Technology and Applications

Renewable Energy | Technology and Applications

Renewable energy sources replenish themselves naturally without being depleted in the earth; they include hydropower, bioenergy, geothermal energy, solar energy, wind energy and ocean (tide and wave) energy and their uses are reported in the table below.

Energy Sources	Energy conversion and usage options
Hydropower	Power generation
Biomass	Heat and power generation, pyrolysis, gasification, digestion
Geothermal	Urban heating, power generation, hydrothermal
Solar	Solar home systems, solar dryers, solar cookers
Direct Solar	Photovoltaic, thermal power generation, water heaters
Wind	Power generation, windmills, water pump
Wave and tide	Barrage, tidal stream

Tab. 1 Renewable energy forms and their uses

These technologies may not be comparable with conventional fuels in terms of production cost, but they could be comparable if we consider their associated externalities, such as their environmental and social effects. Also, it should be noted that economies of scale could play a key role in reducing the unit production cost. Transmission and distribution costs, as well as technologies, do not differ much among the conventional and renewable energies. Below are presented details about the development of the main renewable energy supply technologies with their advantages and disadvantages.

Hydropower

Hydropower is a clean and renewable energy source and it is the most mature and largest source of renewable power. Considering the economic, technical and environmental benefits of hydropower, most countries give priority to its development. Developing hydropower is of great importance to alleviate the energy crisis and environmental pollution resulting from the rapid economic growth of China and other countries in the 21st century[5]

The figure 3 shows the general trend of worldwide hydro electricity consumption from 1965 to 2016 and the figure 4 the trend in the more recent years.[6] , [7]

