Renewable and Sustainable Energy Reviews 39 (2014) 748–764

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Renewable energy resources: Current status, future prospects and their enabling technology

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A R T I C L E   I N F O

Article history:
Received 24 September 2013
Received in revised form
11 July 2014
Accepted 11 July 2014
Available online 6 August 2014

Keywords:
Biomass energy
Geothermal energy
Hydropower energy
Marine energy
Solar energy
Wind energy
Smart grid

A B S T R A C T

Electric energy security is essential, yet the high cost and limited sources of fossil fuels, in addition to the need to reduce greenhouse gasses emission, have made renewable resources attractive in world energy-based economies. The potential for renewable energy resources is enormous because they can, in principle, exponentially exceed the world's energy demand; therefore, these types of resources will have a significant share in the future global energy portfolio, much of which is now concentrating on advancing their pool of renewable energy resources. Accordingly, this paper presents how renewable energy resources are currently being used, scientific developments to improve their use, their future prospects, and their deployment. Additionally, the paper represents the impact of power electronics and smart grid technologies that can enable the proportionate share of renewable energy resources.

Contents

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http://dx.doi.org/10.1016/j.rser.2014.07.113
1364-0321/

1. Introduction

Conventional energy sources based on oil, coal, and natural gas have proven to be highly effective drivers of economic progress. However, with the rapid depletion of conventional energy sources and increasing energy demand, worldwide primary energy consumption has grown by 1.8% in 2012 [1]. Due to certain environmental issues, many related organizations have encouraged intensive research for more efficient and green power plants utilizing advanced technology. Since environmental protection concerns are increasing, both clean fuel technologies and new energies are being intensively pursued and investigated. In fact, fossil fuel and renewable energy prices, social and environmental costs are moving in opposite directions and the economic and policy mechanisms needed to support the widespread dissemination of sustainable markets for renewable energy systems are rapidly evolving. It is clear that future growth in the energy sector is primarily in the new regime of renewable. Therefore, shifting to renewable energy can help us meet the dual goals of reducing greenhouse gas emissions, thereby limiting future extreme weather and climate impacts, and ensuring reliable, timely, and cost-efficient delivery of energy. Investing in renewable energy can have significant dividends for our energy security.

Renewable energies are energy sources that are continually replenished by nature and derived directly from the sun (such as thermal, photo-chemical, and photo-electric), indirectly from the sun (such as wind, hydropower, and photosynthetic energy stored in biomass), or from other natural movements and mechanisms of the environment (such as geothermal and tidal energy). Renewable energy does not include energy resources derived from fossil fuels, waste products from fossil sources, or waste products from inorganic sources [2]. Fig. 1 shows an overview of renewable energy sources [3,4]. Renewable energy technologies turn these natural energy sources into usable forms of energy—electricity, heat and fuels. Fig. 2 illustrates the ability of renewable energy sources to provide over 3000 times the current global energy needs [5].

Renewable energy markets – electricity, heating and transportation – have been growing sharply over the last five years. The deployment of established technologies, such as hydro, as well as newer technologies such as wind and solar photovoltaic, has risen quickly, which has increased confidence in the technologies, reduced costs and opened up new opportunities [6].

Global electricity generation from renewable energy sources is expected to grow 2.7 times between 2010 and 2035, as indicated by Table 1. Consumption of biofuels is projected to more than triple over the same period to reach 4.5 million barrels of oil equivalent per day (mboe/d), up from 1.3 mboe/d in 2010. Almost all biofuels are used in road transport, but the consumption of aviation biofuels will make an inroad towards 2035. The use of modern renewables to produce heat will almost double, from 337 Mtoe in 2010 to 604 Mtoe in 2035. The share of renewables in electricity generation is higher than in heat production or Transportation road, as shown in Fig. 3 [7].

The goal of the paper is to present an overview of the different types of renewable energy resources, their current and future states, their share in different end use applications, and their benefits, growth, investment and deployment. Furthermore, power electronics and smart grid will be discussed as enabling technologies for different renewable energy resources.

2. Description of renewable energy sources

2.1. Biomass energy

Biomass is the term used for all organic material originating from plants, trees and crops, and is essentially the collection and

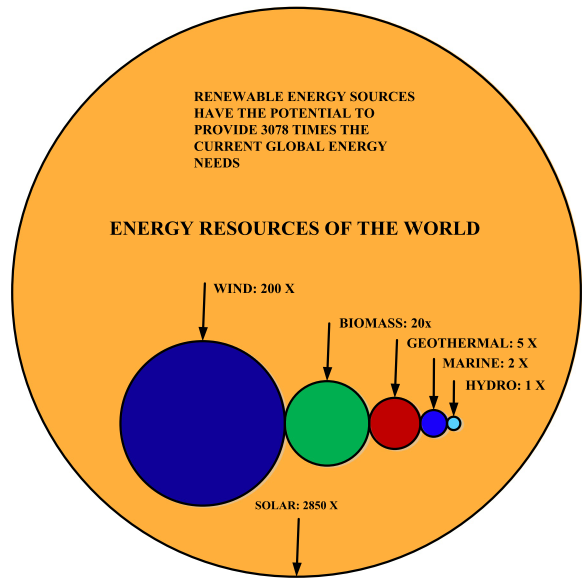

Fig. 2. Energy resources of the world [5].

Table 1
World renewable energy use by type [7].

	2010	2020	2035
Electricity generation (TW h)	**4206**	**6999**	**11,342**
Bioenergy	331	696	1,487
Hydro	3431	4513	5,677
Wind	342	1272	2,681
Geothermal	68	131	315
Solar PV	32	332	846
Concentrating solar power	2	50	278
Marine	1	5	57
Share of total generation	**20%**	**25%**	**31%**
Heat demand (Mtoe)	**337**	**447**	**604**
Industry	207	263	324
Buildings and agriculture	131	184	280
Share of total production	**10%**	**12%**	**14%**
Biofuels (mboe/d)	**1.3**	**2.4**	**4.5**
Road transport	1.3	2.4	4.4
Aviation	–	–	0.1
Share of total transport	**2%**	**4%**	**6%**

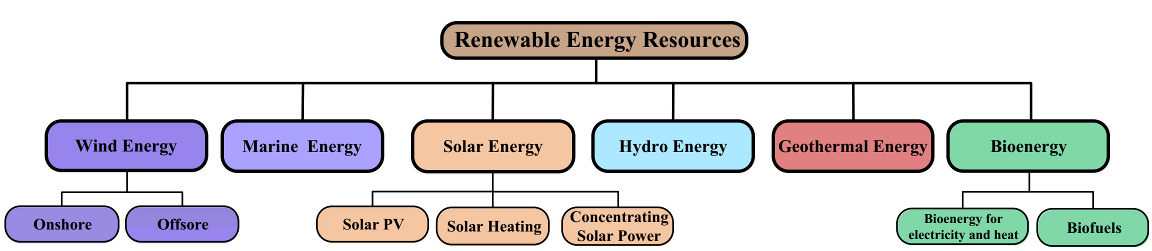

Fig. 1. Overview of renewable energy sources.

storage of the sun's energy through photosynthesis. Biomass energy (bioenergy) is the conversion of biomass into useful forms of energy such as heat, electricity and liquid fuels (biofuels).

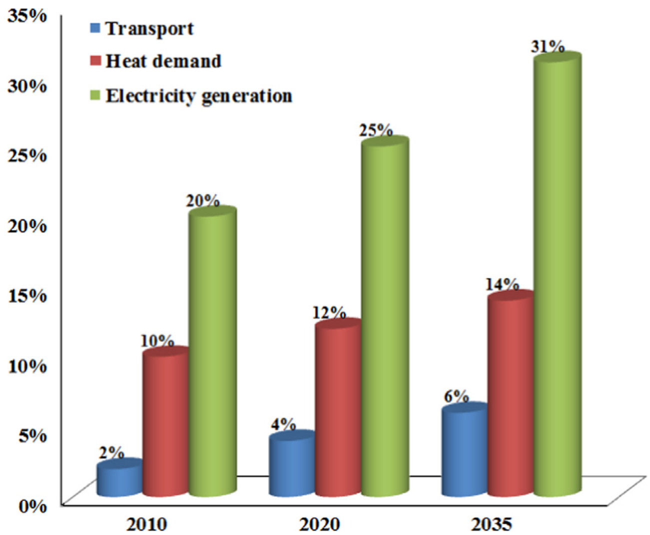

Fig. 3. Share of renewables by category [7].

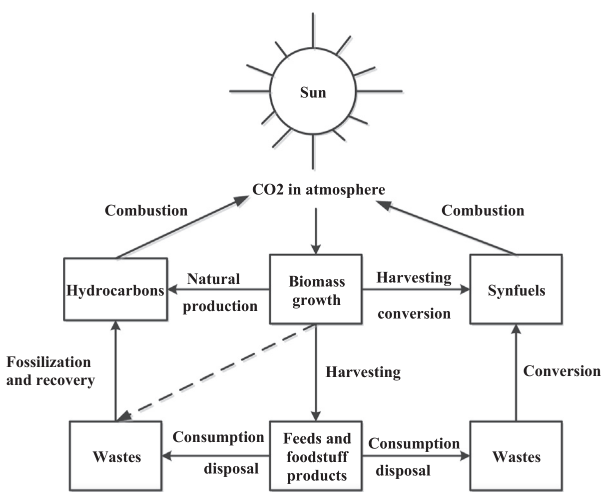

Fig. 4. Main features of the biomass energy technology.

Biomass for bioenergy comes either directly from the land, such as from dedicated energy crops, or from residues generated in the processing of crops for food or other products [8–10].

Biomass energy is renewable and sustainable, but shares with fossil fuels many characteristics. While biomass can be directly burned to obtain energy, it can also serve as a feedstock to be converted to various liquid or gas fuels (biofuels). Biofuels can be transported and stored, and allow for heat and power generation on demand, which is essential in an energy mix with a high dependence on intermittent sources such as wind. These similarities account for the major role biomass is expected to play in future energy scenarios [11]. Therefore, a recently emerging strategy is to develop biorefinery and biotransformation technologies to convert biomass feedstock into clean energy fuels. Interconversion of various biomass and energy forms in the carbon cycle is illustrated in Fig. 4, [12]. Biomass feedstock can be converted in to bioenergy via thermo-chemical and bio-chemical conversion processes. These processes include combustion, pyrolysis, gasification, and anaerobic digestion, as indicated in Fig. 5. Moreover, the utilization of biomass-derived fuels will also greatly mitigate current energy security and trade balance issues, and foster socio-economic developments for many nations, as indicated in Table 2 [13].

