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Abstract:

This chapter aims to provide an overview of renewable energy systems (RESs) and the underlying issues related to the RES theme such as climate change and its mitigation. The types of RESs are also briefly discussed focusing on their characteristics and technological aspects. This is followed by the most important economic aspects as well as the challenges and opportunities of integrating RESs in power systems. This chapter also discusses the need for optimization tools adequately equipped to effectively capture the intrinsic characteristics of RESs and facilitate their optimal integration in power systems. All this leads to an efficient exploitation of their wide-range benefits while sufficiently minimizing their negative impacts. Finally, the chapter is summarized with some concluding remarks.

Keywords: *Renewable Energy Sources, Clime Change,* Large Scale Integration of RES, *Renewable energy trend, RES Integration Opportunities*

Chapter contents:

1.1 An Overview of Renewable Energy Systems

All societies need energy services to satisfy their needs (such as cooking, lighting, heating, communications, etc.) and to support productive services. In order to secure sustainable development, the delivery of energy services needs to be safe and cause low environmental impacts [1, 3]. Social sustainability and economic development require security and easy access to energy resources, which are indispensable to promote sustainable energy and essential services. This means applying different strategies at different levels to revamp economic development. To be environmentally benign, energy services should provoke low environmental impacts, including greenhouse gas (GHG) emissions.

According to the study in [4], fossil fuels are still the main primary energy sources. A major revolution is required in how energy is produced and used in order to preserve a sustainable economy capable of providing the required public services (both in developed and developing countries), and laying effective support mechanisms to climate change mitigation and adaptation efforts [5].

A major concern in both developed and developing countries, including emerging economies, is that without having abundant and accessible energy sources, it is not possible to maintain the current paradigm in the medium and long term, from an economic point of view. In accordance with the International Energy Agency (IEA) reference scenario, the primary global energy consumption will grow between 40% and 50% until 2030, at an annual average rate of 1.6%. Without a major paradigm shift in energy policies throughout the world, fossil fuels are still expected to cover about 83% of the increase in demand [4].

The reasons for this strong growth are essentially two: the continuous increase in world population and the economic convergence between developed and developing countries, especially with emerging economies such as India and China that are leading the economic recovery from the recent global economic crisis, and becoming the major consumers of non-renewable energy sources. This change must be answered with structural measures, such as by putting a real monetary value to energy. Some of the promising solutions are accelerating renewable energy integration, promoting energy efficiency and supporting transport systems modernization. This can be achieved by promoting more transparent markets to flourish and creating an enabling environment for competition in all sectors of the economy and energy production [6].

The sustainability of energy systems is now an important factor for socio-economic development. Sustainability depends on three major components (as schematically demonstrated in Figure 1.1): i) the security of access to energy, ii) the accessibility of services and iii) environmental compatibility.

"Insert Fig. 1.1 here"

Changing the energy scenario presents itself as a huge challenge whose solution ultimately depends on the political will of governing bodies to make the necessary investments on a global scale. In the medium and long term horizon, investment decisions will affect the cost and the environmental impacts of infrastructures. Most likely, the energy supply will be the main factor of possible models for future development at global, regional and national levels.

1.1.1. Climate Change

GHG emissions associated with energy services are the major causes of climate change. The report in [4] indicates that "most of the observed increase in global average temperature since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations”. The carbon dioxide (CO_2) concentrations have grown continuously to about 390 ppm of CO_2 in 2010, a 39% increase since pre-industrial levels [7]. The global average temperature increased by 0.76 ºC (from 0.57 °C to 0.95 °C) between 1850 and 1899. And, between 2001 and 2015, the warming trend has increased significantly. Note that forest abatement, fires, and the release of non-CO_2 gases from industry, trade and agriculture also contribute to global warming [7]. Moreover, all indicators show that there will be a significant increase in demand for primary energy during the twenty-first century [7]. The emission rates are also expected to substantially exceed the natural removal rates, causing a continuous increase in GHG concentrations in the atmosphere, and consequently the rise in average global temperature. The Cancun agreement [8] appeals to reduce GHG emissions and limit the global average temperature rise below 2°C, taking the pre-industrial value as a reference. It has recently been agreed on to a target level of 1.5°C in the average temperature rise.

Historically, developed countries are the main contributors to global CO_2 emissions, and continue to have the highest total history of per capita emissions [9]. In recent years, GHG emissions in most developing countries have been increasing, currently covering more than half of the total emissions. For instance, the total annual emissions in China surpassed that of the USA in recent years [9].

However, the latest climate conference, COP-21 (UN climate conference) in Paris [10], brings hope for the fight against climate change where, for the first time, representatives of almost every country in the world convened together in an effort to reduce emissions and counter the effects of global warming. The Paris Agreement, which will take effect after 2020, underscores the fact that the participation of all nations – not just rich countries – is crucial to combat climate change. On the whole, 195 member countries of the UN Climate Convention and the European

Union have ratified the document [10]. The long-term goal of the agreement is to keep global warming "well below 2°C." This is the point in which scientists argue that the planet is doomed to a future of no return, leading to devastating effects such as rising sea levels, extreme weather events (droughts, storms and floods) and lack of water and food.