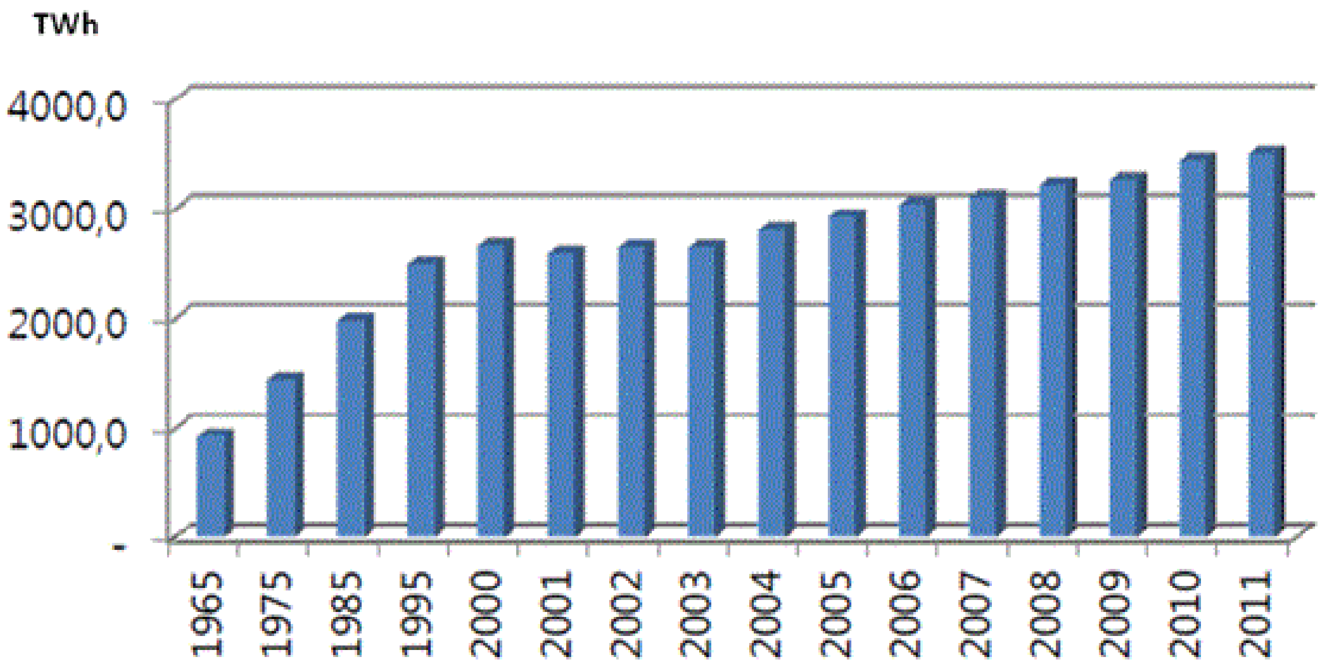

Fig. 3 Worldwide hydro electricity consumption, 1965-2011

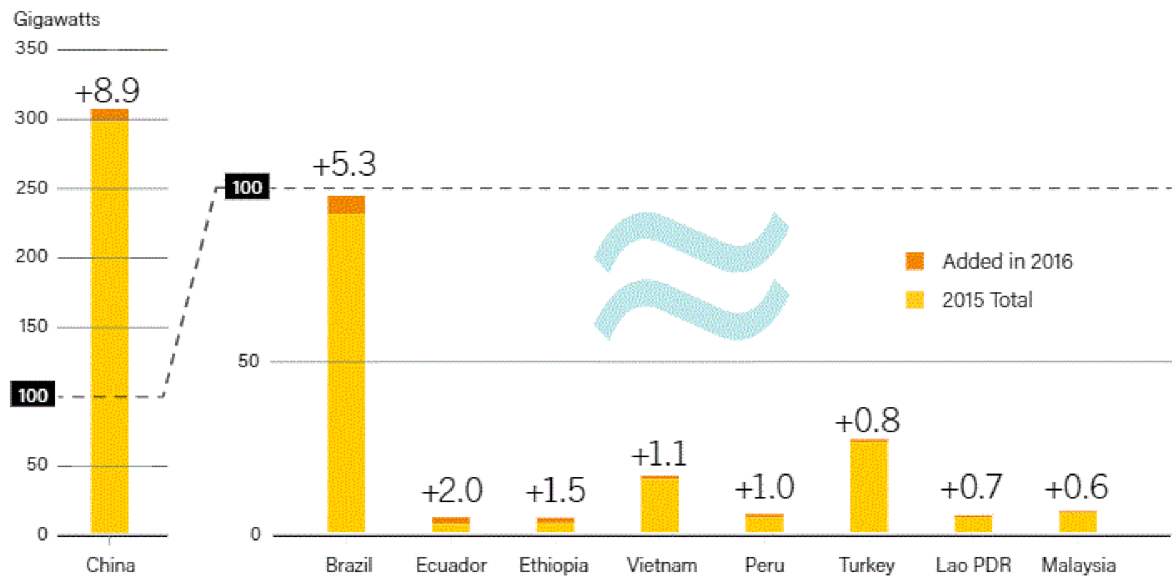

Fig. 4 Hydropower Capacity and Additions, Top 9 Countries for Capacity Added, 2016

Hydropower is an essential energy source harnessed from water moving from higher to lower elevation levels, primarily to turn turbines and generate electricity. The primary energy is provided by gravity and the height the water falls down on to the turbine. The potential energy of the stored water is the mass of the water, the gravity factor ($g = 9.81\ ms^{-2}$) and the head defined as the difference between the dam level and the tail water level. The reservoir level to some extent changes downwards when water is released and accordingly influences electricity production. Turbines are constructed for an optional flow of water.

Although hydropower plants are highly site-specific (the local topography and hydrology will define the type of facilities that can be built), they can be broadly categorized into three main typologies:

1. Storage hydropower: a facility that uses a dam to impound river water, which is then stored for release when needed. Electricity is produced by releasing water from the reservoir through operable gates into a turbine, which in turn activates a generator. Storage hydropower can be operated to provide base-load power, as well as peak-load through its ability to be shut down and started up at short notice according to the demands of the system. It can offer enough storage capacity to operate independently of the hydrological inflow for many weeks, or even up to months or years. The primary advantage of hydro facilities with storage capability is their ability to respond to peak load requirements.
2. Run-of-river hydropower: a facility that channels flowing water from a river through a canal or penstock to drive a turbine. Typically, a run-of-river project will have short term water storage and result in little or no land inundation relative to its natural state. Run-of-river hydro plants provide a continuous supply of electricity, and are generally installed to provide base load power to the electrical grid. These facilities include some flexibility of operation for daily/weekly fluctuations in demand through water flow that is regulated by the facility.

3. Pumped-storage hydropower: provides peak-load supply, harnessing water which is cycled between a lower and upper reservoir by pumps, which use surplus energy from the system at times of low demand. When electricity demand is high, water is released back to the lower reservoir through turbines to produce electricity. Some pumped-storage projects will also have natural inflow to the upper reservoir which will augment the generation available. Pumped-storage hydropower is practically speaking a zero sum electricity producer. Its value is in the provision of energy storage, enabling peak demand to be met, assuring a guaranteed supply when in combination with other renewables, and other ancillary services to electrical grids. One major advantage of pumped-storage facilities is their synergy with variable renewable energy supply options such as wind and solar power (non-flexible power supply options). This is because pump-storage installations can provide back-up reserve which is immediately usable during periods when the other variable power sources are unavailable.

Although there are clear hydropower typologies, there can be overlap among the above categories. For example, storage projects can involve an element of pumping to supplement the water that flows into the reservoir naturally, and run-of-river projects often provide some level of storage capability. Hydropower technologies are not bound by size constraints, the basic technology is the same irrespective of the size of the development. Large-scale hydropower installations typically require storage reservoirs. Smaller-scale hydropower systems can be attached to a reservoir, or they can be installed in small rivers, streams or in the existing water supply networks, such as drinking water or wastewater networks. Hydropower facilities installed today range in size from less than 100 kW to greater than 22 GW, with individual turbines reaching 1000 MW in capacity. [8]

As the vast stock of hydropower facilities around the world ages, modernization and retrofitting of existing facilities continues to be a significant part of industry operations, with the potential to increase greatly the performance of existing plants. In addition to ongoing improvements to mechanical equipment such as turbines, plant operators also continue to implement advanced control technologies and data analytics for digitally enhanced power generation. It is expected that these steps will help to optimize plant management for greater reliability, efficiency and lower cost, while also allowing for more flexible integration with other grid resources, including variable renewable energy. [9]

Bioenergy

Bioenergy is the energy that comes from organic matter, such as plants. Many industries, such as those involved in construction or the processing of agricultural products, can create large quantities of unused or residual biomass, which can serve as a bioenergy source. Many bioenergy technologies and conversion processes are now well-established and fully commercial. A further set of conversion processes, in particular for the production of advanced liquid fuels, is maturing rapidly.

