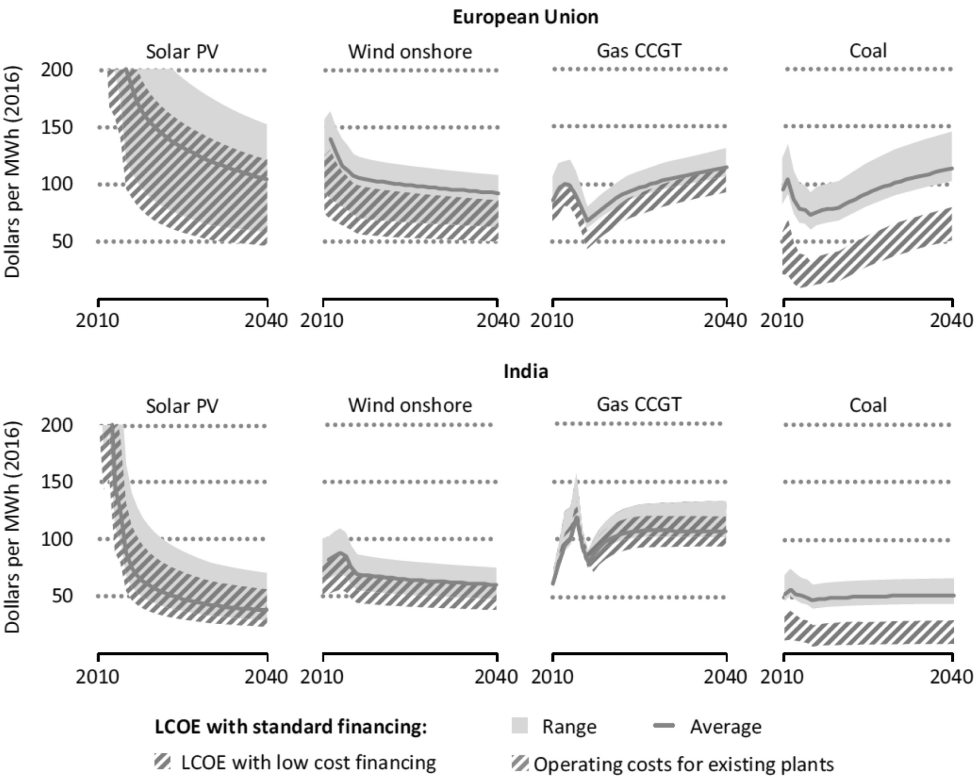


*Figure 4.3* Levelized cost of electricity for selected technologies, European Union and India

*Source*: IEA (2017c).

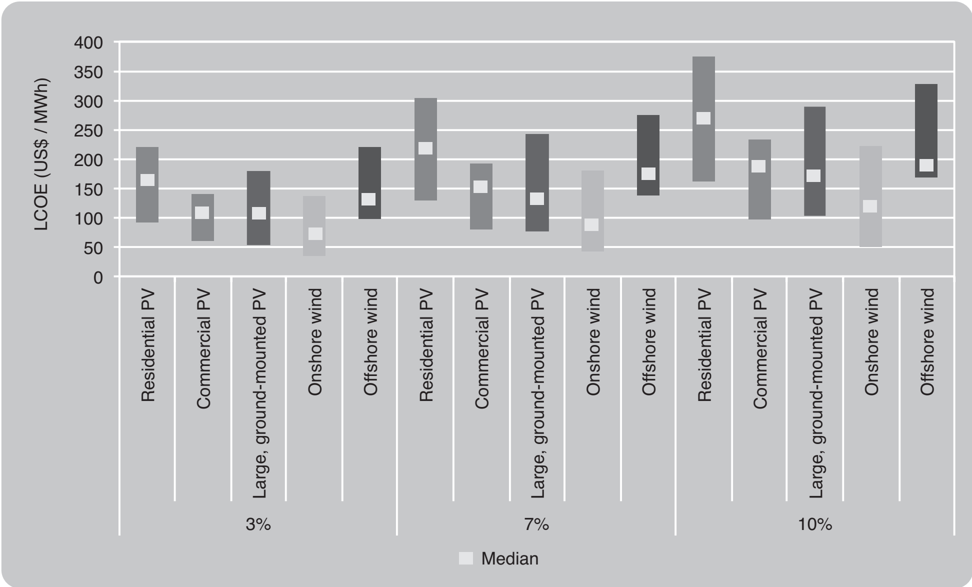


*Figure 4.4* Levelized cost of electricity (LCOE) for solar PV and wind technologies

*Source*: IEA (2015).