1.1.2. Renewable Energy Trend

An increase in an overall world trend in the awareness of climate change and the need for mitigation efforts is bringing forth huge increase in the deployment of renewable energy in comparison to fossil fuel energy sources. The landmark that signals the dawning of this renewable age goes hand in hand with the degree of advancement in technologies and a higher degree of RES penetration, which is being achieved around the world. Furthermore, there are several driving factors for these remarkable growths among which are favorable government support policy and increasing competitiveness in costs. After several decades of efforts in research and continuous development in RES, the yearly growth in the capacity of these plants is becoming greater than the total investment capacity added in power plants based on coal, natural gas and oil all combined together [11]. Nowadays, RESs have reached a significant level of share in energy supply options, becoming one of the prominent global alternative power supply sources. This trend will continue increasing at faster rates as long as the world's desire for industrial scale clean energy sources is on the higher side [4].

The latest global trends in renewable energy investment status reports indicate that, renewables represented a 58.5% of net additions to global power capacity in 2014, with significant growth in all regions, which represents an estimated 27.7% of the world's power generating capacity, enough to supply an estimated 22.8% of global electricity. Wind, solar and biomass power generations reached an estimated 9.1% of the world's electricity in 2014, up from 8.5% in 2013.

According to renewables status report [12], the overall cost-cutting achieved to date helped to ensure such a strong momentum in 2014, reaching an investment boom up to 29% in solar, and 11% in wind technologies, and geothermal managing to raise 23%. Further cuts in the cost of generation for both solar and wind look to be on the cards in 2015 [12].

The report on global renewable energy 2015 [12] also indicates the continued growth of RES participation in parallel proportion with the energy consumption and the falling oil prices. In addition, issues related to the untapped RES potentials indicate that it still requires a growing effort in pursuing innovative approaches to increase its participation in order to guarantee a clean energy future. Concerning the regional expansion of RES utilization, such growth scheme is not limited to the industrialized regions, but also an increasing number of developing countries are even becoming important manufacturers and installers of this fashionable energy source.

Another essential growth trend currently being observed, which is worth mentioning here, is the diversity of applications of the renewable sources. The use of renewables is no more limited to the power generation only, but its use is expanding in heat related and transpiration applications. In this regard, several supporting technologies like heat supply and storage systems are helping flourish the deployment of these important energy resources across many countries. Also, a significant contribution to the world transport sector is being promoted with an increased share in the use of Ethanol and Biodiesel in combination with fossil fuels.

In relation to the job creation opportunities, renewable energy employment continues expanding, which according to IRENA [13], in 2014 an estimated 7.7 million people are working directly or indirectly in this sector. Also, concerning government policies, the number of countries, states and provinces which adopted renewable policies and targets tripled since 2004. Regarding investment mechanisms, innovative approaches have been introduced like in the case of Asian investment banks, representing a new investment vehicles for renewable energy projects such as green bonds, yield companies, and crowd funding which have attached new classes of capital providers and are helping to reduce the cost of capital for financing renewable energy projects [12]. As a result, the investment flow in renewables has outpaced fossil fuels for five consecutive years in all regions.

According to the global status report [12], currently, there is no systematic linkage between the so called renewable energy twin pillars: the renewable energy sources and energy efficiency, in technical as well as policy wise.

1.2 Types of Renewable Energy Systems

1.2.1. Introduction

A major change in the energy sector between 2014 and 2015 has been the rapid fall of oil prices, as well as natural gas and coal but not so drastically. After an extensive period of stable high oil price, it has been falling from more than $ 100 until the middle of 2014 to a level below $ 50 at the beginning of 2015 [13]. In 2016, further fall is observed, and as it stands now the price of oil oscillates around 30 $/barrel.

Renewable technologies are becoming increasingly competitive in a number of countries but government support is still needed to enhance the development of these schemes in many other countries. The capacity increase of base renewable generation is estimated to be 128 GW in 2014 (Table 1.1) [9], out of which 37% is related to wind, nearly a third to solar energy and more than one quarter to hydropower [9] (see in Fig. 1.2). The growth in installed wind power capacity has been developed mainly onshore, but offshore wind development has also shown substantial. China continues to have the largest wind power market with a 20 GW installed capacity.

Germany stands second by installing more than 5 GW of wind power, while the wind capacity added in the US was at a very low level in 2013 and 2014, standing at almost 5 GW [14]. The solar photovoltaic (PV) was greatly expanded in Asia, especially in China and Japan. In Japan, the expansion is supported by generous feed-in tariffs. The low price of oil proves to be a challenge for other forms of renewable energy, including biofuels for transport and renewable based heating system, as the latter directly competes with natural gas based heating (whose price is still, in many cases, linked to the oil price). Although biofuels face challenges stemming from lower oil prices, some other developments served to improve their prospects.