Converting biomass into gas is a process known as gasification. Using gas turbines, these gases can be used to generate electricity. Methane gas produced during the decay of biomass in landfills can also be used to generate electricity or for other industrial processes. Global bio-power capacity increased an estimated 6% in 2016, to 112 GW. Generation rose 6% to 504 terawatt-hours (TWh) . The leading country for electricity generation from biomass in 2016 was the United States (68 TWh), followed by China (54 TWh), Germany (52 TWh), Brazil (51 TWh), Japan (38 TWh), India and the United Kingdom (both 30 TWh).[10]

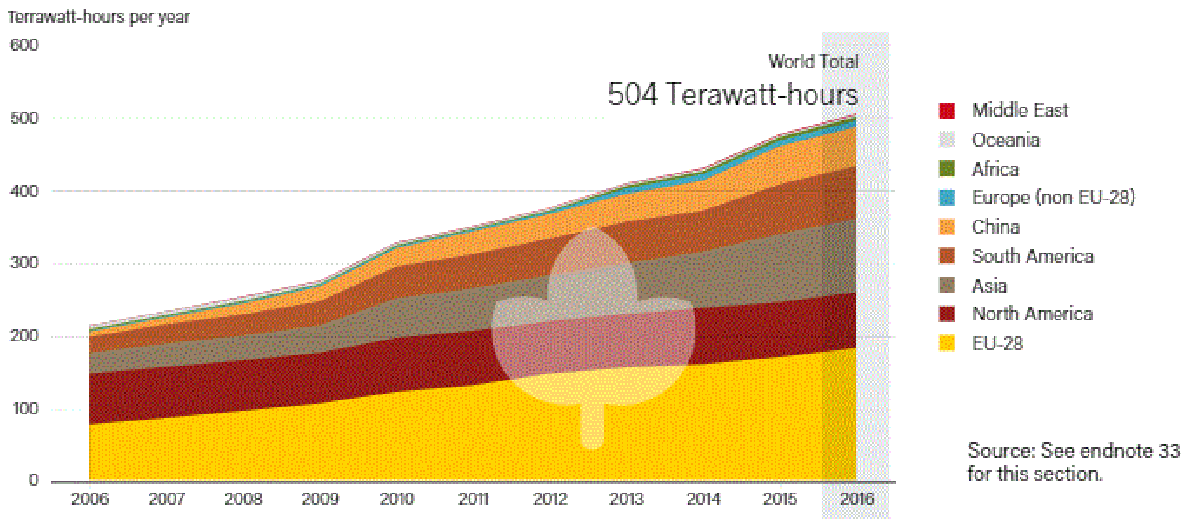

Fig. 5 Global Bio-Power Generation, by Region, 2006-2016

Biomass can also be converted into a liquid fuel referred to as biofuel through a conversion process. An example of biofuel is ethanol. The current largest source of ethanol is corn. Some cities use ethanol as a gasoline additive to help meet air quality standards. Another example of biofuel is biodiesel, produced from fats of vegetables and animals can be used as fuel for vehicles or as a fuel additive to reduce emissions. In 2016, global biofuels production, which closely tracks demand, increased around 2% compared to 2015, reaching 135 billion liters. This increase was due largely to a rebound in biodiesel production after a decline in 2015. The United States and Brazil remained the largest biofuels producers by far, accounting for 70% of all biofuels between them, followed by Germany, Argentina, China and Indonesia. An estimated 72% of biofuel production (in energy terms) was fuel ethanol, 23% was biodiesel, and 4% was hydrotreated vegetable oil (HVO). Biomass can also be heated in the absence of oxygen to chemically convert it into a fuel oil called pyrolysis oil.

Pyrolysis oil can be used for power generation and as a feedstock for fuels and chemical production. In the following figure there are some conversion methods for biofuels production [10].