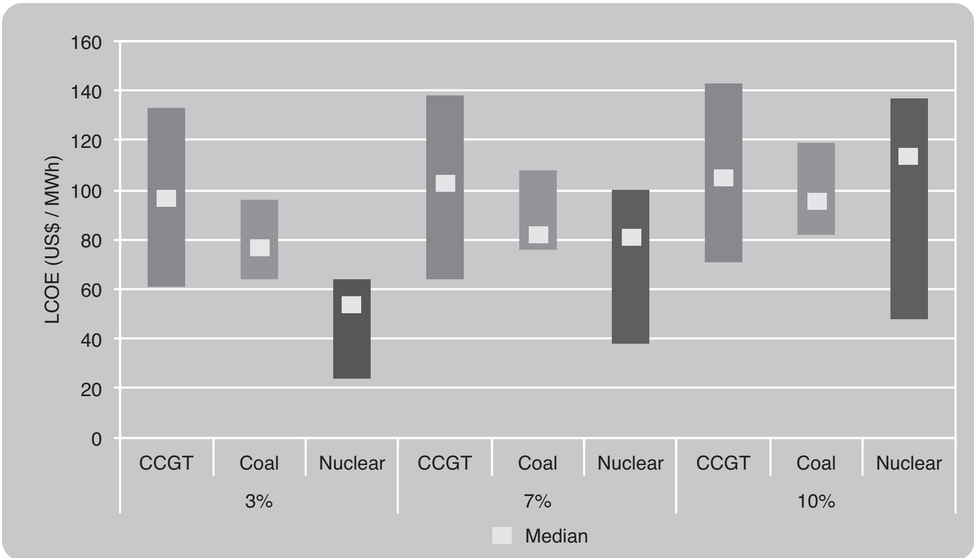


*Figure 4.5* Levelized cost of electricity (LCOE) range for baseload technologies

*Source*: IEA (2015).

Another important cost component is the cost of intermittency of non-dispatchable generation technologies such as solar and wind. Dispatchable technologies have in general more value to a system than less flexible technologies (Khatib and Difiglio, 2016). A dispatchable generation technology refers to that can generate and dispatch electricity on demand of power grid operators, according to market needs. Dispatchable technologies allow generators to be turned on or off, or adjust their power output. When including costs (essentially capacity and energy costs) and benefits (such as avoided capacity and avoided energy costs according to the LACE principle), net costs and benefits of renewables are less favorable than those of gas, nuclear and hydro, as can be seen from Figure 4.6.

Comparing costs and benefits is a tricky task because individual generating technologies are characterized by very different impacts at the systems (i.e. the grid) level. These impacts vary substantially, depending on numerous factors. Even when performing LCOE calculations, many factors have to be taken into account to properly account for the "true" (generating) cost. Many comparisons between fossil and renewables are biased as result of an incomplete analysis. An important issue is the removal of subsidies. Critics of the "energy transition" argue that subsidizing renewables is too costly, and subsidies should be removed. On the other hand, fossil and nuclear fuels have been and still are massively subsidized. The IEA (2017c) estimates that global fossil fuel subsidies amount to USD 260 billion, with electricity and oil industries the largest recipient of those subsidies. Even though fossil fuel subsidies declined from their peak of USD 500 billion in 2012, they still provide an incentive for their use. Environmental externalities are another important factor that biases the comparison between fossil/nuclear technologies and renewables. Efforts to internalize those external costs (e.g. the costs of global warming), have so far not been sufficient in promoting renewables. Carbon pricing schemes, as those implemented