"Insert Table 1.1 here"

"Insert Fig. 1.2 here"

For instance, to overcome the current dark prospects of biofuels in Brazil, the government increased the ethanol rate of mixture from 25% to 27% and from 5% in biodiesel to 7%, and increased gasoline taxes, while Argentina and Indonesia have increased their biofuels mandates [9]. A long period of low oil prices could result in neglecting the promotion of energy efficiency and instead returning to wasteful consumption. However, there is no evidence to date that this has occurred [11].

1.2.2. Wind Power

Wind power has been used for thousands of years in a variety of applications. Wind energy can be transformed into mechanical energy or electricity. But wind power remained in the background in detriment of other fuels for various technical, social and economic reasons. It was the oil crisis in the 1970s, which led to a renewed interest in wind power technology especially for electricity generation connected to the grid, to pump water and to provide power in remote areas.

The technical potential of wind power to serve the energy needs is immense. Although wind resource varies around the globe, there is enough potential in most regions to support high levels of wind power generation. Wind resources are not a barrier to the global expansion of this technology in the coming decades. New wind power technologies have contributed to significant advances in wind power penetration. In a general perspective, the global wind power capacity has been increasing [15], smoothly from 2000 to 2006, and in a more accentuated way from 2007 to 2013 as shown in Figure 1.3.

"Insert Fig. 1.3 here"

More than 51 GW of wind power were added to the power systems, representing a 44% increase compared to 2013, making an overall contribution of approximately 370 GW to the energy production mix, as shown in Table 1.2. The top 10 countries accounted for 84% of the installed capacity in the world at the end of 2013, but there are dynamic and emerging markets in most regions [9].

"Insert Table 1.2 here"

In continental terms, Asia is the one that have successively grown in recent years and holds half of the new capacity added, followed by the European Union in Europe (23% in 2014, compared with about 32% in 2013) and North America, which has grown by 13% in 2014, an 8% less compared with 2013. From Table 1.2, it can be seen that only China accommodates 45% of the new wind added globally, followed by Germany, United States and India. Other countries in the top 10 are Canada, UK, Sweden, France and Denmark. Growth in some of the major markets was driven by uncertainty about future policy changes.

The significant wind power growth is due to the continuous technological advances and relative maturity, supporting mechanisms and incentive packages, favorable policy, continuously falling capital costs among others. Table 1.3 [9] shows the main wind power generation technologies, their technical characteristics and associated costs. The three main turbine types are classified by their sizes and deployment site (onshore or offshore). For each technology, two types of capital costs are shown in US dollars per kW and the typical costs of energy production in US cents per kWh.

"Insert Table 1.3 here"

1.2.3. Solar Energy

1.2.3.1. Solar Photovoltaic

Solar energy is the main and largely inexhaustible source of energy for most countries [16]. In recent years, the deployment of PV has been breaking records year after year. After nearly a stagnated period, it has steadily grown to be one of the leading technologies in terms of installed capacity. More than 39 GW has been added in 2013, bringing the total installed capacity to over 139 GW in this technology by 2013.

There has been a geographical shift of the biggest installers, led by China, Japan and the United States, and Asia is becoming the largest solar PV market worldwide instead of Europe. China have witnessed higher growth than Europe, and other promising markets such as the US and others have experienced an extremely slow growth [17].

In 2013, nine countries added more than 1.0 GW of solar PV to their networks, and new facilities continue to appear as can be seen in Table 1.4. At the end of 2013, at least 10 GW of total capacity was added in five countries instead of two in 2012. The leaders of solar energy per capita were Germany, Italy, Greece, Czech Republic and Australia [9]. The Asia added

22.7 GW at the end of 2013, bringing the total amount of solar PV in operation to almost 42 GW. China had almost a one third share of the global installed capacity. Apart from Asia, about 16.7 GW were added around the world, mainly in the EU (about 10.4 GW) and North America (5.4 GW) in which the United States led became the third largest market in 2013.

"Insert Table 1.4 here"

The Solar PV technologies can be divided into two main types depending on where they are placed, rooftop or ground-mounted. Each has a set of characteristics. However, it can be said that there are three transverse characteristics of both types of technologies: the peak capacity, the capacity factor and the conversion efficiency (as depicted in Table 1.5 [9]). These technologies are also distinguished based on where/how they are being deployed: residential, commercial and industrial consumer in particular with respect to peak capacity. Note that the receptivity of each type of technology varies greatly from one geographical area to another mainly due to the differences in energy cost of each of these areas, and often the incentives/compensation for the adherence to these technologies [16].

"Insert Table 1.5 here"

1.2.3.2. Concentrated Solar Power

The concentrated solar power (CSP) is a market that is so far small but it is growing mainly thanks to the increased efficiency levels in places with direct sunlight and low humidity. This technology continues to spread to new markets with significant projects already completed in late 2013 in Australia, Italy and the United States and progress in Chile, Namibia, Portugal, Saudi Arabia, among others [9]. The biggest market is China with 50 MW. More than 165 MW were added in systems operating in over 20 countries led by China and the United States, as can be seen in Table 1.6 [9] .