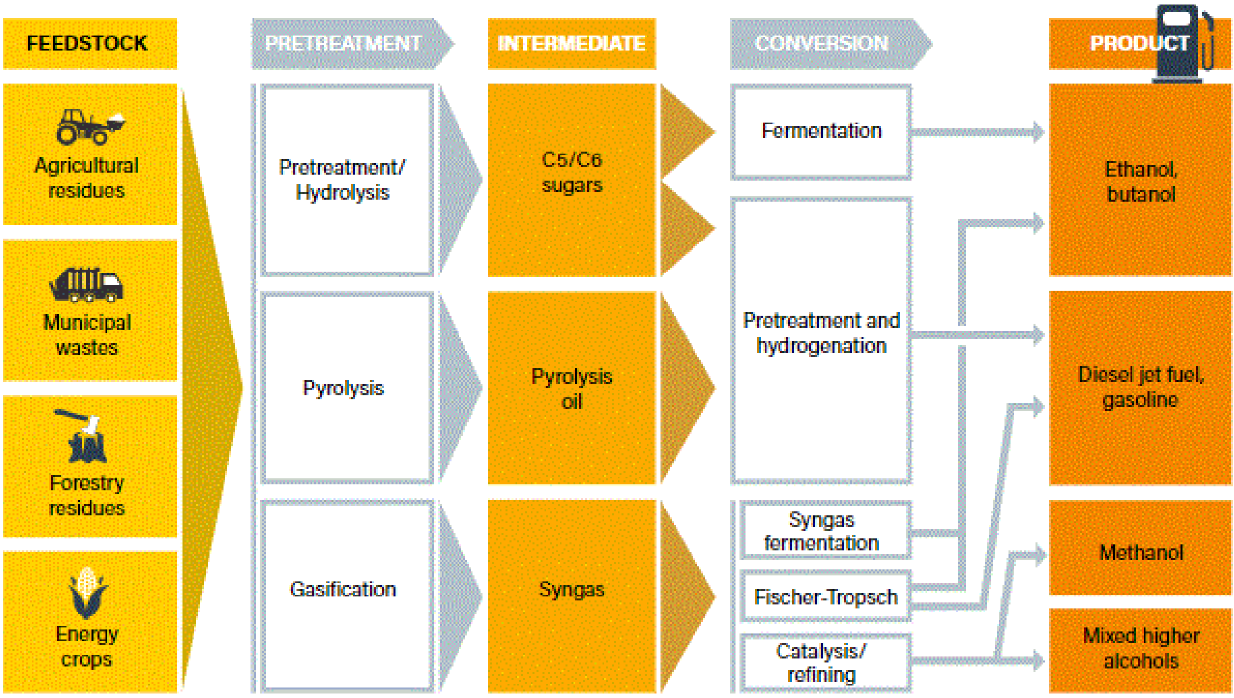

Fig. 6 Some conversion Pathways to Advanced Biofuels

Geothermal Energy

The geothermal process involves trapping heat underground and building energy that rises near the surface in the form of heat. When this heat naturally creates hot water or steam, it is harnessed and then used to turn a steam turbine to generate electricity. The Italians were the first to use geothermal energy for commercial purposes in the early 1900's. Geothermal energy is extremely kind to the environment. It offers a constant, efficient supply of clean energy with minimal impact on its surroundings.*[11]*

Geothermal energy is created by radioactive decay, with temperatures reaching 4,000˚C at the core of the Earth. While geothermal energy is available worldwide, there is an important factor called the geothermal gradient that indicates whether a region is a favored place for enactment. It measures the rate at which the temperature increases as the depth of the Earth increases. For example, the average geothermal gradient in France is 4˚C/100m with a range of 10˚C/100m in the Alsace region to 2˚C/100m in the Pyrenees Mountains. In Iceland and the volcanic regions, the gradient can reach as high as 30˚C/100m.[12] The geothermal gradient is not the only tool used to measure the accessibility of geothermal energy. The permeability of rocks, which determines the rate of flowing heat to the surface, is considered to be another important measure in the availability of geothermal energy.

Geothermal energy has many different uses that can be grouped into three categories: for generation of electricity, for heating systems (and direct use), and for use in geothermal heat pumps.

Some geothermal plants produce both electricity and thermal output for various heat applications. An estimated 0.4 GW of new geothermal power generating capacity came online in 2016, bringing the global total to an estimated 12 GW, as shown in figure 7.[13]