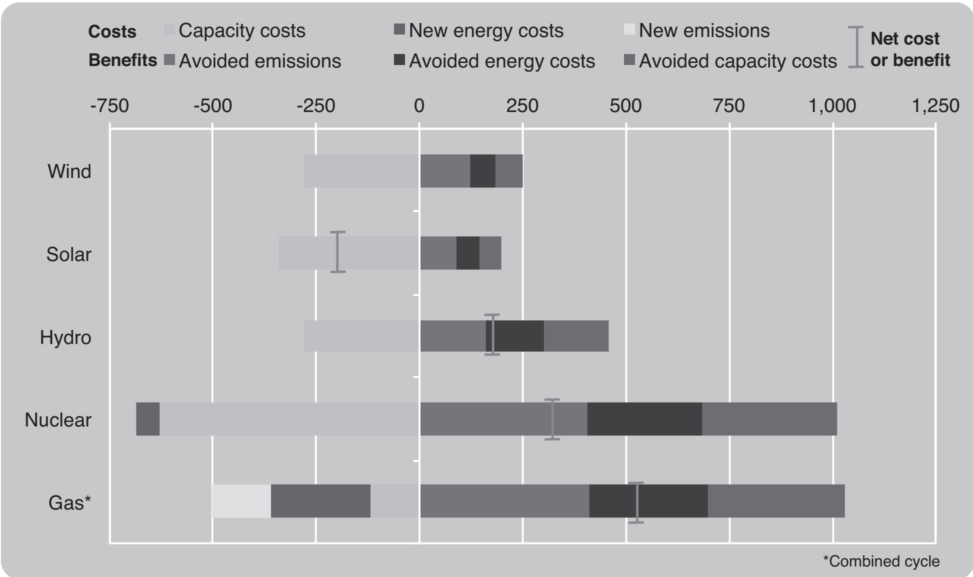


*Figure 4.6* Net costs and benefits per year per MW compared with coal baseload generation, United States, $1000 (2014)

*Source*: *Economist*, 29 July 2014.

by the European Union, are largely flawed and provide too little incentive for a large scale switch to renewables (Agora Energiewende and Sandbag, 2018). Non-dispatchable renewables can contribute to fuel supply security, especially when fuels have to be imported. Largely as result of lower energy density, the use of renewables also can have significant impact on a region's economy (Jenniches, 2018).

Edenhofer et al. (2013) provide a comprehensive analytical framework for the assessment of renewable energy from a societal perspective. They point to numerous cases of market failure. A social welfare function must include aspects such as climate change mitigation, green jobs, energy security, green growth, poverty reduction, and regional impacts of energy use. Multiple public policy objectives, multiple instances of externalities and the availability of multiple policy instruments constitute a significant challenge for energy policy.

Expenditure on energy research and development (R&D) is important to assure further cost reductions. Composition of public energy-related R&D expenditure changed substantially over time. In 1974 it accounted for more than 70% of all public energy-related R&D expenditure, by 2015 this share has fallen slightly more than 20%. Renewable energy and energy efficiency increased, as can be seen from Figure 4.7. This figure shows quite impressively the focus on nuclear energy research in 1974. Had this amount been spent on renewables, they would probably already have achieved full cost competitiveness.

The ultimate goal of mechanisms to promote renewables must be their full competitiveness even without subsidization. Therefore, energy policy should always provide a "sunset clause" which defines a clear date for phase out of subsidies. Criteria for the assessment of mechanisms to financially support renewables are typically efficiency (least cost) and effectivity (extent to which a goal is achieved). Experience shows that there tends to be a trade-off between these two criteria. Highly effective mechanisms such as feed-in tariffs (FITs) are not cost-effective, at least not in the short run. On the other hand, theoretically superior instruments, such as auction-based mechanism, often fail due their lack of effectivity, which in many cases is result of investment