In contrast to the benefits, there are significant barriers to biomass-to-energy facilities. Biomass fuels have low energy densities, and collection and transportation can be cost prohibitive. Using biomass to generate electricity is technologically well established, but the price paid for electricity seldom offsets the full cost of the biomass fuel. Bioenergy fuels are intensive in the use of inputs, which include land, water, crops, and fossil energy, all of which have opportunity cost.

Globally, installed biomass plant capacity rose from 66 GW in 2010 to 72 GW by the end of 2011 and with annual average growth rate of about 5% in 2012, the accumulated capacity reached 76 GW. In the long term, biomass and waste power generation could grow from 62 GW in 2010 to 270 GW in 2030, as illustrated by Fig. 6 [14].

2.2. Geothermal energy

Geothermal energy is a powerful and efficient way to extract renewable energy from the earth by natural processes. This can be performed on a small scale to provide heat for a residential unit by using a geothermal heat pump, or on a large scale for energy production through a geothermal power plant. Geothermal power

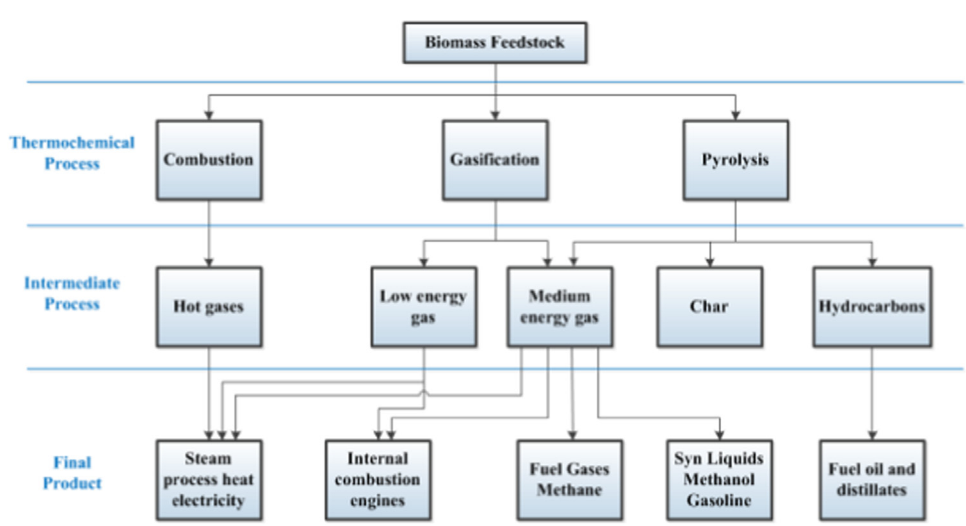

Fig. 5. Biopower conversion processes for different end products.

Table 2
Potential benefits and technical limitations of biomass energy [13].

Potential benefits	Technical limitations
Environmental gains	***Environmental threats***
• Reduced dependency on environmentally damaging fossil fuels and petroleum products	• Use of protected land for biomass production
• Lowered levels of greenhouse gas emissions	• Depletion of local water supplies
• Reduced smog and toxic chemical emissions	• High demand for fertilizers, herbicides and pesticides, leading to an increase in air and soil pollution
• Use of waste materials reducing the need for landfill sites	• Possibility of global climate change with increased atmospheric CO_2 production
	• Use of genetically engineered crops and microorganisms can possibly affect ecosystems
Economic benefits	• Reduced biodiversity due to soil pollution and/or industrial cultivation of favored crop species
• Relatively inexpensive resources	• Increased particulate carbon emissions from wood burning
• Locally distributed energy sources provide constancy and reliability	
• More widely distributed access to energy	***Associated technologies***
• Price stability	• Collection storage of feedstock
• Generation of employment opportunities in rural communities	• Pre-treatment of biomass
• Biomass and bioenergy technology export opportunities	• Enzyme production
• Use of underutilized biomass resources as a renewable and inexhaustible fuel source	• Cost of technology manufacturing and maintenance

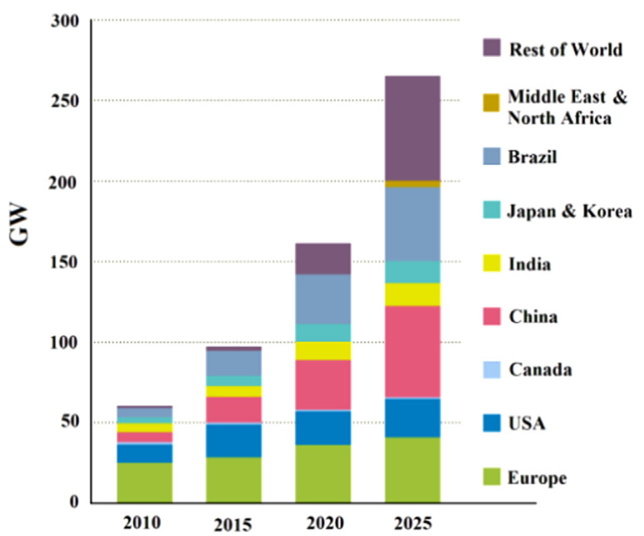

Fig. 6. Biomass and waste installed capacity for power generation states as projected from 2010 to 2025 [14].

is considered a cost effective, reliable, and environmentally friendly energy source [15].

Geothermal energy resources consist of thermal energy from the earth's interior stored in both rock and trapped steam or liquid water. Geothermal systems occur in different geological environments where the temperatures and depths of the reservoirs vary accordingly. Many high-temperature hydrothermal systems (greater than 180 °C) are associated with recent volcanic. Intermediate-temperature (between 100 and 180 °C) and low-temperature (less than100 °C) systems are also found in continental settings, where above-normal heat production through radioactive isotope decay increases terrestrial heat flow or where aquifers are charged by water heated through circulation along deeply penetrating fault zones. Under appropriate conditions, high, intermediate and low temperature geothermal fields can be utilized for both power generation and the direct use of heat [16,17].

Geothermal energy sources are classified as hydrothermal systems, conductive systems and deep aquifers. Hydrothermal systems include liquid and vapor dominated types. Conductive systems include hot rock and magma over a wide range of temperatures, and deep aquifers contain circulating fluids in porous media or fracture zones at depths typically greater than 3 km, though they lack a localized magmatic heat source.

Geothermal energy resource utilization technologies can be grouped under types for electrical power generation, direct use of heat, or combined heat and power in cogeneration applications. Geothermal heat pump (GHP) technologies are a subset of direct use. Currently, the only commercially exploited geothermal systems for power generation and direct use are hydrothermal. Table 3 summarizes the resources and utilization technologies [18,19].

In 2012, geothermal capacities grew by 2.6% (290 MW) to reach 11.4 GW, as shown in Fig. 7. The US has the largest geothermal capacity, now just under 3.4 GW (29.6% of the world total), followed by the Philippines (2.0 GW), Indonesia (1.3 GW) and Mexico (0.8 GW), Fig. 8a illustrates the installed geothermal electric capacity as of 2012 in the top ten countries [20]. By 2050, the projected installed capacity of geothermal power plants is expected to be between 140 GWe and 160 GWe, while the potential installed capacity for direct uses could reach 800 GW_{th}, as indicated in Fig. 8b [21].

2.3. Hydropower energy

Hydropower is a power that is derived from the energy of moving water. Flowing water creates energy that can be captured and converted into electricity by using turbines. The most prevalent form of hydropower is dams, although newer forms harnessing wave and tidal power are becoming more common.

Hydropower is generated from water moving in the hydrological cycle, which is driven by solar radiation. It is the flow of water in rivers, driven by the force of gravity to move from higher to lower elevations that can be used to generate hydropower. Hydropower plants (HPP) span a very large range of scales, from a few watts to several GW. The largest projects are Itaipu in Brazil with 14,000 MW and Three Gorges in China with 22,400 MW, both producing between 80 to 100 TW h/yr. Hydropower projects are always site-specific, and, thus, designed according to the river system they inhabit. Historical, regional hydropower generation from 1965 to 2012 is shown in Fig. 9 [22,23]. Five countries make up more than half of the world's hydropower production: China, Brazil, Canada, USA and Russia [24]. Fig. 10 illustrates the top ten countries in hydropower generation in 2012. Over the next decade, hydropower should increase by approximately 180 GW of installed capacity if projects currently under construction proceed as planned. This increase corresponds to roughly one-quarter of the

Table 3
Types of geothermal resources, temperatures and their applications.

Type	In-situ fluids	Subtype	Temperature range	Utilization	
				Current	Future
Convective systems (hydrothermal)	Yes	Continental	H, I and L	Power, direct use	
		Submarine	H	None	Power
Conductive systems	No	Shallow (< 400 m)	L	Direct use (GHP)	
		Hot rock (EGS)	H, I	Prototypes	Power, direct use
		Magma bodies	H	None	Power, direct use
Deep aquifer systems	Yes	Hydrostatic aquifers	H, I and L	Direct use	Power, direct use
		Geo-pressured		Direct use	Power, direct use

H: high, I: intermediate, L: low.

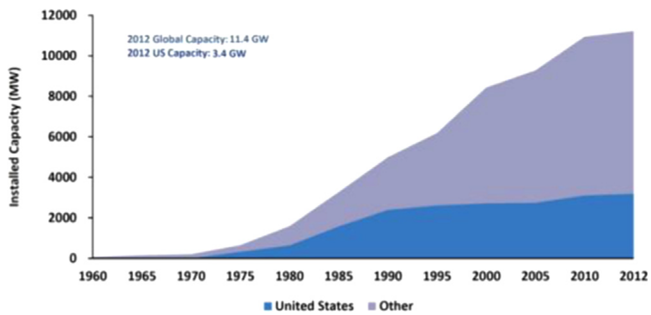

Fig. 7. Global context of global and US geothermal installed capacity 1960–2012.

currently installed capacity. One-third of this increase will come from China alone; furthermore, Turkey will see the largest capacity additions. Brazil and India also have a large capacity under construction, as shown in Fig. 11 [3].

Hydropower plants are classified into three categories according to operation and type of water flow. Run-of-River (RoR), storage (reservoir) and pumped storage HPPs vary from small to large in terms of scale, depending on the hydrology and topography of the watershed. A RoR HPP draws the energy for electricity production mainly from the available flow of the river. Such a hydropower plant may include some short-term storage, allowing for some adaptations to the demand profile, but the generation profile will vary according to the local river flow conditions; therefore, generation depends on precipitation and runoff and may have substantial daily, monthly or seasonal variations. Hydropower plants with a reservoir are called storage hydropower since they store water for later consumption. The reservoir reduces the dependence on the variability of the inflow, and the generating stations are located on a downstream connected to the reservoir through pipelines. The type and design of reservoirs are decided by the landscape. Pumped storage hydropower plants are not energy sources, but they can be as storage devices. In such a system, water is pumped from a lower reservoir into an upper reservoir, usually during off-peak hours, while flow is reversed to generate electricity during the daily peak load period. Although the losses of the pumping process make such a plant a net energy consumer, the plant is able to provide large-scale energy storage system benefits. In fact, pumped storage is the largest-capacity form of grid energy storage now readily available worldwide [21,25].