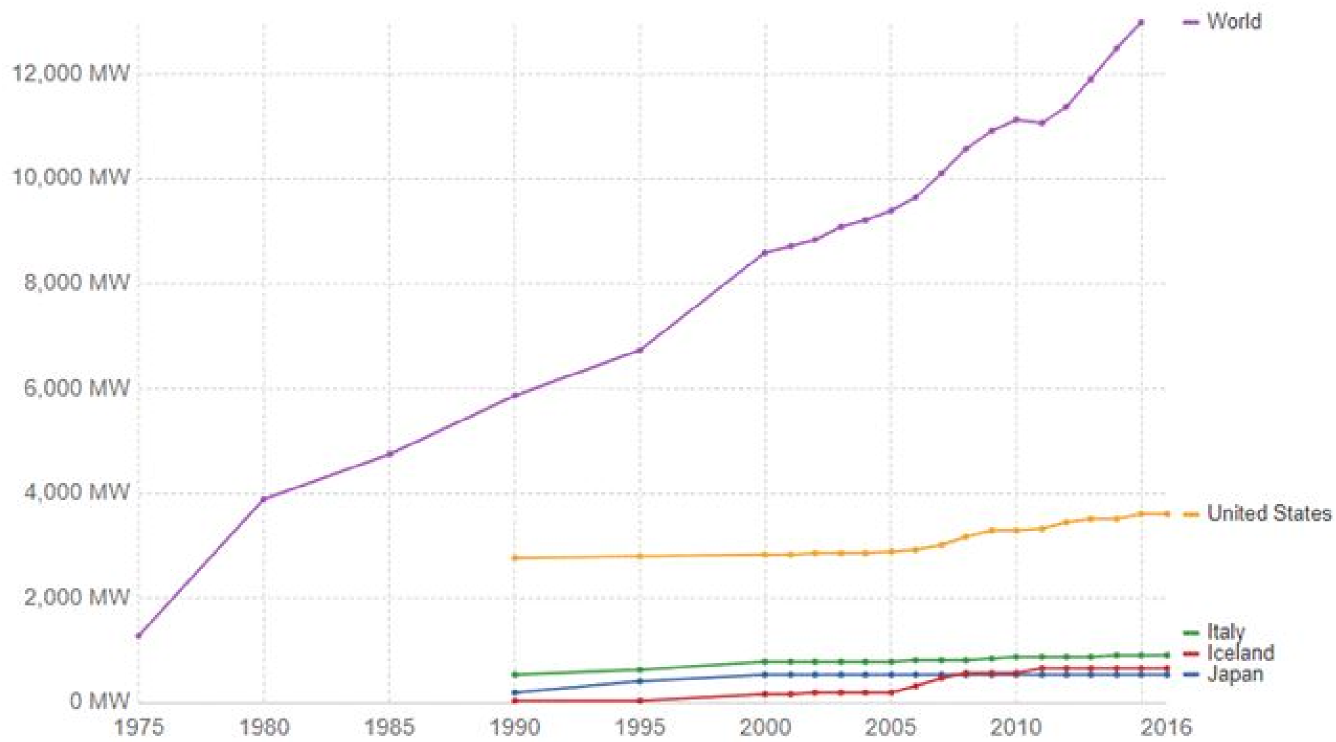

Fig. 7 Cumulative installed geothermal capacity

There are three types of geothermal power plants: Dry steam plants, Flash steam plants and Binary cycle plants. Dry steam plants draw from steam reservoirs, whereas both the flash steam and binary cycle plants draw from hot water reservoirs. Flash steam plants typically use water at temperatures greater than 180 °C. Binary cycle plants transfer heat from the water to a so called working fluid, therefore can operate using water at lower temperatures of about 110°C to 180°C.

Research continued in the field of enhanced (or engineered) geothermal systems (EGS) during 2016, particularly in the United States, where government-funded research has aimed to realize commercial, cost-competitive power production [14]. The common feature among all the most productive geothermal regions of the world is naturally occurring hydrothermal activity, defined by the presence of high heat, geothermal fluid and permeability. To achieve economical geothermal production elsewhere, or to enhance production at existing locations, fracturing of sub-surface rock formations can create the needed permeability to form a productive geothermal reservoir, which is known as EGS [15]. In other instances, adequate permeability may exist in hot sedimentary aquifers, but fracturing may be needed to ensure adequate well productivity [16]

Solar Energy

Solar energy uses the unlimited power of the sun to produce heat, light, and power thus is the most abundant renewable resource on our planet. In spite of this abundance, only 0.04% of the basic power used by humans comes directly from solar sources because using a photovoltaic (PV) panel costs more than burning fossil fuels. Organic materials have recently been intensively studied for PV applications, not because of harvesting the sun's power more efficiently, but because power generation from organic photovoltaic (OPV) materials will cost considerably less than other PV technologies. [17]

During 2016, at least 75 GWdc of solar PV capacity was added worldwide, equivalent to the installation of more than 31,000 solar panels every hour. More solar PV capacity was installed in 2016 (up 48% over 2015) than the cumulative world capacity five years earlier. By year's end, global solar PV capacity totalled at least 303 GW, as schows the figure 8. For the fourth consecutive year, Asia eclipsed all other markets, accounting for about two-thirds of global additions. The top five markets – China, United States, Japan, India and the United Kingdom – accounted for about 85% of additions; others in the top 10 for additions were Germany, the

Republic of Korea, Australia, the Philippines and Chile. [18]