"Insert Table 1.6 here"

The solar thermal power market continues to grow after the record in 2012. In 2013, the overall capacity grew by 36%, more than 3.4 GW, with Spain and the United States being the major markets [16].

A summary of the main CSP technologies can be found in Table 1.7 [9], which shows the main characteristics as well as the cost of these technologies by country or area. In the typical characteristics, the main types of CSP, the size of the plants and the capacity factor are shown.

"Insert Table 1.7 here"

1.2.4. Geothermal Power

Geothermal energy can be used efficiently in the development of networks whether they are connected or not, and is especially useful in rural electrification schemes and direct applications such as district heating, cooking, bathing and industrial processes, etc. [18]. Geothermal resources provide energy in electrical form and heating/ direct cooling. Global electricity generation from geothermal sources is estimated to be just under half of the total geothermal production of 76 TWh, with the remaining 91 TWh accounting for direct use [18].

From Table 1.8, it can be seen that, in 2013, the estimated generation capacity added was at least 530 MW, bringing the total global capacity to 12 GW, with an estimated annual generation of 76 TWh [9]. The countries that added more production capacity in 2013 were New Zealand, Turkey, the United States, Kenya, Mexico, Philippines, Germany, Italy and Australia. By the end of 2013, the countries with the largest installed generation capacity were the United States with 3.4 GW, the Philippines with 1.9 GW, Indonesia with 1.3 GW, Mexico with 1.0 GW, Italy with 0.9 GW, New Zealand with 0.9 GW, Iceland with 0.7 GW and Japan with 0.5 GW.

"Insert Table 1.8 here"

This resource can be classified into two categories [19]:

- High temperature (T> 150°C): This resource is usually associated with areas of volcanic activity, seismic or magma. At these temperatures, it is possible to use the geothermal resource for power generation purpose;
- Low temperature (T <100°C) generally results from the meteoric rise of water circulation in faults and fractures as well as resident water inside porous rocks at deep underground.

The geothermal energy conversion process involves energy transfer by convection, transforming the heat produced and contained inside the earth into a useful energy in the form of electricity or other forms. The energy can also be extracted using the water injection technology from the surface in hot rock formations. Table 1.9 summarizes some general characteristics of geothermal technologies.

"Insert Table 1.9 here"

1.2.5. Hydro Power

The production of hydroelectricity is mainly through hydroelectric plants, which are associated with large or medium capacity dams, forming a reservoir of water by interrupting the flow of water. Also this energy has been exploited by applying the so-called small hydro plants, which consist of the construction of small reservoirs or dams that divert part of rivers for a unlevelled location (where the turbines are installed), thereby producing electricity. The production of hydroelectricity is the most efficient and one of the least polluting processes. Many of the effects are reversible, and nature with the human contribution, ultimately find a new balance.

The capacity of global hydropower production in 2013 increased by 4% (approximately 40 GW), which varies every year according to the metrological conditions of the places where they are located, was estimated at 3,750 TWh in 2013. The countries with the highest production capacity are China (260 GW/ 905 TWh), Brazil (85.7 GW/ 415 TWh), the US (78.4 GW/ 269 TWh), Canada (76.2 GW/ 388 TWh), Russia (46.7 GW/ 174.7 TWh), India and Norway, which together have 62% of global installed capacity (Table 1.10) [4].

"Insert Table 1.10 here"

It is estimated that a pumped storage capacity in the order of 2 GW was added in 2013, bringing the global hydropower to 135-140 GW. The country that installed more hydropower capacity in 2013 was China. Other countries with significant installed hydropower capacity were Turkey, Brazil, Vietnam, India and Russia.

Hydropower is the most developed technology among the renewables, reaching levels of optimality when coupled with the wind. The summary of the main technological characteristics can be found in Table 1.11, including the typical technology cost for each type. It can be emphasized that, among the presented technologies, it is the one that has the lowest typical cost.

"Insert Table 1.11 here"

1.2.6. Bioenergy

Bioenergy is the designation for the energy obtained from biomass. There are three forms of fundamental energy: heat energy, mechanical energy and electricity, all of which can be obtained from biomass sources.

The systems that produce mechanical energy as combustion engines or turbines of direct and indirect combustion are coupled to electrical generators, which convert mechanical energy into electrical energy. The conversion of mechanical energy to electrical energy generates heat approximately two-third to one-third of the generated electricity, which demonstrates the increased economic efficiency of cogeneration (simultaneous production of heat and electricity) in stationary applications. The biogas from landfills, recycling of agricultural wastes and other organic wastes can be used in stationary power plants for energy production [20].

Bioenergy has shown steady growth rates in the last years and it is expected to keep on this path in the future. In EU, the consumption of biomass energy is projected to increase by at least 33 Mtoe by 2020, as shown in Figure 1.4. The electricity generation in the EU from solid biomass in 2014 was approximately 81.6 TWh. The five top producers were the US followed by Germany, Finland, United Kingdom, Sweden and Poland having a total production in Europe of 63% [21].