Hydropower is a proven and well-advanced technology based on more than a century of experience. Hydropower today is an extremely flexible power technology with among the best conversion efficiencies of all energy sources (90%, water to wire) due to its direct transformation of hydraulic energy to electricity. Still, there is room for further improvement by refining operation, reducing environmental impacts, adapting to new social and environmental requirements and developing more robust and cost-effective technological solutions [21].

2.4. Marine energy

The renewable marine (ocean) energy comes from six distinct sources: waves, tidal range, tidal currents, ocean currents, ocean thermal energy conversion and salinity gradients, each with different origins and requiring different technologies for conversion. All ocean energy technologies, except tidal barrages, are conceptually undergoing intensive research and development, or are in the pre-commercial prototype and demonstration stage. The theoretical potential for ocean energy technologies has been estimated at 7400 EJ/yr, exceeding current and future human energy needs. Relatively few assessments have been conducted on the technical potential of the various ocean energy technologies and such potentials will vary based on future technological development [26–28]. Fig. 12 shows the global ocean energy forecasting depending on device technology and infrastructure available [29]. Since the ocean energy sectors are still in the development phase, less than 3 MW of capacity were installed per year for both wave power and energy from tidal currents during the period 2004–2009. However, things are progressing, especially in the UK, the USA and Portugal, and the installed capacity should increase by around 25 MW/yr, as indicated by Fig. 13, [30].

2.5. Solar energy

Solar energy generation involves the use of the sun's energy to provide hot water via solar thermal systems or electricity via solar photovoltaic (PV) and concentrating solar power (CSP) systems. These technologies are technically well proven with numerous systems installed around the world over the last few decades [31].

2.5.1. Photovoltaic

Solar photovoltaic (PV) systems directly convert solar energy into electricity. The basic building block of a PV system is the PV cell, which is a semiconductor device that converts solar energy into direct-current electricity. PV cells are interconnected to form a PV module, typically up to 50 to 200 W. The PV modules, combined with a set of additional application-dependent system components (e.g., inverters, batteries, electrical components, and mounting systems), form a PV system. PV systems are highly modular, i.e., modules can be linked together to provide power ranging from a few watts to tens of megawatts.

The most established solar PV technologies are silicon based systems. More recently, so called thin film modules, which can also consist of non-silicon semiconductor material, have become increasingly important. Although thin films generally have a lower

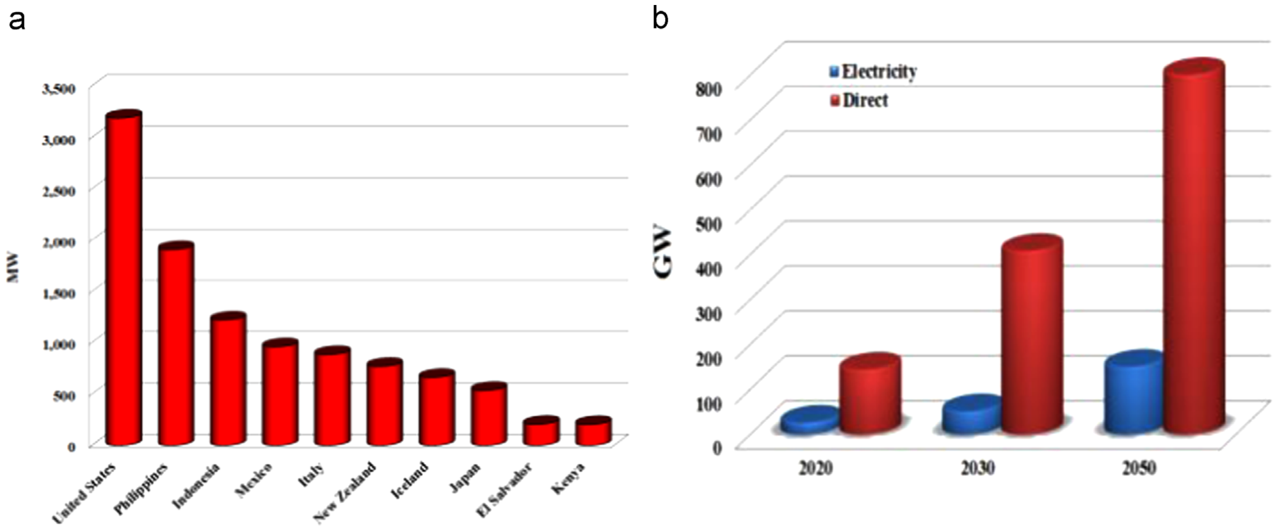

Fig. 8. (a) Cumulative installed geothermal generating capacity by top ten countries in 2012 (b) estimated geothermal deployments for electricity and heat applications [21].

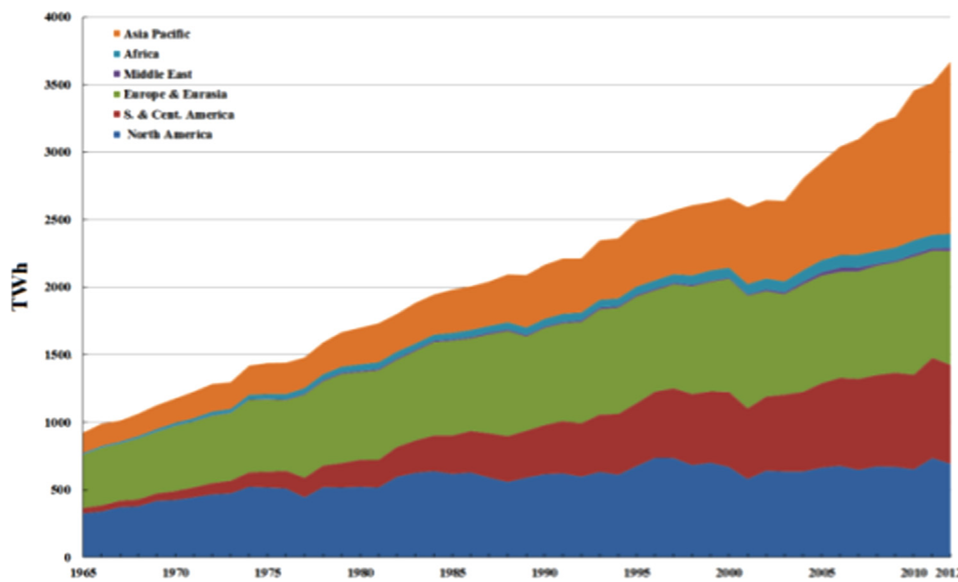

Fig. 9. Hydropower generation (TW h) by region.

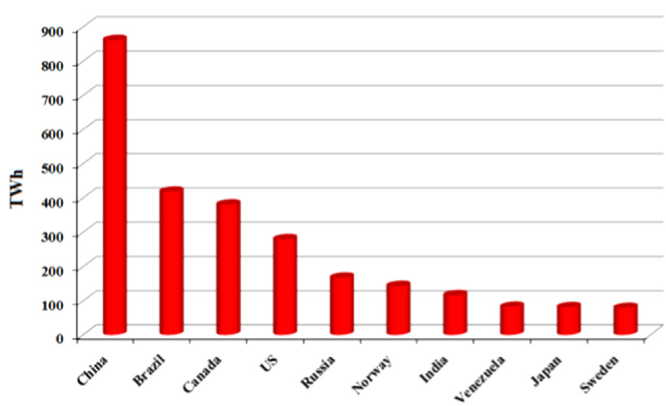

Fig. 10. Hydropower generation by top ten countries in 2012.

efficiency than silicon modules, their price per unit of capacity is lower. Concentrating PV, where sunlight is focused onto a smaller area, is on the edge of entering full market deployment. Concentrating PV cells have very high efficiencies of up to 40%. Other technologies, such as organic PV cells, are still in the research phase [32].

Solar PV combines two advantages. On the one hand, module manufacturing can be done in large plants, which allows for economies of scale. On the other hand, PV is a very modular technology. Compared to concentrating solar power (CSP), PV has the advantage that it uses not only direct sunlight but also the diffuse component of sunlight, i.e., solar PV produces power even if the sky is not completely clear. This capability allows the effective deployment in many more regions in the world than for CSP [33].

Photovoltaic systems are classified into two major types: off-grid and grid-connected applications. Off-grid PV systems have a significant opportunity for economic application in the un-electrified areas of developing countries, and off-grid centralized PV mini-grid systems have become a reliable alternative for village electrification over the last few years. Centralized systems for local power supply have different technical advantages concerning electrical performance, reduction of storage needs, availability of energy, and dynamic behavior. Centralized PV mini-grid systems could be the most cost efficient for a given level of service, and

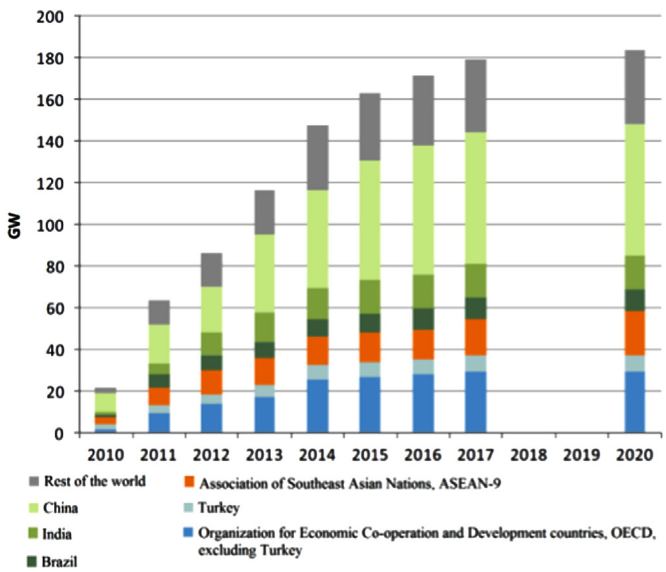

Fig. 11. Global hydropower projects under construction, cumulative additional capacity by year of expected commissioning [3].

they may have a diesel generator set as an optional balancing system or operate as a hybrid PV-wind-diesel system. These kinds of systems are relevant for reducing and avoiding diesel generator use in remote areas [34].