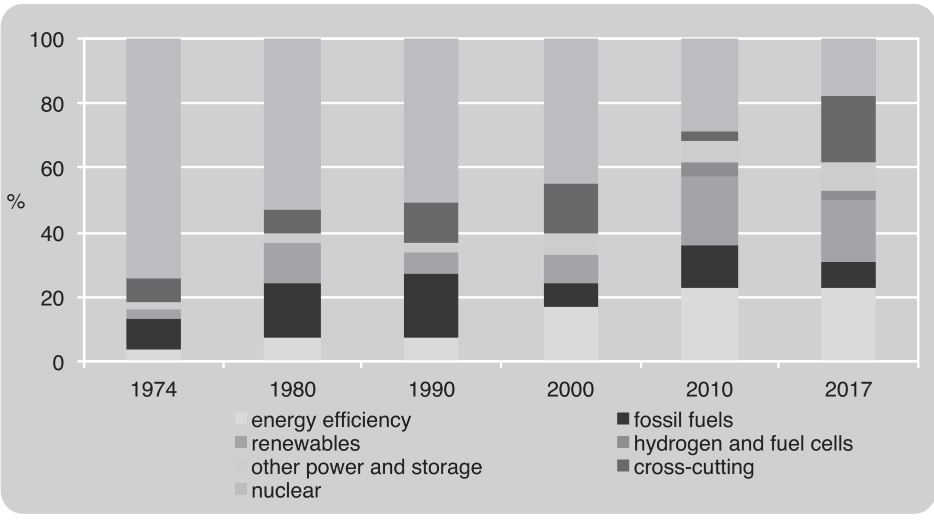


*Figure 4.7* Total public R&D budget by technology in IEA countries

*Source*: IEA (2018b).

insecurity. Mechanisms can either focus on price (feed in tariffs, competitive bidding) or quantity (mandated market share). They can also target the supply or the demand side.

As a result of the financial burden they constitute, feed in tariffs are being phased out, especially in China. The country's alternative, "top runner", a reverse auction, is gaining popularity internationally. Power purchase agreements based on reversed auction have already resulted in unexpected low bids in sunny and windy places (see e.g. Dobrotkova et al., 2018; Rego and de Oliveira Ribeiro, 2018). Haufe and Ehrhart (2018) provide an overview of recent experience with auction-based mechanisms. They conclude that auctions are the instrument of choice globally and that success of renewable energy auctions is outstanding. Even though a high degree of competition may put project developers under pressure, high realization rates (i.e. effectiveness) can be achieved. The competitive environment also provides innovation incentives which can be expected to result in further cost declines.

The market penetration of renewables depends on investment decisions taken today. The IEA (2017c) estimates that even under the assumptions of the Sustainable Development Scenario, fossil fuel investment will dominate investment decisions in the world's energy sector over the simulation horizon 2017–2040.

Concerning investment in power plants,

> renewables capture two-thirds of global investment in power plants as they become, for many countries, the least-cost source of new generation. Rapid deployment of solar photovoltaics, led by China and India, helps solar become the largest source of low-carbon capacity by 2040, by which time the share of all renewables in total power generation reaches 40%. In the European Union, renewables account for 80% of new capacity and wind power becomes the leading source of electricity soon after 2030, due to strong growth both onshore and offshore.
> *(IEA, 2017c)*

Table 4.1 shows annual and cumulative global investment by type and scenario over the simulation horizon to 2014.

European Union energy policy wants to achieve a renewables share of 32% by 2030. In light of objectives to globally increase the share of renewable energy, current trends in renewable energy investment are pointing in the other direction. According to IEA (2018d), global investment in

*Table 4.1* Global energy investment by type and scenario, 2017–2040 ($2016 billion)

| | *2010–16* | *New Policies* | | *Current Policies* | | *Sustainable Development* | |
|---|---|---|---|---|---|---|---|
| | *Per year* | *Cumulative* | *Per year* | *Cumulative* | *Per year* | *Cumulative* | *Per year* |
| Fossil fuels | 1,103 | 24,713 | 1,007 | 29,932 | 1,247 | 15,496 | 646 |
| Renewables | 297 | 7,950 | 331 | 6,350 | 265 | 12,828 | 534 |
| T&D | 236 | 8,025 | 334 | 8,524 | 355 | 8,145 | 339 |
| Other low-carbon | 14 | 1,127 | 47 | 1,095 | 46 | 2,325 | 97 |
| **Supply** | **1,650** | **41,276** | **1,720** | **45,901** | **1,913** | **38,795** | **1,616** |
| Power sector share | 41% | | 47% | | 41% | | 63% |
| Oil and gas share | 54% | | 50% | | 55% | | 35% |
| **End-use** | **295** | **18,809** | **784** | **11,912** | **496** | **30,340** | **1,264** |