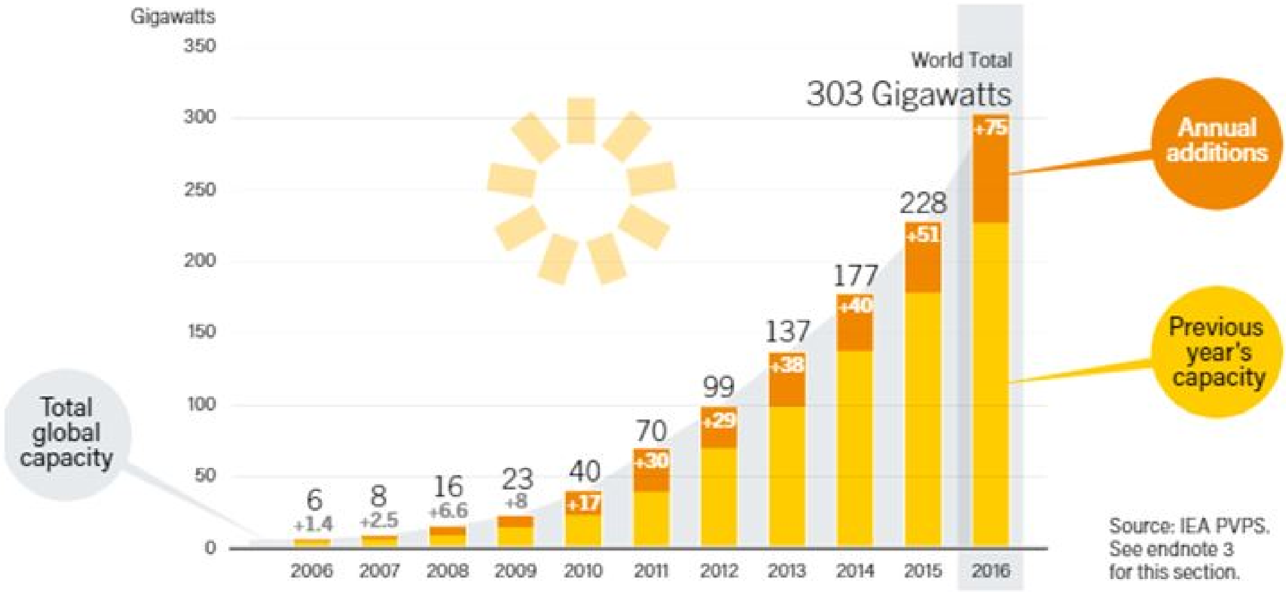

Fig. 8 Solar PV Global Capacity and Annual Additions, 2006-2016

While demand is expanding rapidly for off-grid solar PV, the capacity of grid-connected systems is rising more quickly and continues to account for the vast majority of solar PV installations worldwide. Decentralized (residential, commercial and industrial rooftop systems) grid-connected applications have struggled to maintain a roughly stable global market (in terms of capacity added annually) since 2011, particularly with the transition from FITs and net metering to self-consumption. Centralized large-scale projects, by contrast, have comprised a rising share of annual installations – particularly in emerging markets – despite grid connection challenges, and now represent the majority of annual installations. [19]

Innovations and advances continued during the year in manufacturing, product efficiency and performance, installation and O&M. They were driven largely by rapid price reductions, which have forced companies to move forward their roadmaps to decrease costs and differentiate themselves. Module manufacturers continued increasing the number of busbars to reduce internal electrical resistance, as well as reducing barren spaces on modules to enhance light trapping [20]. Perovskites achieved further improvements in efficiency and stabilization through ongoing R&D [21]. Efficiency gains from such advances have reduced the number of modules required for a given capacity, lowering soft costs. Labor and other soft costs of large-scale projects also are falling thanks to customized design testing, pre-assembly of systems and advances in racking. Inverters also are becoming more sophisticated and making a growing contribution to grid management, and manufacturers are working to improve long-term reliability and system-prediction methods. During 2016, key areas of focus included advancing both materials and self-regulating technologies in order to build higher-voltage central inverters and thereby reduce balance of systems costs and the levelised cost of electricity (LCOE), as well as improving performance and software to reduce O&M costs. Efforts to advance recycling processes continued, although there was relatively small demand for recycling of waste and solar panels (at end-of-life, or damaged or defective panels) as of 2016 [22]. The cost of new photovoltaic power is dropping rapidly, and if the photovoltaic industry continues to grow and improve technologically, by 2020 the cost could be comparable to the cost of conventional power, as will the cost of solar thermal power. [23]

Concentrated Solar Power

CSP technologies use sun-tracking mirrors to collect and concentrate the sunlight and use it as a form of high-temperature heat for electricity generation and industrial processes. Despite the higher investment cost, operating costs for CSP plants are lower than fossil fuel alternatives, and there are no costs for the “fuel”. Identifying economical reflecting materials could further reduce investment costs [24] .There are three types of CSP systems: power towers (central receivers), parabolic troughs, and dish/engine systems. This also has low operating costs and high efficiency, and can produce a reliable supply of energy by utilizing thermal storage [25]. Currently glass mirrors lined with silver are the most efficient material for CSP (95%), yet due to their high cost, weight, fragility and risk of corrosion from dust storms, CSP developers and operators are seeking alternatives. Two parameters were defined to assess the quality of all types of solar reflector materials: reflectance and specularity (capacity to reflect all light into the direction of the solar receiver). Four commercially available materials (floating glass mirrors, metalised polymer films, polished aluminium and anodised aluminium) were tested. The best optical performance was achieved by glass mirrors lined with silver as they presented the highest solar reflectance and optimum specular behavior [24] .

Wind Energy

Wind energy has been the fastest growing source of energy in the world since 1990. Wind power is a very simple process. A wind turbine converts the kinetic energy (motion) of wind into mechanical energy that is used to generate electricity. The energy is fed through a generator, converted a second time into electrical energy, and then fed into the grid to be transmitted to a power station. Wind turbines are highly sophisticated power systems that capture the wind's energy by means of new blade designs or airfoils.

Almost 55 GW of wind power capacity was added during 2016, increasing the global total about 12% to nearly 487 GW. Gross additions were 14% below the record high in 2015, but they represented the second largest annual market to date as shown in figure 9. By the end of 2016, over 90 countries had seen commercial wind power activity, and 29 countries – representing every region – had more than 1 GW in operation. A significant decline in the Chinese market (following a very strong 2015) was responsible for most of the market contraction. Even so, China retained its lead for new installations, followed distantly by the

United States and Germany, with India passing Brazil to rank fourth [26].