Grid tied PV systems use an inverter to convert electricity from direct current to alternating current, and then supply the generated electricity to the electric grid. Compared to an off-grid installation, system costs are lower because energy storage is not required since the grid is used as a buffer. Grid-connected PV systems are classified into two types of applications: distributed and centralized. Grid-connected distributed PV systems are installed to provide power to a grid-connected customer or directly to the electric network. These systems have a number of advantages: distribution losses in the electric network are reduced because the system is installed at the point of use; extra land is not required for the PV system, and costs for mounting the systems can be reduced if the system is mounted on an existing structure; and the PV array itself can be used as a cladding or roofing material, as in building-integrated PV. Typical sizes are 1 to 4 kW for residential systems, and 10 kW to several MW for rooftops on public and industrial buildings.

Grid-connected centralized PV systems perform the functions of centralized power stations. The power supplied by such a system is not associated with a particular electricity customer, and the system is not located to specifically perform functions on the electricity network other than to supply bulk power. Typically, centralized systems are mounted on the ground, and they are larger than 1 MW. The economic advantages of these systems are the optimization of installation and operating costs by bulk buying and the cost effectiveness of the PV components and balance of systems on a large scale. In addition, the reliability of centralized PV systems can be greater than distributed PV systems because they can have maintenance systems with monitoring equipment, which can be a smaller part of the total system cost [35].

New installations totaling 30.2 GW in 2012 took global solar power generating capacity to 100 GW by year-end, a 43.3% increase versus the end of 2011. Capacity has grown more than ten-fold over the past 5 years, with more than half of the growth in capacity in Europe, led by Germany (7.6 GW) and Italy (3.4 GW). Germany remains the world's leader for cumulative installed capacity (32.6 GW), and Italy (16.2 GW) comes in second. The top markets—Germany, Italy, China, the United States, and Japan—were also the leaders for total capacity, as indicated by Fig. 14 [1]. In addition, Fig. 15 shows the global PV annual market scenarios until 2016 [36,37].

2.5.2. Concentrating solar power

Concentrating solar power (CSP) technologies produce electricity by concentrating direct-beam solar irradiance to heat a liquid, solid or gas that is then used in a downstream process for electricity generation. Large-scale CSP plants most commonly concentrate sunlight by reflection, as opposed to refraction with lenses. Concentration is either to a line (linear focus) as in trough or linear fresnel systems or to a point (point focus) as in central-receiver or dish systems. CSP applications range from small distributed systems of tens of kW to large centralized power stations of hundreds of MW. The earliest commercial CSP plants were the 354 MW of solar electric generating stations in California that continue to operate commercially today. As a result of the positive experiences and lessons learned from these early plants, the trough systems tend to be most often applied today as the CSP industry grows [38,39].

Regarding the CSP electricity generation, at the beginning of 2009, more than 700 MW of grid-connected CSP plants were installed worldwide, with another 1500 MW under construction. The majority of installed plants use parabolic trough technology. A central receiver comprises a growing share of plants under construction and those announced.

The concentrating solar thermal power (CSP) market continued to advance in 2012, with total global capacity up more than 60% to about 2550 MW. The market doubled relative to 2011, with Spain accounting for most of the 970 MW brought into operation, as indicated by Fig. 16. The bulk of the operating capacity is installed in Spain and the South-Western United States, as shown in Fig. 17 [21].

2.5.3. Solar thermal heating and cooling

Solar heating and cooling technologies collect thermal energy from the sun and use this heat to provide hot water, space heating, cooling, and pool heating for residential, commercial, and industrial applications. By the end of 2012, global solar thermal capacity in operation reached an estimated 282 GW_{th}. Global capacity of glazed water collectors reached 255 GW_{th}. The top countries for total capacity in operation were China, Germany, Turkey, Brazil and India. Fig. 18 indicates solar water heating global capacity for glazed water collectors only, [40].

2.6. Wind energy

Wind power is defined by the conversion of wind energy by wind turbines into a useful form, such as using wind turbines to make electricity, wind mills for mechanical power, wind pumps for pumping water or drainage, or sails to propel ships. The first wind turbines for electricity generation were developed at the beginning of the 20th century. The technology has gradually improved since the early 1970s. By the end of the 1990s, wind energy has re-emerged as one of the most important sustainable energy resources [41].

Generating electricity from the wind requires that the kinetic energy of moving air be converted to mechanical and then electrical energy, thus challenging the industry to design cost effective wind turbines and power plants to perform this conversion. The amount of kinetic energy in the wind that is theoretically available for extraction increases with the cube of the wind speed. However, a turbine only captures a fraction of that available energy (40–50%), so wind turbine design has focused on maximizing energy capture over the range of wind speeds experienced

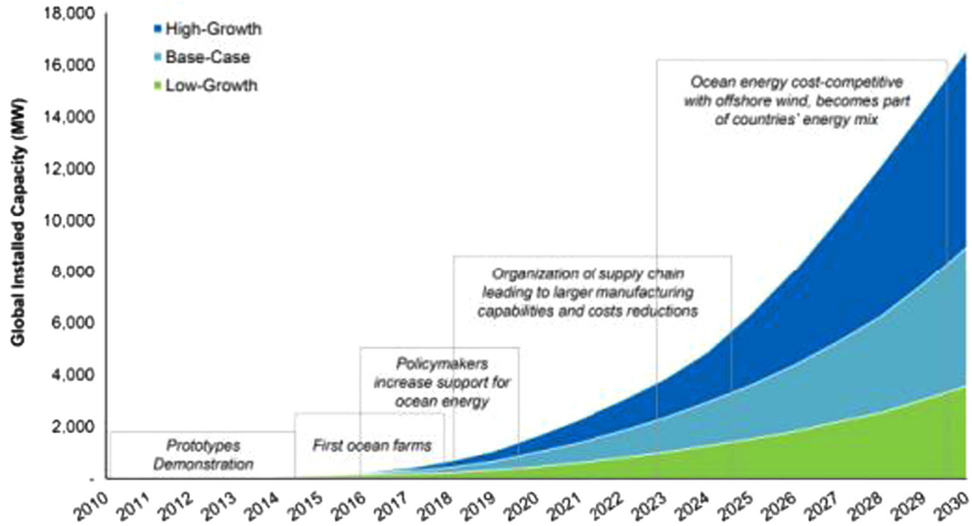

Fig. 12. Global Ocean energy forecasting.

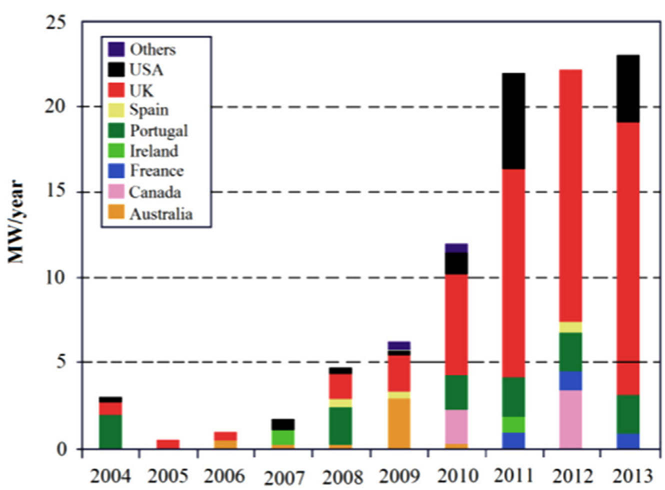

Fig. 13. Installed capacity for waves and sea currents for 2004–2013 [30].

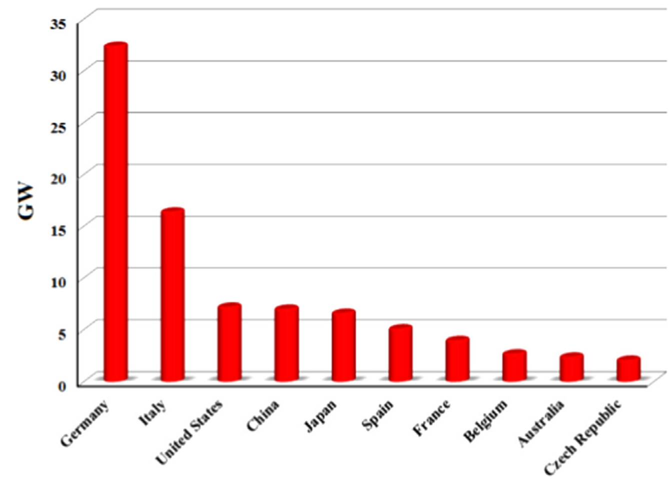

Fig. 14. Solar PV global capacity, shares of top 10 countries, 2012 [10].

by wind turbines, while seeking to minimize the cost of wind energy tacking all parameters in account. To minimize cost, wind turbine design is also motivated by a desire to reduce materials usage while continuing to increase turbine size, increase component and system reliability, and improve wind power plant operations.

From 1970 to 1980, a variety of onshore wind turbine configurations were investigated, including both horizontal and vertical axis designs. Gradually, the horizontal axis design came to dominate, although configurations varied, particularly the number of blades and blades orientation. Onshore wind turbines are typically grouped together into wind power plants, sometimes also called wind farms. These wind power plants are often 5 to 300 MW in size, though smaller and larger plants do exist. Offshore wind energy technology is less mature than onshore, and has higher investment. The motivations for developing offshore wind energy include: the higher-quality wind resources located at sea; the ability to use even larger wind turbines; the ability to build larger power plants than onshore; and the potential reduction in the need for land-based transmission infrastructure [42,43].

From an electric system reliability perspective, an important part of the wind turbine is the electrical conversion system. For large grid-connected turbines, electrical conversion systems come in three different forms. Fixed-speed induction generators were popular in earlier years for both stall-regulated and pitch-controlled turbines; in these arrangements, wind turbines were net consumers of reactive power that had to be supplied by the electric network. For modern turbines, these designs have now been replaced with variable-speed machines. Two arrangements are common, doubly-fed induction generators and synchronous generators with a full power electronic converter, both of which are almost always coupled with pitch-controlled rotors. These variable speed designs essentially decouple the rotating masses of the turbine from the electric system, thereby offering a number of power quality advantages over earlier turbine designs. These turbines can provide real and reactive power, as well as some fault ride-through capability, all of which are required by electric network operators.

During 2012, almost 45 GW of wind power capacity began operation, increasing global wind capacity 19% to almost 283 GW, as shown in Fig. 19a. Approximately 44 countries added capacity during 2012, at least 64 had more than 10 MW of reported capacity by year's end, and 24 had more than 1 GW in operation. From the end of 2007 through 2012, annual growth rates of cumulative wind power capacity averaged 25%. The United States and China together accounted for nearly 60% of the global market in 2012, followed distantly by Germany, India, and the United Kingdom. Others in the top 10 for capacity added were Italy, Spain, Brazil, Canada and Romania as shown in Fig. 19b [44].