*Source*: IEA (2017c).

renewable power generation fell by 7%, and fossil fuels increased their share in energy supply investment in 2017 – for the first time since 2014. Large part of the growth in fossil energy can be attributed to the fracking of oil and gas in the United States. Globally, energy investment fell by 2% in 2017, with electricity taking a bigger share than oil and gas for the second year in a row. The only exception is solar energy where a record investment could be achieved. China attracts most investment in solar energy, ahead of the United States and Europe. For the first time renewable energy investment dominates investment in fossil fuels in India. Bloomberg NEF (2018) provides a detailed overview of latest clean energy investment trends.

In regions with little growth in electricity demand, such as Europe, increasing generation by renewables depresses wholesale electricity prices, making renewables somehow victims of their own success, indicating the limits of marginal cost pricing (Edenhofer et al., 2013). Wholesale electricity prices slumped from about EUR 80/MWh in 2008 to EUR 30–40. In an industry where marginal costs are of great importance to the overall economics (merit order), the economics of renewables affects electricity markets to an extreme extent, leading electric utilities to separate their renewables (and grid) businesses from (loss making) conventional generation. Blazquez et al. (2018) claim that the world is caught in a vicious circle: renewable energy subsidies increase their deployment, which depresses prices, thereby further increasing the need for financial support. In the extreme case of 100% (non-dispatchable) renewables, the marginal cost-driven market price would fall to zero, deterring any investment that is not fully subsidized. Therefore, the more successfully policies to support renewables are, the more expensive and less effective policies become. The utility model of generating electricity is in many cases broken, as are markets. The "zero marginal cost society" (Jeremy Rifkin) may not be as easy to achieve as commonly thought.

Views on how expensive the transition to an energy (electricity) system fully based on renewables diverge substantially. For the United States there are estimates ranging from lower costs than fossil fuels, even when excluding nuclear, bioenergy, and combustion of fossil fuels with carbon capture and storage (Jacobson et al., 2015) to extremely high costs as result of the "vicious cycle" and the non-utilization of other carbon free options such as nuclear and energy storage (Clack et al., 2017).

The transition to a new energy (electricity) system is accompanied by a fundamental restructuring of the institutional setting of this industry. There is a trend towards a substitution of incumbent utilities by independent power producers in the European Union and the United States. Small-scale electricity producers at the household level ("prosumers") also contribute to this restructuring, by fundamentally changing the industrial organization towards a quite decentralized structure which makes grid operation more challenging. These changes produce winners and losers (Kelsey and Meckling, 2018). For example, between 2008 and 2013 the top 20 European utilities lost more than half of their stock market valuation. Transition pathways towards a sustainable energy future are characterized by different and still largely unexplored, distributional dynamics. New technologies, including blockchain, provide opportunities for new business models based on decentralized electricity generation.

## 3 Renewable energy policies, challenges, and barriers

### *3.1 Policies*

REN21 (2018) provide an overview of the status of various renewable policies at the global level. Renewable energy targets, feed-in tariffs, renewable purchase obligation (RPS)/quota, renewable projects tendering/auctions, and financial incentives including tax rebates are well-known renewables support policies. In 2017, 179 countries had overall renewable energy targets, of which 57 had 100% renewable electricity targets. Feed-in policies, the most popular mechanism, was in use in 113 countries, and RPS/quota policy in 33 countries. For biofuels, 70 countries had mandates. A review of renewables policies in the REN21 based on inputs from a large number of stakeholders had the following observations:

- Renewable energy policies and targets remain focused on the power sector, with support for heating and cooling and transport still lagging;
- Policies aligning renewables and energy efficiency are common in the buildings sector, but not in industry;
- Cities lead in "greening" public transport fleets, but policy attention is lacking for rail, aviation and shipping;
- Use of tendering continues to spread, yet feed-in policies remain vital in support schemes for renewables;
- New cross-sectoral integrated policies are emerging to support integration of variable renewables.