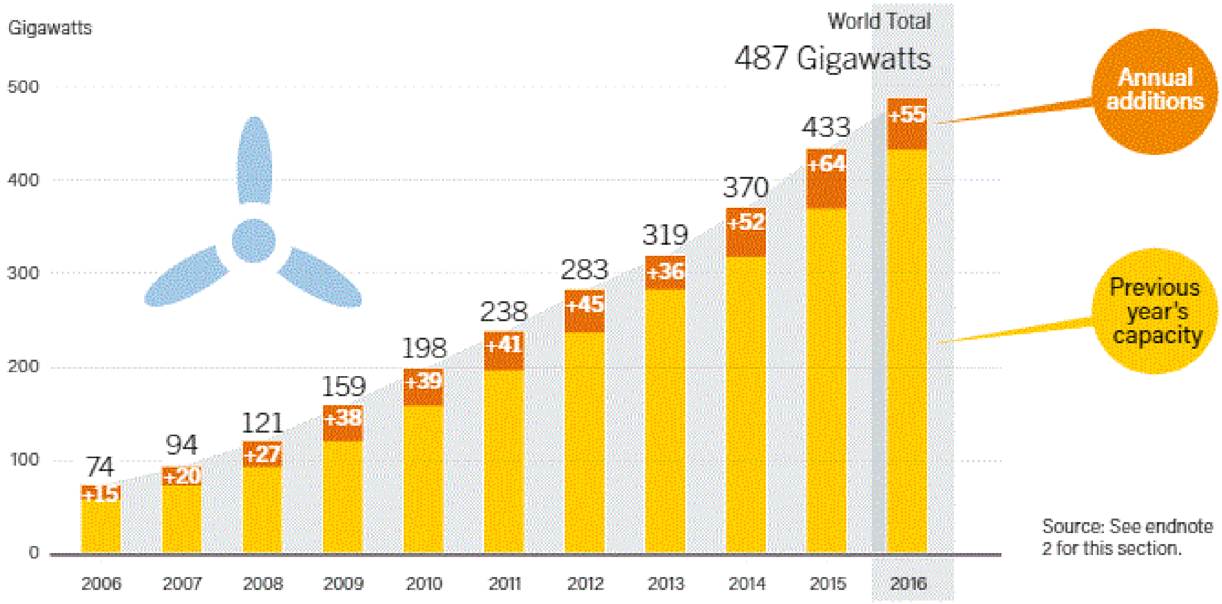

Fig. 9 *Wind Power Global Capacity and Annual Additions, 2006-2016*

Ocean Energy

Extracting energy from the ocean is considered to be an interesting option, due in part to the wide availability of ocean sources. Surface waves are created when wind passes over water. The faster the wind speed, the longer the wind is sustained, the greater distance the wind travels, the greater the wave height, and the greater the wave energy produced. Ocean energy refers to any energy harnessed from the ocean by means of ocean waves, tidal range (rise and fall), tidal streams, ocean (permanent) currents, temperature gradients and salinity gradients.

Ocean thermal energy can be used for many applications, including electricity generation. Electricity is generated by using either the warm surface water or boiling the seawater to turn a turbine, which starts a generator. Using tidal and wave energy to produce electricity usually involves mechanical devices. A dam is typically used to convert tidal energy into electricity by forcing the water through turbines. Meanwhile, wave energy uses mechanical power to directly start a generator, to produce electricity [27].

Few commercial ocean energy facilities have been built to date. Of the approximately 500 MW of operating capacity at the end of 2016, see figure 10.[28]