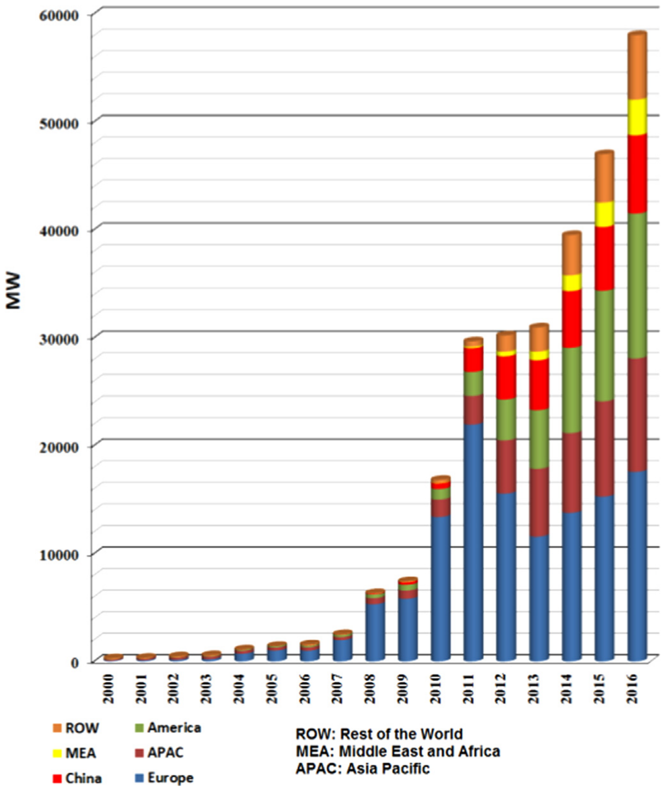

Fig. 15. Total global annual PV market divided per region until 2016 [36].

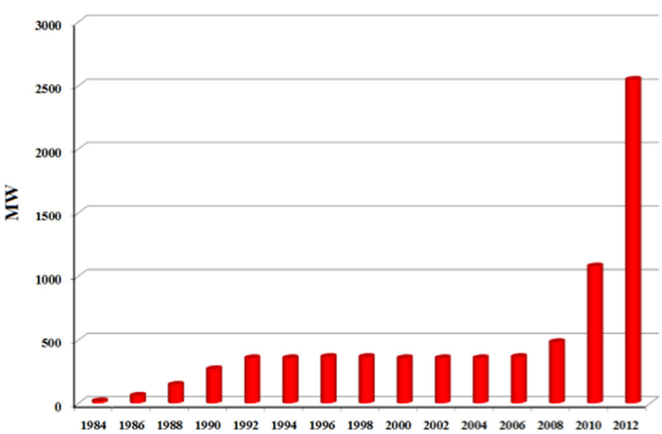

Fig. 16. Global installed PV capacity, 1984–2012 [40].

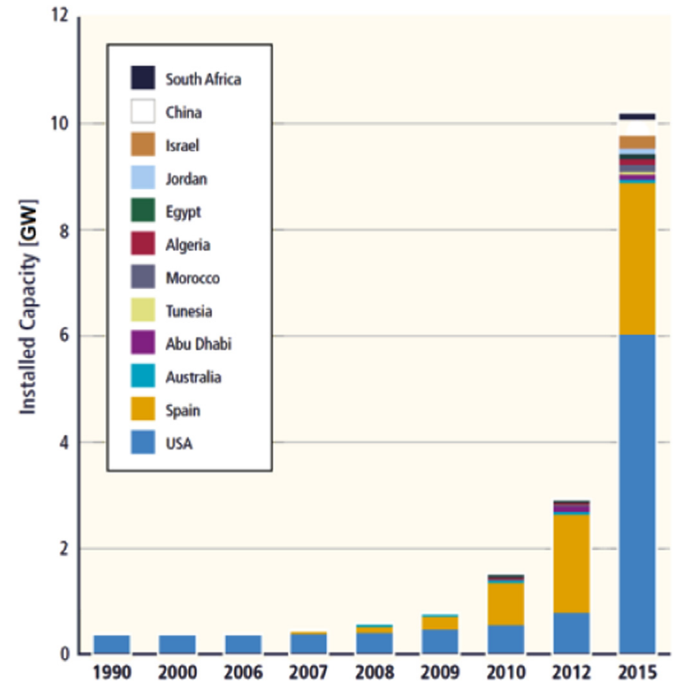

Fig. 17. Global installed and planned concentrated solar power (CPS) plants distributed by country [21].

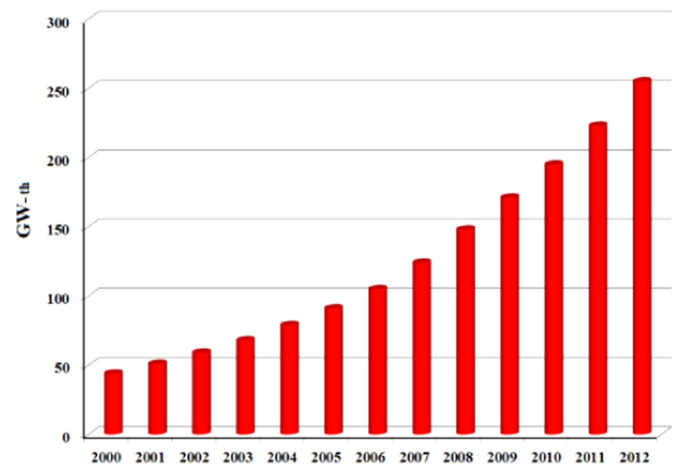

Fig. 18. Solar water heating global capacity, 2000–2012 [40].

After the description of the different renewable energy sources, it should be noted that each source of renewable energy has its advantages and disadvantages as summarized by Table 4, furthermore, Table 5 shows some negative environmental impacts of renewable energy resources.

3. Renewable energy: Benefits, growth, investment and deployment

Renewable energy can provide a host of benefits to society, as shown in Fig. 20. In addition to the reduction of carbon dioxide (CO_2) emissions, governments have enacted renewable energy (RE) policies to meet a number of objectives including the creation of local environmental and health benefits; facilitation of energy access, particularly for rural areas; advancement of energy security goals by diversifying the portfolio of energy technologies and resources; and improving social and economic development through potential employment opportunities [45].

Global demand for renewable energy continued to rise during 2011 and 2012, supplying an estimated 19% of global final energy consumption in 2011. Total renewable power capacity worldwide exceeded 1470 GW in 2012, up about 8.5% from 2011. Hydropower rose 3% to an estimated 990 GW, while other renewables grew 21.5% to exceed 480 GW. Globally, wind power accounted for about 39% of the renewable power capacity added in 2012, followed by hydropower and solar PV, each accounting for approximately 26%. In power generation, global wind power capacity grew by 20% in 2011 (to 238 GW), after growing by an annual average of 26% over the five-year period 2006–2011. Solar PV capacity grew by a record 74% in 2011 (to 70 GW), after growing by an average of 58% over the five-year period. Solar thermal power (CSP) grew by 35% in 2011. In contrast, hydropower, biomass, and geothermal power have been mature for decades, and five-year growth rates for these renewables were more on par with conventional energy technologies. In terms of total power generation capacity, renewable

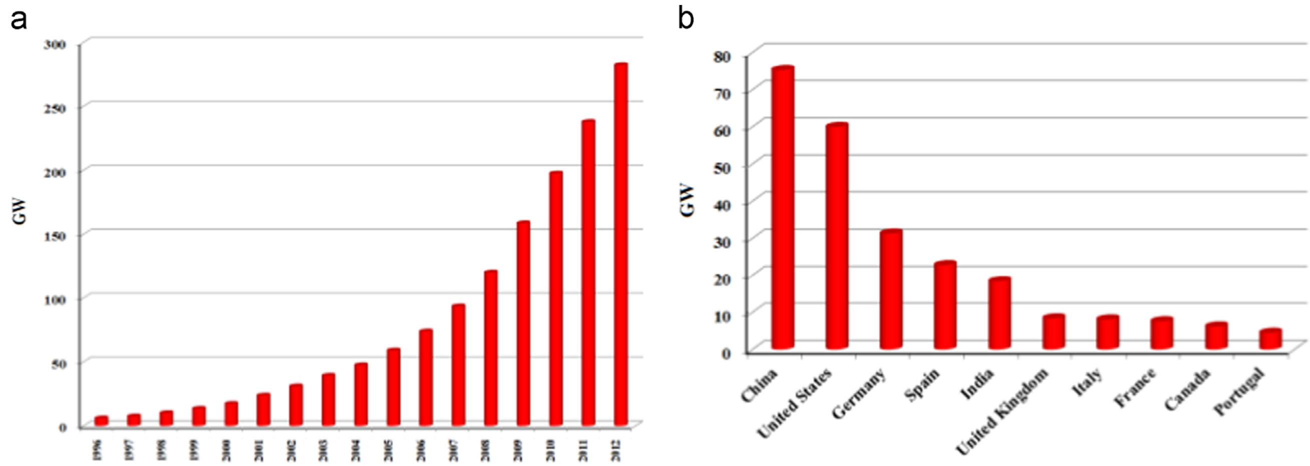

Fig. 19. (a) Wind power total world capacity, 1996–2012, (b) wind power capacity, top 10 countries, 2012 [40].

Table 4
Advantages and disadvantages of different renewable energy resources.

Energy source	Advantages	Disadvantages
Biomass energy	• Abundant and renewable • Can be used to burn waste products	• Burning biomass can result in air pollution • May not be cost effective
Geothermal energy	• Provides an unlimited supply of energy • Produces no air or water pollution	• Start-up/development costs can be expensive • Maintenance costs, due to corrosion, can be a problem
Hydropower	• Abundant, clean, and safe • Easily stored in reservoirs • Relatively inexpensive way to produce electricity • Offers recreational benefits like boating, fishing, etc.	• Can cause the flooding of surrounding communities and landscapes. • Dams have major ecological impacts on local hydrology. Can have a significant environmental impact • Can be used only where there is a water supply • Best sites for dams have already been developed
Marine energy	• Ideal for an island country • Captures energy that would otherwise not be collected	• Construction can be costly • Opposed by some environmental groups as having a negative impact on wildlife • Takes up lots of space and difficult for shipping to move around
Solar energy	• Potentially infinite energy supply • Causes no air or water pollution	• May not be cost effective • Storage and backup are necessary • Reliability depends on availability of sunlight
Wind energy	• Is a free source of energy • Produces no water or air pollution • Wind farms are relatively inexpensive to build • Land around wind farms can have other uses	• Requires constant and significant amounts of wind • Wind farms require significant amounts of land • Can have a significant visual impact on landscapes • Need better ways to store energy

Table 5
Some negative environmental impacts of different renewable energy resources.