"Insert Fig. 1.4 here"

The estimated growth of bioenergy market in 2014 was 5 GW, bringing the total capacity worldwide to approximately 93 GW. Country wise, the bio-generation leaders are the United States with 69.1 TWh, Germany with 49.1 TWh, China with 41.6 TWh, Brazil with 32.9 TWh and Japan with 30.2 TWh.

1.2.7. Ocean Power

Ocean power refers to any energy harnessed from the ocean waves, tidal range (up and down), tidal currents, ocean currents, temperature gradients and salinity gradients [22]. The development of this emerging sector can contribute to the achievement set targets for renewable energy integration, reduction of GHGs and their harmful effects, and simultaneously boost economic growth through innovation and new job creation [23].

At the end of 2013, the capacity of the ocean energy was about 530 MW, most of this coming from the tidal power category [4]. Majority of ocean power projects currently in operation generate power from ocean tides. Among these is the Sihwa plant in Korea, completed in 2011 with a capacity of 254 MW, the central Rance in France with a capacity of 240 MW, the central Annapolis Nova Scotia, Canada with a capacity of 3.9 MW and Jiangxia in China with the capacity of 3.9 MW. Other projects are smaller, and many of them are pre-commercial demonstration projects with a remarkable concentration of wave and tidal development facilities (in the order of 11 MW) in the UK [9]. Some of the tidal technology characteristics are summarized in Table 1.12.

"Insert Table 1.12 here"

1.3. Economic Aspects of Renewable Energy Systems

1.3.1. Introduction

Installation cost, net annual energy production and value of energy are the three main economic factors to make a decision about employing RESs. The value of energy is equal to the electricity price or tariff for RESs located on the supply side; while it can be equal to the retail price for demand side renewable resources (the systems that use energy on site). The reason for using retail price in studies of RESs on the demand side is that, the purchased energy from the grid by the consumer is displaced by the on-site generation.

In order to investigate economic feasibility of renewable resources, they have to enter in a competition with other available energy resources and technologies. Fossil fuel prices have had considerable variations over the past ten years, and there is an uncertainty about these prices in future. Considering carbon emission is also another factor that has affected the fossil fuel cost [24]. In order to concentrate on the fuel cost and its uncertainty in more details, it should be noted that a cost between 0.5 and $1.0/gallon is added to the gasoline cost in the US that is related to the military expenditures just to ensure the oil flow from the Middle East [25].

In order to improve the penetration level of renewable energy resources in the power system, the installation costs should be returned during a rational period. This would be obtained by producing sufficient power at an appropriate price. In the cases that RESs are installed in places where there is no connection to the power system network, the price of electricity would be high, because it would be obtained by a cost competition with other available energy careers. On this basis, the electricity price of RESs is associated with the range of prices of the energy careers. There are many factors that induce uncertainty in the future cost of energy careers. These factors are mostly related to the level of dependency on imported energy careers, policies on emission reduction, as well as policies on developing renewable energy resources [26].

The price of all energy careers is strongly associated with the price of oil that has been difficult to forecast due to many factors such as political aspects [27]. Fluctuations of oil price in the past few years prove this claim that prediction of energy prices has become more complex. For example, in some reports, the peak time of oil price was forecasted to occur in 2007, while other reports forecasted it to happen in 2015 and even 2040 [28]. Note that, since the oil price is also related to the demand growth, a wide range of its fluctuations must be considered for each time and geographic area [29].

It should be noted that, energy economics is highly dependent on incentive- and penalty-driven policies. On this basis, it is very difficult to impose life cycle costs without considering the impacts of emission and government supports that motivate investors for investing in RESs [30].

According to the aforementioned description, the regulatory supports for RESs have been driving the world market.

1.3.2. Affecting Factors

Many factors affect investors to invest in RESs. Incentives are a key element in choosing the renewable systems, since both type and size of RESs are determined by investors based on the differences between market incentives. Another affecting factor is the cost of land that has an important impact on type and number of RESs. In order to have the optimal rate of return, RESs should have the highest amount of availability to ensure they can produce an appropriate level of energy. On this basis, they should have the capability to be operated as much time as possible. To this end, the reliability of the network and consequently the unavailability to transfer generated power due to network failures should be estimated.

It should be noted that, if the RES generates when the demand peak occurs, the income of the system is augmented due to the increase in energy price. Owners of on-site renewable resources can also benefit more when the generated energy by the systems is required by the on-site demand. For example, the wind power generator produces electricity at nights when the space heating systems are highly required during winter.

RESs are able to generate power to supply the on-site demand, or to inject to the grid. The amount of energy that is consumed by on-site demand is replaced with the supplied energy by the grid. On this basis, if the amount of generation is less than the on-site demand, using RESs can reduce the net load. On the contrary, if the on-site consumption is less than the generated energy, the surplus is injected into the grid at a price/tariff based on an agreement with the utility.