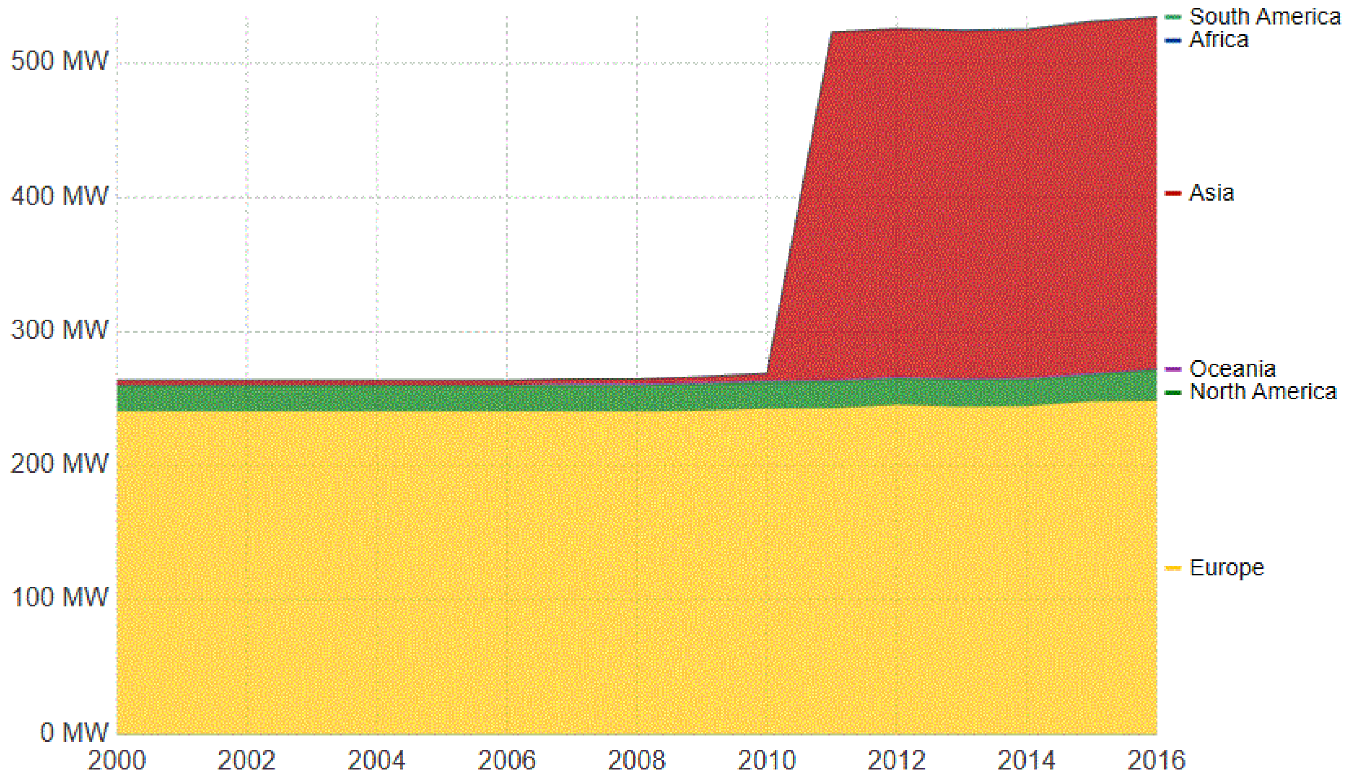

Fig. 10 Cumulative installed marine energy capacity

A great number of research and development (R&D) projects is under way in a growing number of countries, with several new deployments of ocean energy devices in 2016 . Most of the projects focus on tidal stream and wave energy, but some active projects also exist in the areas of thermal and salinity gradients. To accommodate R&D, ocean energy test centers are proliferating around the world, often with the active support of local governments . As of late 2016, projects were under way in Canada, Chile, China, the Republic of Korea, the United States and several countries in Europe [29].

It is interesting to note that despite several tidal devices still operating to date, and the first tidal arrays likely to be built in 2015, many wave energy companies have fared badly. Companies such as Pelamis (considered at one point to be the leaders in the sector) have been taken into administration. The reasons for such failures are not clear, though installing devices in areas of high wave energy is likely to pose greater challenges than was initially thought. Given the uncertainties and harsh environment in which wave devices have to operate, the regular nature of tidal currents appears to make this type of technology more predictable and easier to maintain and operate than waves. [30] .

Advantages and Disadvantages

In the table below advantages and disadvantages for renewable energy sources is reported.

Energy Sources	PROS	CONS
Hydropower	• no particulate pollution • capable of storing energy for many hours • high level of reliability • proven technology • high efficiency • very low operating and maintenance costs • ability to easily adjust to load changes	• can affect wildlife habitats • can affect the water quality • high initial costs of facilities • dependence on precipitation
Biomass	• contains less sulphur than coal • considered part of the terrestrial carbon cycle	• insufficient source of energy compared to fossil fuels • removal of the green vegetation
Geothermal	• sustainable and safe for the environment • renewable, abundant, and reliable energy source • low emission	• rarity of suitable geothermal power plant locations • safety concerns due to hazardous materials from underground • produced energy is difficult to transport

Solar	• does not create greenhouse gases • no noise • no moving parts • require very little maintenance • maintenance and repair costs very reasonable	• solar panels production is almost expensive • required to store the energy for use • cannot be collected at night • dependent on weather conditions
Wind	• free, abundant, and sustainable energy • located onshore (land) or offshore • fully cost-competitive	• far from population centres • intermittent and unpredictable nature • environmental constrains • interference with radio and TV signals • interfering with migratory birds
Wave and Tide	• most appropriate source of energy for small island states • quick reduction of costs in next future	• at the initial stage of commercialization • expensive • time and season dependant • impact coastal ecosystems or habitats

Tab. 2 Pros e Cons for renewable sources of energy

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[7] *Førsund, F. R. (2015). Hydropower economics (Vol. 217). New York: Springer*

[8] *https://www.worldenergy.org/wpcontent/uploads/2017/03/WEResources_Hydropower_2016.pdf*

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[10] *http://www.ren21.net/wpcontent/uploads/2017/06/178399_GSR_2017_Full_Report_0621_Opt.pdf*

[11] *http://www.geothermalengineering.co.uk/*

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[13] https://ourworldindata.org/renewables#geothermal

[14] *https://www.energy.gov/sites/prod/files/2017/03/f34/GTO%202016%20Annual%20Report_1.pdf.83*

[15] *https://energy.gov/sites/prod/files/2016/05/f31/EGS%20Fact%20Sheet%20May%202016.pdf*

[16] *https://setis.ec.europa.eu/sites/default/files/reports/2015_jrc_geothermal_energy_status_report.pdf.85Ibid.239ff*

[17] *Moule, A., 2010. Current Opinion in Solid State & Materials Science, 14 (6):123-130.*

[18] *Førsund, F. R. (2015). Hydropower economics (Vol. 217). New York: Springer*

[19]*Residential markets are located primarily in Australia, several countries in the EU, Japan and the United States. In 2015, the global solar rooftop segment declined by 1 GW relative to 2014*

[20] http://www.photovoltaic-conference.com/press-media/blog-2017/118-blog-2017-170104.html.1

[21]*http://www.kit.edu/kit/english/pi_2016_133_record-for-perovskite-cigs-tandem-solar-module.php*

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[30] *Recent Developments in Ocean Energy and Offshore Wind: Financial Challenges and Environmental Misconceptions, Miguel Esteban1, Alexandros Gasparatos2, Christopher N.H. Doll3, 2017*