## 3.2 Challenges

*Energy systems integration*: Energy from wind and solar is referred to as variable renewable energy (VRE) due to their intermittent nature of availability, leading to challenges to integrate it into the existing energy systems. The problem gets compounded in cases where electricity grid is primarily supplied from coal and nuclear, since backing them down creates problem for the system. At part loads, efficiency is low, and shutting down and re-starting a unit can take several hours, if not days. In case of grids that have hydro and gas-based electricity, integration is relatively manageable. For example, Denmark is able to dispatch its surplus production from wind to Nordic grid, which has a good proportion of hydro (from Norway). Depending on mix of power plants in a grid, or its access to flexible grids (with hydro and gas plants), the issue of integration puts a limit on percentage of renewable energy a grid can absorb. This is an area where a lot of research is going on, including on electrical storage systems, load management and load shifting, smart grids to manage supply and demand better, pump storage, new technologies and uses, such as heat pumps and electric vehicles.

*Energy efficiency*: The other challenge is to create awareness and take policy measures to integrate energy efficiency and renewable energy. Energy efficiency currently offers cheapest and huge opportunity to reduce GHG emissions and energy intensity of the output. Reduced energy use for same level of output along with shift to renewable energy can therefore bring synergy in addressing climate change problem (IEA, 2014).

*100% Renewable*: Several countries have targets to produce 100% renewable power by 2050. Challenges related to that are indicated in Box 4.2.

### Box 4.2 100% Renewable energy

Advances in technologies, falling costs and increases in investment have led to faster growth than anticipated a few years back. As a result, renewable energy contributes to more than 20% of energy supply in more than 30 countries around the world (REN21, 2018).

A study by Jacobson and Delucchi (2011) indicated that producing all new energy with wind power, solar power, and hydropower by 2030 is feasible and existing energy supplied by non-renewables can also be replaced by renewables by 2050. The study concluded that it is economically and technically feasible and barriers are primarily social and political. Wiseman et al. (2013) also confirmed these findings.

In the course of preparation of Global Status Report 2018, REN21 carried out a survey of experts and stakeholders in several countries to come out with barriers for 100% renewable by 2050. The results were mixed but on expected lines. African experts found it too ambitious and identified inconsistent and uncoordinated energy policies as a serious political barrier, in addition to the lack of knowledge and information. Chinese experts pointed to the variability of wind and solar as a major barrier, and a lack of appropriate technologies for industry and transport sector a significant barrier. European experts opined that it was feasible but requires political commitment. Experts in India were divided in their opinion on this, but overarching view was the need for consistent and long-term policies and availability of technical know-how. Cost competitiveness, financing, and a lack of political and institutional support were identified as barriers in Latin America. Experts in the United States were skeptical about the prospects of achieving 100% renewables as early as 2050. Application in transportation was identified as a major problem, followed by a lack of know-how on energy and technology issues and insufficient political will. Overall, a majority of the energy experts interviewed agreed (35%) or strongly agreed (36%) that 100% renewables on a global level is feasible and realistic, 17% disagreed, and 12% were neutral (IRENA, 2018).

## *3.3 Barriers*

A number of studies have gone into the issue if barriers to renewable energy, including the IEA (Muller, 2011), REN21 (2018), IRENA (2018), IPCC (2012), Wiseman et al. (2013), UCS (2017), Kariuki (2018), Reddy and Painuly (2004). In the early years of the first decade, most of the barriers were common across countries and many, even across various type of renewables. The list of barriers included awareness, economic and financial, technical, political and regulatory, institutional, capacity, market, and social and cultural. However, over a period of time, many of these barriers have been addressed, particularly in developed countries and emerging economies, which the scale of investment in the renewables reflects. In many developing countries, most or all of these barriers still remain, but the nature of barriers in countries that are leaders in renewables has changed.