Energy source	Potential negative impacts on the environment
Biomass	May not be CO_2 natural, may release global warming gases like methane during the production of biofuels, landscape change, deterioration of soil productivity, hazardous waste
Geothermal	subsidence, landscape change, polluting waterways, air emissions
Hydropower	Change in local eco-systems, change in weather conditions, social and cultural impacts
Marine energy	Landscape change, reduction in water motion or circulation, killing of fish by blades, changes in sea eco-system
Solar	Soil erosion, landscape change, hazardous waste
Wind	Noises in the area, landscape change, soil erosion, killing of birds by blades

energy reached 1360 GW in 2011, including 970 GW of hydropower. This means that global renewable capacity represented about one quarter of total global power capacity [40].

From 2008 to 2012, as shown in Fig. 21, installed capacities of many renewable energy technologies grew very rapidly, with the fastest growth in the power sector. Total capacity of solar photovoltaics (PV) grew at rates averaging 60% annually. Concentrating solar thermal power (CSP) capacities increased more than 40% per year on average, growing from a small base, and wind power increased 25% annually over this period. Hydropower and geothermal power are more mature technologies and their growth rates have been more modest, in the range of 3–4% per

year. Bio-power is also mature but with steady growth in solid and gaseous biomass capacity, increasing at an average 8% annually [40].

Renewable energies have accounted for a growing share of electric capacity added worldwide each year; in 2012, they comprised more than 26% of total global power generating capacity and supplied an estimated 21.7% of global electricity. They are currently used in the transport sector in the form of liquid and gaseous biofuels, which, in 2012, provided over 2.5% of global transport fuels [40].

Projections for global renewable energy capacity in 2030, from a variety of scenarios, show wind power capacity increasing between 4-fold and 12-fold, solar PV between 7-fold and 25-fold, CSP between 20-fold and 350-fold, bio-power between 3-fold and 5-fold, geothermal between 4-fold and 15-fold, and hydro between 30% and 80%, based on actual 2011 GW of capacity [40].

New global investments in renewable power and fuels was USD 244 billion in 2012, down 12% from the previous year's record amount of USD 279 billion, as indicated in Fig. 22. The decline in investment, after several years of growth, resulted from uncertainty over support policies in Europe and the United States, as well as from actual retroactive reductions in support. On a more positive note, it also resulted from sharp reductions in technology costs. Fig. 23 shows the global 2012 new investment in renewable energy distributed by technology. Renewable energy sources present the prospect of energy utilization with minimum impact on the environment, particularly in relation to gas emission. The importance of renewable energy development is gaining global importance.

Fig. 24 depicts a diagram of a renewable energy market development. Technological changes play a significant role in the dynamics of renewable energy development, and through this development, efficiency and effectiveness of investments is determined, particularly the cost and maturity of a specific technology. Furthermore, as time passes and the use of a technology increases, costs will be reduced. During this development process, the government is influential in several ways, such as supporting capacity expansions, setting regulations, and promoting global use of renewable energy. Additionally, market and customers' satisfaction affects the producers of renewable energy in their ability to compete with conventional energy producers.

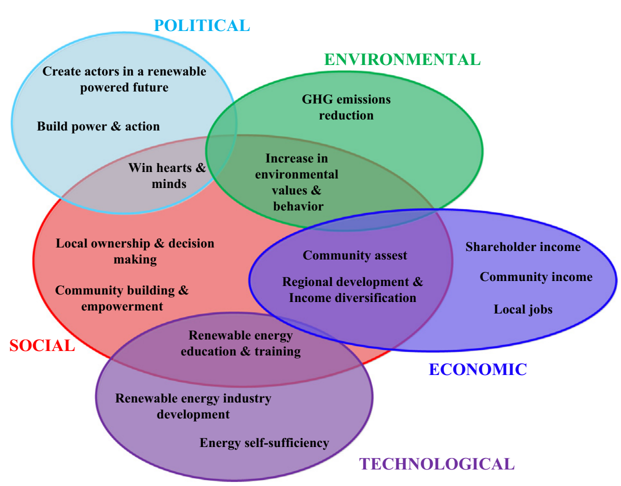

Fig. 20. Global benefits of renewable energies production

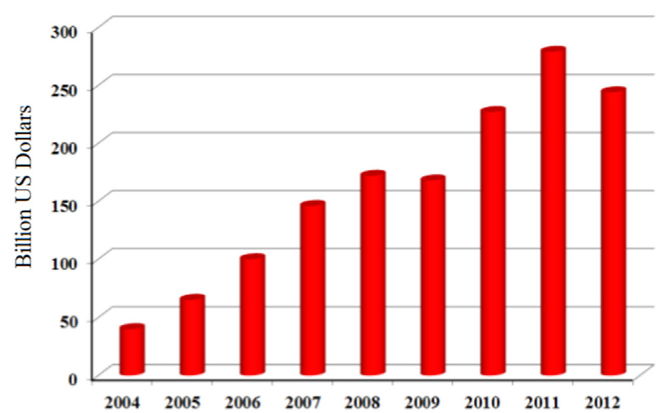

Fig. 22. Global new investment in renewable energy, 2004–2012.

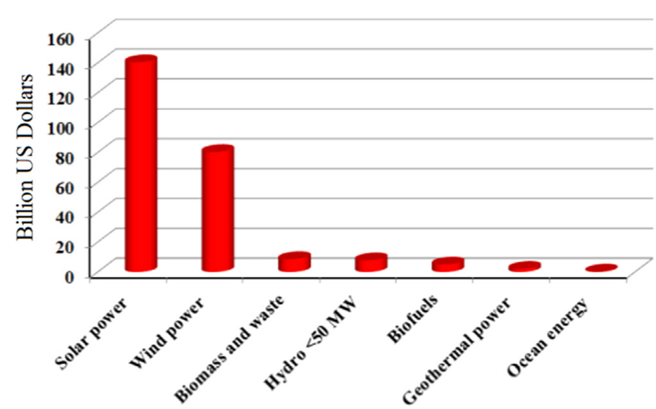

Fig. 23. Renewable energy investments in 2012 classified by technology.

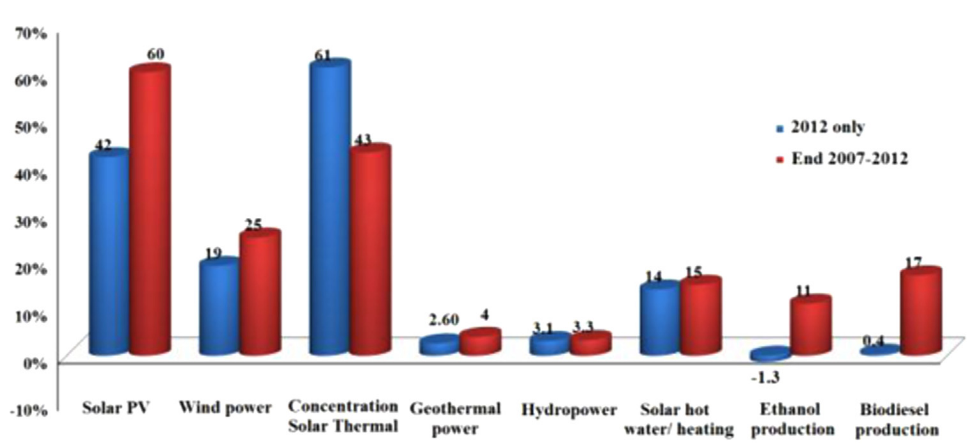

Fig. 21. Average annual growth rates of renewable energy capacity production, end-2007–2012 [40].

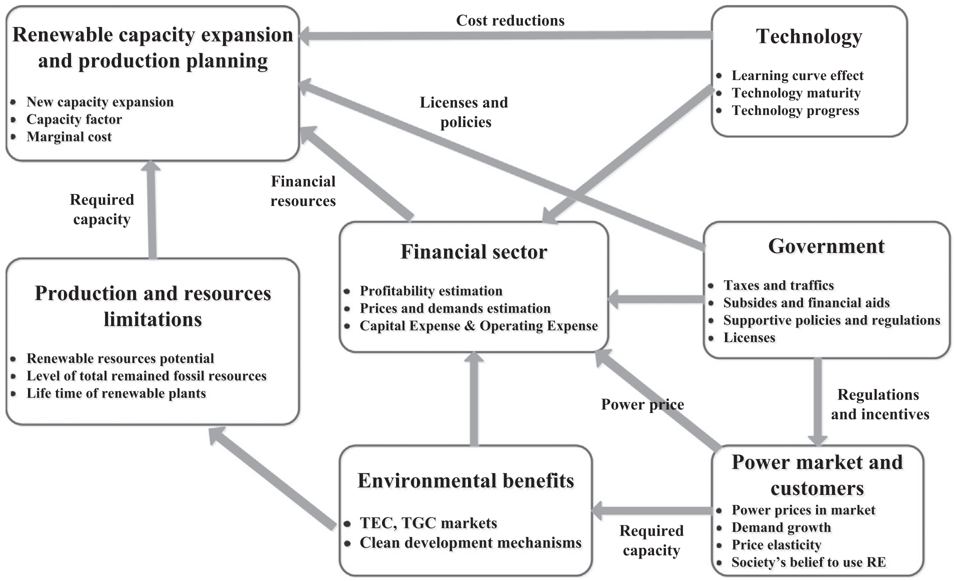

Fig. 24. Renewable energy market development process.

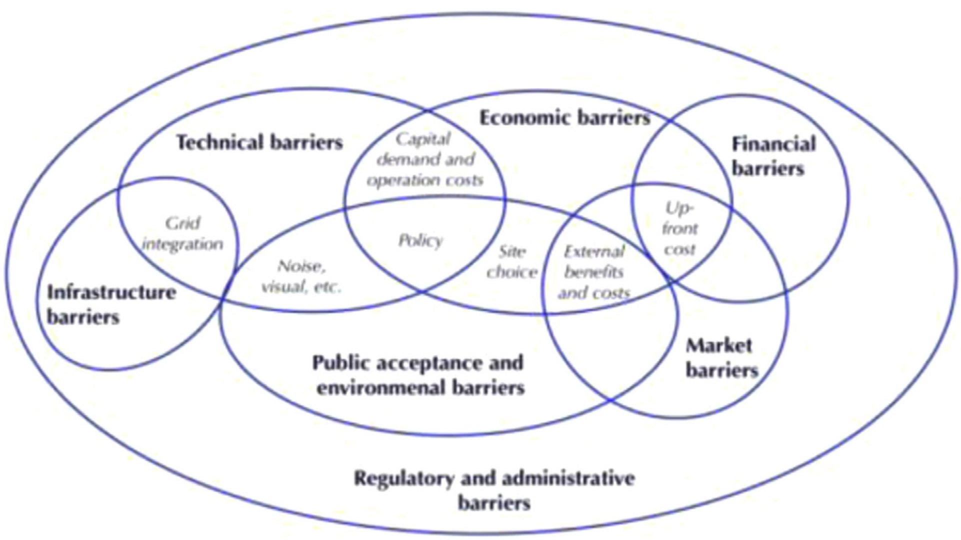

Fig. 25. Barriers to renewable energy technology deployment [47].