Externalities are also an important factor for making a decision about renewable energy resources. This is due to the fact that in life-cycle cost analysis emission and carbon dioxide costs should be considered [31, 32]. There is a wide range of rates of externalities that depends on the rules and regulations in various countries. Since power producers do not like paying the cost of externalities, in the US there are litigations by all sides to decrease the externality rates based on the reason that there is no reliable evidence to prove carbon dioxide emission is harmful to society. In European countries, there are various costs for carbon dioxide emission that provide a better base for renewable energy resources by making them more cost competitive [32].

1.3.3. Life-Cycle Costs

The life-cycle cost is a method that analyzes the total cost of the system by considering the expenditures during the system life and salvage value [14]. By using a life-cycle cost analysis different investment options can be compared. Moreover, the most economic design for the system can be achieved. There are some other options that the RESs must compete with such as small-scale diesel generators and electrical energy storage systems. In this case, the effective factors are the initial cost, the electricity price, and the required infrastructures [33, 34]. It is noteworthy that, the life-cycle cost is also useful to compare different plans even if the RES is the only choice. Furthermore, this analysis is employed to determine if a hybrid renewable-based system can be the most economic plan. The life-cycle cost analysis enables to investigate impacts of employing several components with various reliability and lifetimes.

Discount rate indicates how much increase or decrease in finance happens over the time. Note that, using the inaccurate amount of discount rate for calculating life-cycle cost can cause to unrealistic solutions. Although most of the RESs are economical, in order to select the best plan between all available options, the life-cycle cost analysis is the best method [33, 34]. The financial assessment can be carried out over an annual base to calculate economic indices such as payback period and cash flow.

It should be mentioned that, annualized cost of energy considered for RESs should be compared with that for other resources. In other words, the annualized cost of energy should not be directly compared with the current cost of energy, since it is not sensible. The mentioned costs of energy create an appropriate base to compare different plans considering alternative resources and to select the best resource of energy.

There are some calculating tools to analyze renewable energy projects and assess the life-cycle cost, and even emission considerations [35]. These calculations prove that the current RESs are economical.

1.3.4. Economic Trend of Renewable Energy Systems

RESs are strongly promoted by policy makers, because they are a key element for economic development. The renewable systems are able to compete with current thermal power plants [27]. They can also improve the economy by job creation, since more than 100 jobs for installing a wind power plant and more than 10 jobs for its operation are required for each 100 MW project [25]. There are some attempts to reduce the property tax of wind power plants in order to better motivate the investor to invest in the renewable system and consequently the economic development [36].

Wind power generation is one of the most economic RESs, since its cost of energy (COE) is about $70/MWh that can compete with thermal units. Trend studies have shown that before 2003, COE of wind power plants was higher than fuel fossil units; however, in the period of

2003 to 2009, it approximately equaled to the thermal units [25]. In 2009, the COE of wind farms dropped to the levels lower than conventional power.

The studies on various resources indicate that annualized COE of wind power plants can even compete with the one of combined cycle gas turbines, although the fuel price of these thermal units is low [37]. In some countries such as the US, conventional power plants benefit from that the fuel costs are not taxed, whereas the RESs do not have the cost of fuel at all. On this basis, the main issue of renewable resources is the high investment cost, which causes people to prefer paying for the fuels. It should be noted that, in the case of on-site RESs, the small-scale wind power generation cannot compete with the retail prices [38].

In the case of supply side, another barrier to integration of RESs is the capacity of transmission network that may cause the power curtailment in order to ensure the system security [39]. Since most of the renewable energies such as wind, solar and geothermal resources are far from the load centers, they can impose an extra cost on the transmission system [40].

Although the future of energy is uncertain and ambiguous, and every prediction can be risky, as oil price forecast has been a challenge, the trend of renewable energies is almost evident [29]. On this basis it can be expected that in future distributed RESs will have more penetration and even some new distributed electricity markets will help these new resources [38]. In addition, with developments of the high-voltage transmission network, large farms of RESs will be installed much far from the load centers [39]. In near future, renewable energy resources can better compete with other energy alternatives just due to the carbon cost. Even other air emission costs such as NO_X and SO_X will motivate people to invest in systems without fuel and emission costs.

This can cause that renewable energies, particularly wind power, become the most economic resource of producing electricity [33, 34].

It should be noted that one part of the installation cost of RESs has been supplied by the income resulted from carbon trading. The future of energy without RES developments would be an unsolvable problem due to the growth of environmental concerns. In order to avoid this problem and to provide a sustainable energy, policy makers should put more weight on the renewable energy as well as conservation and energy efficiency.

1.4. Opportunities and Challenges of Renewable Energy Systems Integration

1.4.1. Renewable Energy Systems Integration Opportunities

Most of the electric energy consumed comes from non-renewable energy sources (mainly, fossil fuels). This has led to a series of questions from energy dependence concerns to climate change issues, which are some of the major drivers of RES integrations in many power systems across the world. It is now widely recognized that integrating RESs in power systems brings about a lot of economic, environmental, societal and technical benefits to all stakeholders. These are some of the reasons behind the rapid growth of RES integrations in many power systems across the world, as indicated in a 2015 report by the International Energy Agency (IEA). The report further shows that, in 2013, an approximately 19.1% of global electric energy consumption came from RESs, most of which was from hydropower [4].