Technology specific barriers have emerged that impede large-scale deployment. Increased use of bioenergy requires a sustainable framework that also considers environmental issues. For geothermal, economic viability and sustainability of the enhanced geothermal systems (EGS) on a large scale is a challenge (IPCC, 2012). Ecological and social impacts in case of new hydropower projects can have ecological and social issues while ocean energy development may require testing infrastructure, enabling policies, and regulations. Environmental concerns and public acceptance in case of wind energy can be an issue. In many countries, issues include complicated licensing procedures and difficulty with land acquisition and permissions.

In case of some technologies, primarily solar and wind, the focus is now on large-scale deployment. It requires a level playing field through removal of subsidies to fossil fuels and accounting for their social and environmental costs. An infrastructure barrier has also emerged, which relates to capacity of the power grid to absorb variable renewable energy. With increase in deployment of renewable power, grid infrastructure may need to be upgraded to ensure adequate transmission and distribution infrastructure. In the case of Germany, for example, wind energy is produced in the north of the country, while demand is located in the south. Lack of transmission capacities result in severe problems in grid operation – problems that spill over to neighboring countries. Excess supply on windy days can drive wholesale electricity prices even into negative territory.

Policy ambiguity due to political uncertainty can also create problems. Unfavorable policies, a lack of transparency, and inconsistency in policies undermine investor confidence. A big dilemma facing policy makers is balance between competitive prices that are consumer friendly versus renewable power procurement by utilities through long-term power purchase agreements (PPAs) that creates certainty for investors but makes power expensive for consumers. With falling prices, many utilities in some countries are looking at heavy losses with long-term contracts through feed-in policies. Policies that ensure healthy growth of the sector and yet safeguard consumer interest are important

Some other recommendations include focus on end-use sectors in addition to power generation (current focus area), enabling policies for renewables use in heating and cooling, enabling policies for use of renewables in transport sector, and promoting measures to support integration of variable renewable energy (IRENA, 2018).

## 4 Conclusions

Advances in technology, falling costs and increases in investment have led to faster growth of renewables than anticipated only a few years ago. Renewable energy has come a long way with global investment in renewables reaching $279.8 billion in 2017, and renewable energy contributes to more than 20% of energy supply in more than 30 countries around the world (REN21, 2018). As of 2016, renewable energy accounted for an estimated 18.2% of global total final energy consumption, with modern renewables representing 10.4%. Maximum contribution from renewables came to power generation with renewables meeting 25% of the global power demand in 2017. Decentralized renewable power is being used to provide electricity access to those where grid is not available. Renewables also contributed marginally to heating and transportation sectors.

PV technology development coupled with supportive policies resulted in levelized cost of the electricity from utility-scale solar PV projects declining by 70% from 2010 to 2016, and this trend is continuing. There is some concern that subsidies to renewables through various mechanisms can be counterproductive. However, the support may be necessary until a level playing field has been provided by eliminating global fossil fuel subsidies and environmental externalities from use of fossil fuels are taken into consideration. Mechanisms such as feed-in tariffs, quotas, and auctions have been successfully used to promote renewables, but each one has its own limitations and inefficiencies. Reverse auctions are now being used successfully in several countries, including China.

Investment in renewable power plants was almost two-thirds of the global investment in power plants in 2017. With an increasing number of countries committing to renewables and 57 countries targeting 100% renewables power by 2050, overall trend in increase in investment in renewables can be expected to continue.

Renewable energy targets, feed-in tariffs, renewable purchase obligation (RPS)/quota, and renewable projects tendering/auctions have been popular mechanisms to promote renewables. However, these cater to only renewable use for power production. Renewable use for heating and cooling and transport holds a lot of potential and needs policy support.

As the renewable power production increases, it faces a challenge in integrating it into the existing energy systems due to its intermittent nature of production. Though a number of barriers have been addressed in developed countries and emerging economies, in developing countries, still a variety of barriers exist that include awareness, economic and financial, technical, political and regulatory, institutional, capacity, market, and social and cultural. They may need to be supported if their renewable energy targets are to be met.

Further research is urgently required on how to bring about – in a cost-efficient manner – the global "energy transition" towards an energy system (not only electricity) based to a large extent on renewables. Intermittency of some forms of renewable energy constitutes a very significant challenge, one that could be overcome as soon as feasible storage technologies become available.

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