Financially, however, needs are fulfilled with respect to profitability levels, estimated prices, demand, and costs. The market development process should also include capacity expansion and short to long-term production planning. Finally, the equipment potentially used in renewable resources and its life time should be taking in consideration through this process.

The challenges involved with deploying renewable energies can be summarized in Fig. 25. An economic barrier is present if the cost of a given technology is above the cost of competing alternatives, even under optimal market conditions, with a direct connection between technological maturity and economic barriers. All other types of barriers are categorized as non-economic, though these barriers have just as an important role in shaping the cost of renewables. The importance of the barriers differs for each technology and market, and the priority changes as a technology matures along the path to commercialization.

A variety of renewable energy technologies are available at different stages of the development cycle, as indicated in Fig. 26. Hydro power and bioenergy are already major sources of energy worldwide. Other options, although technically proven and available on commercial terms, still occupy only a fraction of their potential markets. For this reason, there are many opportunities to improve performance and reduce costs [47–49].

4. Power electronics in renewable energy systems

Power electronics technology has gained significant maturity after several decades of dynamic evolution of power semiconductor devices, converters, pulse width modulation (PWM) techniques, electrical machines, motor drives, advanced controls, and simulation techniques. Power electronics deals with the conversion and control of electrical power with the help of power semiconductor devices that operate in switching mode; therefore, the efficiency of power electronic apparatus may approach as high as 98–99%. With the advancement of technology, the lowered cost of power electronics, the reduced size, and the improved performance, power electronics applications are proliferating in industrial, commercial, residential, aerospace, military, utility, and transportation systems. In addition, the impact of power

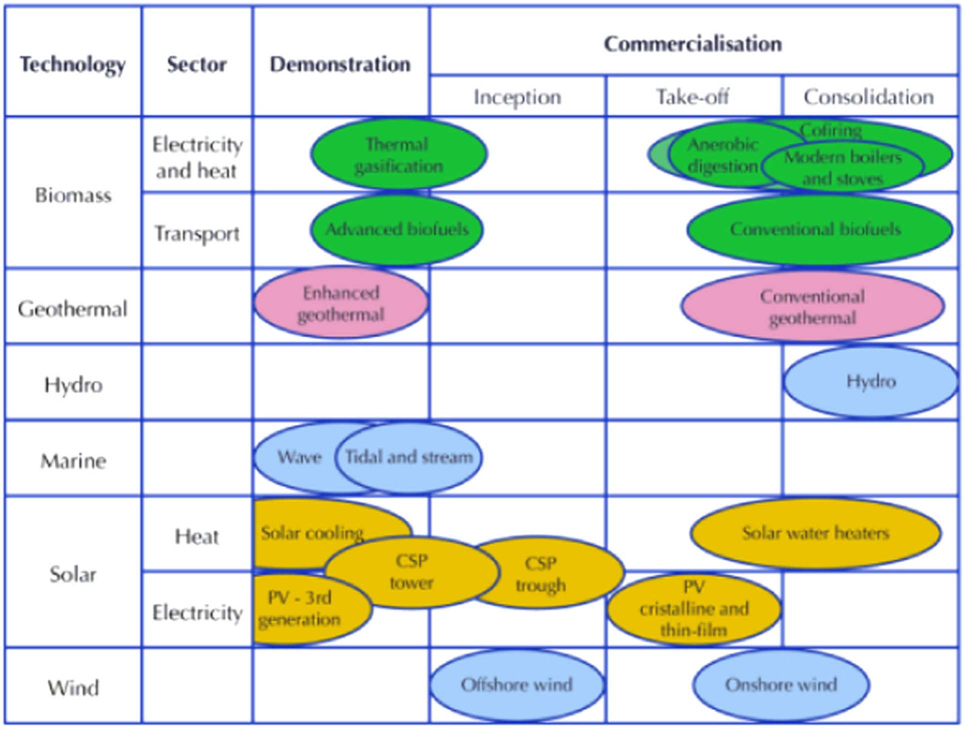

Fig. 26. Maturity of selected renewable energy technologies [47].

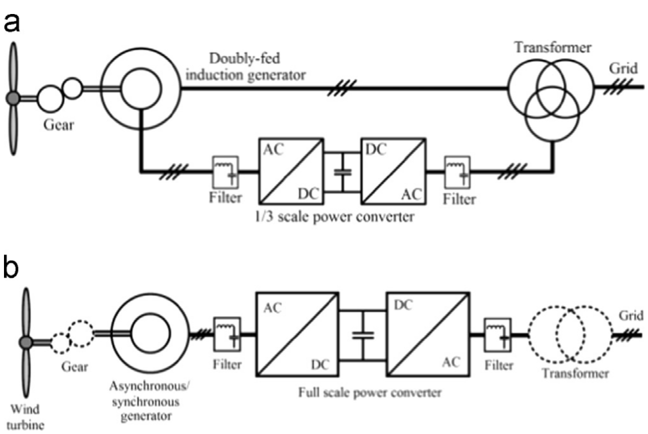

Fig. 27. Different power electronics converter for wind turbines [57].

electronics in renewable energy systems is significant in solving our energy shortage because it enable the efficient generation, use, and distribution of electrical energy by substantially improving energy conversion efficiency. Indeed, power electronics are needed in almost all kinds of renewable energy systems. It is used both for controlling the renewable source and for interfacing to the load, which can be grid-connected or working in stand-alone mode. The power may flow in both directions, of course, depending on the topology and applications [50–55]. Power electronics converters configurations interfacing different renewable energy sources will be presented in the following subsections.

In wind power generation systems, power electronic converters are predominantly applied to regulate the fluctuating input power and maximize the electrical energy harvested from the wind. Up until now, the configuration of a Doubly Fed Induction Generator (DFIG) equipped with partial-scale power converter is dominating on the market, but in the near future the configuration with a Synchronous Generator (SG) with full-scale power converter is expected to take over. Full-scale power converter solutions are becoming the preferred technology choices in the bestselling power ranges of the wind turbines. Fig. 27a shows a power electronics converter adopted in conjunction with the DFIG. The stator windings of DFIG are directly connected to the power grid, while the rotor windings are connected to the power grid by the converter, with the normal 30% capacity of the wind turbine. Fig. 27b introduces a full-scale power converter interconnected with the power grid and stator windings of generator, thus regulating all the generated power from the wind turbine. The Asynchronous Generator, Wound Rotor Synchronous Generator (WRSG) or Permanent Magnet Synchronous Generator (PMSG) have been reported as solutions to be used [56,57].

In photovoltaic (PV) systems, PV inverters are used for efficiently converting the DC voltage for AC applications or integration of the output energy into electrical grid. There are a variety of photovoltaic power system topologies as a result of the range of situational requirements and the rapidly advancing state of the art. There are four general classes of PV topologies, with the multilevel topologies building from these: (1) Centralized, (2) String, (3) AC Modules and (4) Multistring, as shown in Fig. 28 [58,59].

Solar photovoltaic panels or small wind turbines depend on climatic conditions to operate and produce electrical energy. Systems that merge both sources, wind and sun, are more effective in electric energy production, and are called hybrid systems. They can supply stand-alone systems or grid-connected systems. Even with hybrid systems there are periods of time when neither of the sources produce energy. In stand-alone systems energy storage is required to overcome this situation and provide energy during such periods. A hybrid system combines a small wind turbine and photovoltaic solar panels, with their outputs optimized by power controllers. The extracted energy is used to charge a battery bank or supply energy to an inverter, which is connected to the consumer loads and, when it is present, to the electrical power grid, as shown Fig. 29, [60,61].

A major source of biofuel is biogas. There are a variety of biogas sources including the energy stored in trees, green crops,

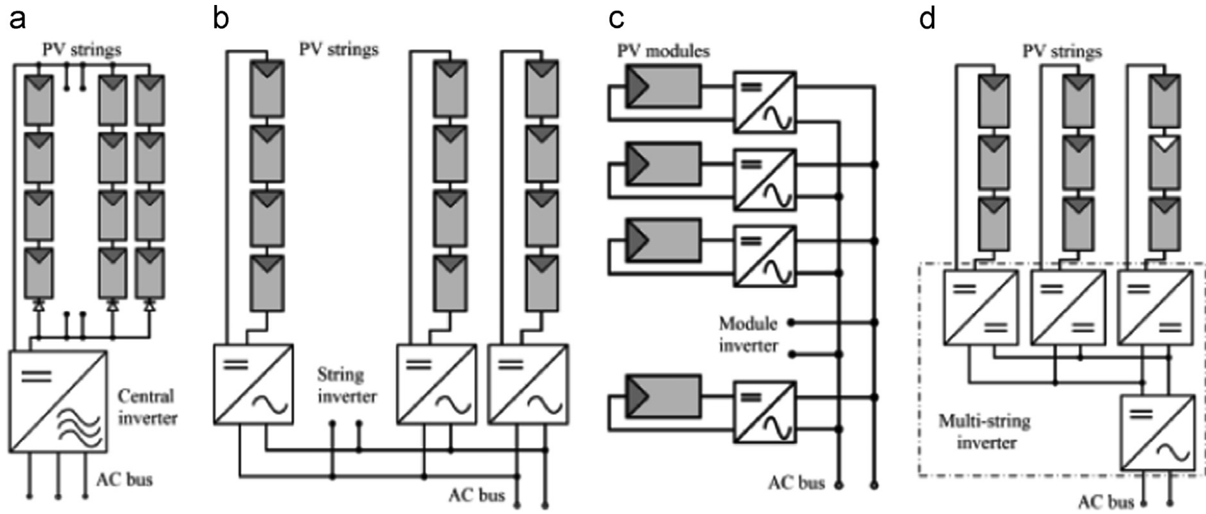

Fig. 28. Different grid-connected PV inverter structures. (a) Central inverter; (b) string inverter; (c) module inverter; (d) multi-string Inverter [59].