Among the wide-range benefits of RESs is their significant contribution to the GHGs which are leading to not only climate change and its dire consequences but also series environmental and health problems. Most RES technologies (wind and solar PV, for instance) have very low carbon footprints, making them very suitable to mitigate climate change and reduce its consequences.

Hence, integrating RESs in power systems partly replaces polluting (conventional) power generation sources, resulting in a “cleaner” energy mix i.e. one with lower emission levels.

RES integration also has an undisputable positive impact on the social and economic development of nations. It is widely understood that the three socio-economic indicators, per capita income, per capita energy use and economic growth, are highly correlated with each other. Economic growth can be considered, for instance, as the main driver for energy consumption. Therefore, RESs can spur economic growth and create job opportunities. Because of their distributed nature, RES integration can also be integrated into a national policy (especially, in developing countries) to foster rural development. Currently, the RES business currently employs an estimated 7.7 million people throughout the world [4].

RESs also play an important role in energy access. Currently, more than 1.2 billion people do not have access to electricity globally (85% of which are in rural areas where RESs are abundant) [4]. Exploiting the potential of RESs should be at the forefront to address this societal problem.

Energy security concern is also one of the main drivers of RES integration. Current electric energy production scheme is dominated by conventional generation sources, which use fossil fuels whose prices are subject to significant volatilities. In addition to these volatilities, geopolitical availability of fossil fuels is also becoming a concern for many countries. The combination of all these can have significant impacts on the energy supply security. Because of this, generation of electricity locally using RESs can significantly contribute to the energy security of nations. As a result, this can reduce the heavy dependence on fossil fuels for power generation.

In addition to the benefits briefly explained above, RESs can bring technical benefits such as improved system stability and voltage profiles, reduced losses and electricity prices, etc. The combination of conventional generation capacity with the renewable generation capacity will be able to address the continuous increase in demand, in opposition to the scenario of conventional generation capacity only, which according to forecasts would not be able to meet the demand, Figure 1.5.

"Insert Fig. 1.5 here"

1.4.2. Renewable Energy Systems Integration Challenges and Barriers

Despite the robust growth of integration RES in many power systems, there are still certain challenges and barriers that impede the smooth integration of RESs. These challenges and barriers can be broadly classified into two categories: technical and non-technical. The non-technical category includes challenges and barriers related to capital costs, market and economic issues, information and public awareness, socio-cultural matters, the conflict between stakeholders, regulation and policy.

The variable cost of energy production by RESs is very small (close to zero); however, they are generally capital intensive. Even if the capital costs are declining for most RES technologies, their levelized costs of electricity (LCOE) are yet to be competitive with that of conventional energy sources. This can make investing in RESs less attractive for potential investors. However, this is likely to change as RES costs continue to fall while that of conventional energy sources become more expensive amid resource depletion and policies to internalize external costs such as environmental pollution costs.

Market and economic barriers exist when there is a lack of clearly designed economic and financial instruments to support RES integration efforts. For instance, whenever there is market failure associated with internalizing the cost of environmental pollution, it is very difficult to expect a lot of investments coming in from RES developers. Information gap and lack of public awareness on RESs and their benefits can also significantly hinder RES integration. Moreover, socio-cultural issues such as conflicting land use requirements can sometimes lead to contentious issues regarding RES development, directly affecting the level of penetration. The conflict between stakeholders is another barrier, more specifically the lack of communication, as shown in Figure 1.6. The challenges and barriers related to the regulatory and policy issues emanate from the structure of energy industries and existing technical regulations, the level of support for technology transfer and R&D, etc.

"Insert Fig. 1.6 here"

Technical limitations (barriers), on the other hand, are related to the nature of the resources and the power systems. Some of the most common RESs depend on primary energy sources such as wind speed, solar radiation and wave, which are subject to high level variability and unpredictability (the latter also known as uncertainty), resulting in considerable grid integration challenges [41]. This is because the uncontrollable variability and uncertainty of such sources introduce a lot of technical problems in the system, making the real-time operation of the system very challenging. The intermittent nature of power production from these resources also dramatically affects the reliability of energy supply. Moreover, such sources are found geographically dispersed across a vast area, and their availability is site-specific. Unlike conventional power sources, these energy sources cannot be transported to areas close to demand centers. This means harnessing these resources requires the higher need for network investments than conventional ones.

In addition, RESs based on the aforementioned primary energy sources are characterized by low capacity factors (i.e. low energy production per MW installed) compared to conventional power sources. In other words, the spatial energy intensity of RESs based on these sources is very low. This means that, for the same amount MW installed, the size of land required for such RESs is several times higher than that of the conventional one, which can sometimes be problematic during integration efforts because this creates fierce competition with other land use claims or requirements [42].