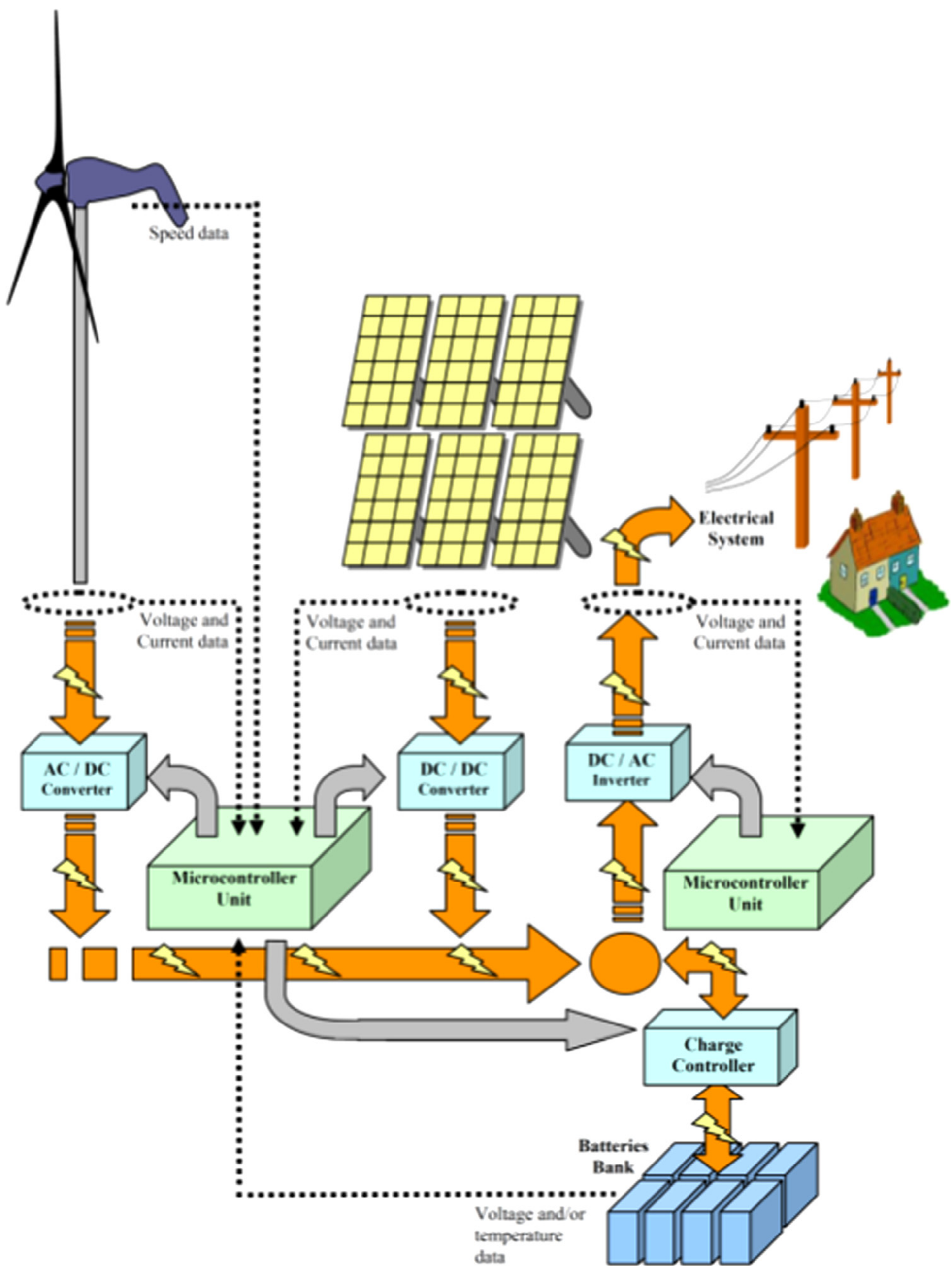

Fig. 29. Hybrid system block diagram [60].

vegetable coal, and wastes from forests, urban and prominent agricultural wastes. There are several efficient methods of biomass energy utilization proposed recently. The schematic of a biogas system (BGS) is shown in Fig. 30, which shows a BGS unit supplying a 3-phase AC–AC converter system. There is a HFAC link in concatenation with the AC converter unit. At the load end, there is 3-phase AC–AC converter to regulate the power and supply the desired power to the utility grid [52].

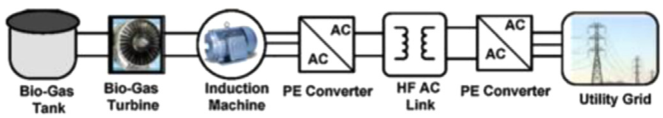

Fig. 30. Biogas based power system interfaced to the grid through power converters [52].

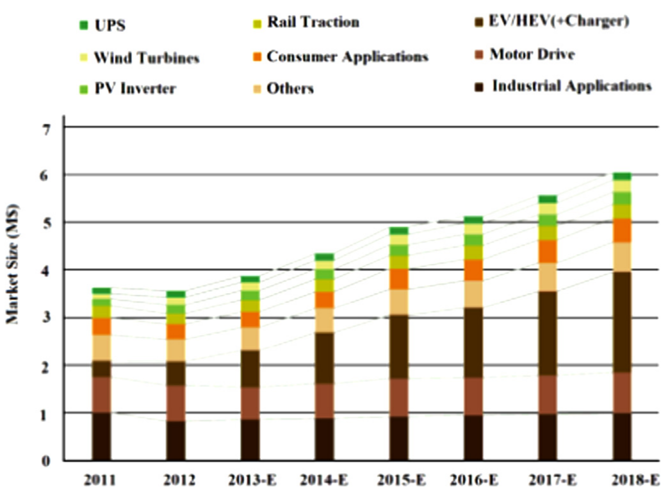

Fig. 31. IGBT market forecast 2011–2018, Yole development, France.

Since power electronics converters are the most important system component for the grid integration of renewable energies, the investment in this track will increase as will the investments in renewable energies. Fig. 31 shows the IGBT market for six key applications: motor drive—the largest IGBT; renewable energies (PV and wind) are trending well, though they can be unpredictable because they rely on government investments, they can be unpredictable—; mass transportation and UPS, which are based on infrastructure needs—with the need for greater efficiency pushing these markets.

5. Smart grid enable renewables

The world's electric power systems face different challenges such as ageing infrastructure, continuous demand growth, integration of more renewable energy resources, in addition to, improving the supply security and lowering carbon emissions. Smart grid technologies offer ways not just to meet these challenges but also to develop a cleaner energy supply that is more energy efficient, more affordable and more sustainable. Fig. 32 demonstrates the evolutionary character of smart grid. Smart grid tools and technologies implemented in the electrical grid infrastructure enable bidirectional flows of energy and communication. These new capabilities can lead to improved efficiency, reliability, interoperability, and security [62].

Renewable energy resources can be used for power generation as standalone or isolated system but their benefits are significantly enhanced when they are integrated into electric utility system. With greater use of smart grid enabling technologies, higher degrees and rates of penetration can be accommodated. However, the energy production from renewable energy sources is variable (not dispatchable, intermittent and uncertain). Integration of renewable sources in power system with their variable generation schedules introduces certain challenges in the systems. It will necessitate the changes in power system planning and operation while keeping reliability and economy constraints in considerations. Several factors which need to be addressed during

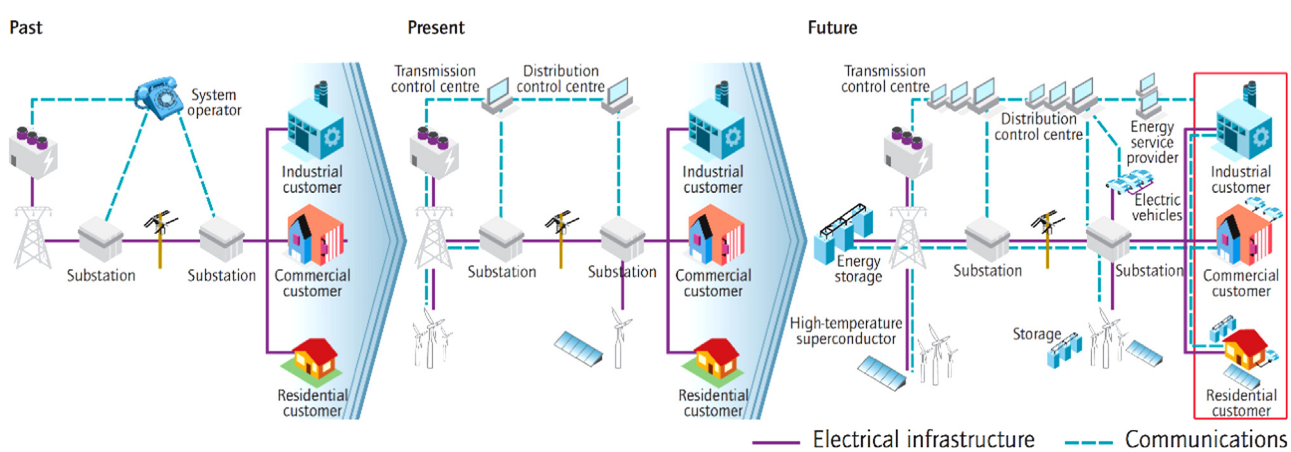

Fig. 32. Smarter electricity systems [62].

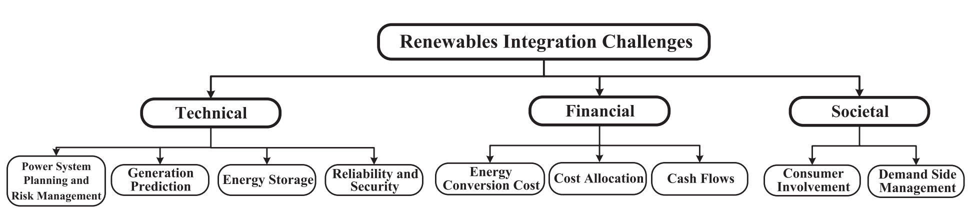

Fig. 33. Potential challenges in integration of renewable energy resources into the smart grid.

integration are power quality, reliability, energy conversion cost and power system efficiency. Research and development regarding these issues are underway and several methodologies and algorithms have been proposed in order to meet these challenges and making power grid transition towards smart one in an effective manner. Fig. 33 gives the brief classification of challenges faced in integration [63,64].

6. Conclusion

Due to the shortage of inexhaustible resources, and environmental problems caused by the emissions, traditional power generation based on fossil fuels are generally considered to be unsustainable in the long term. As a result, many efforts are made worldwide for introducing more renewable energies in the energy mix. Renewable energy resources are innovative options for electricity generation and their potential is enormous as they can, in principle, meet the world's energy demand many times over. This paper presents an up-to-date and detailed current status and future projection of major renewable energy resources, as well as their benefits, growth, investment and deployment. In addition, the role of power electronics converters as enabling technology for using different renewable energy resources is illustrated. Furthermore, integration of renewable energy resources into smart grid system, keeping in mind all challenges, will help in meeting ever-increasing electric energy demands effectively.

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