1.4.3. Alleviating the Challenges and Barriers

Most of the challenges and barriers explained before have proven solutions that happen to be overlooked in many systems [43]. In general, these are summarized as follows:

- Market and economic barriers are often fixed by streamlining appropriate market and economic signals related to carbon taxes, emission trading schemes, finances, and incentive mechanisms as well as enhancing public support for R&D, and creating a conducive environment for RES development. All this can have a considerable positive impact on the level of RES integration.
- Setting energy standards, continuous information campaigns and technical training about RESs and their benefits can enhance public knowledge and awareness, which can in the end have supportive roles in RES development.
- Creating an enabling environment for R&D, improving technical regulations, scaling up international support for technology transfer, liberalizing energy industries, providing incentive packages to RES developers, designing appropriate policies of RESs and conventional energy sources etc minimize the regulatory and policy barriers to developing RESs.

- Coordinating investments of RESs based on variable generation resources such as wind and solar power with large-scale energy storage systems, demand side management participation and grid expansion can significantly increase the level of RES integration.
- Enhancing operation and the flexibility of conventional power generation sources can also be very useful to scale up RES integration.
- Designing an efficient wholesale market such as dynamic retail pricing and developing coordinated operation and planning tools (such as joint network and generation investment planning models) can have a positive role in RES integration.

- For full utilization of RESs, the coordination between distribution system operators (DSOs) and transmission system operators (TSOs) is also vital.
- Ensuring regional interconnections via regional cooperation and increasing the level of participation of all stakeholders (including RES generators) in voltage control, provision of reserves, reactive power support, etc are significantly helpful for the stated purpose.
- It is also important to improve prediction tools, monitoring and control protocols that can help efficient utilization of the RESs.
- Using smart-grid technologies and concepts are also expected to facilitate smooth integrations of large-scale RESs because these are equipped with advanced control and management tools to counterbalance the intermittent nature of most RES energy productions.

1.4.4. Current Trends and Future Prospects

During the past decades, the level of global RES integration has been steadily growing. This has been against a number of odds such as the recent global financial crisis, the dramatically falling fuel prices and the slowdown of increasing global electricity consumption that have been thought to decelerate or stall this trend [12]. In general, there is a general consensus globally that RESs will cover a significant amount of electricity consumption in the years to come. The high uncertainty of RESs can be partially solved by the introduction of a bigger operational flexibility, as shows in Figure 1.7, through coordinated participation of various stakeholders. The recent developments in the 2015 Paris climate conference (COP-21), overall trends in international policy on RESs, energy dependence concerns, the falling capital costs of several matured RES technologies, and other techno-economic factors are all favorably expected to further accelerate the level RES integrated into power systems.

"Insert Fig. 1.7 here"

1.5. The Need for Optimization Tools to Solve Problems Related to Renewable Energy Systems

The power system operation must be conducted in order to optimize the production cost and to ensure the security of supply. The classic problem aims to optimize the provided power by each group of service generators, leading to an overall minimum cost of power production while satisfying the load and system security. The availability of powerful calculation methods and efficient algorithms for optimization has made it possible to obtain "optimal" solution of these problems for large electrical systems [44].

The need for optimization tools is indispensable in power system operation and planning in the presence of RESs. This is because of the increased variability and uncertainty introduced to the electric system as a result of integrating variable energy sources [45]. In addition, the demand variability over time and the uncertainty related to unexpected interruptions of generators (or other system components) all suggest the need for efficient optimization tools.

Uncertainty is introduced to the system as a result of the increasing level of intermittent integration and uncontrollable generation (like wind or solar energy) because of the limited predictability. Unexpected changes in outputs usually lead to the need for higher levels of reserves for the efficient and reliable operation of the power supply [45, 46]. Therefore, when a large amount of intermittent energy is used to feed a conventional electrical network, scheduling has to be taken into account by placing controllable energy sources as a backup to cover variations and unplanned injections of renewable energy.

Operators need to know how much energy a renewable plant can deliver in order to gain the best price for each megawatt-hour [45]. Therefore, the need to develop optimization tools to solve RES-related problems is crucial to the sustainable electrical system development, so that it operates in a more efficient and reliable way while respecting all operational constraints minimizing energy costs for end users. This is further discussed in subsequent chapters of this book.

1.6. Conclusions

The potential of RESs is colossal because in principle they can meet several times the world demand. RESs such as wind, biomass, hydro, biomass and geothermal can provide sustainable energy services based on available resources in all parts of the world. The transition to renewable energy based power systems tends to increase, while their costs continuously decline as gas and oil prices continue to oscillate. In the last half century, the demand for wind and solar systems has been continuously increasing, experiencing a reduction in capital costs and generated electricity costs. There have been continuous performance improvement and R&D undergoing in the sector in the past decades. As a result, the prices of renewable energy and fossil fuels, as well as social and environmental costs are to diverge in opposite directions. Economic and political mechanisms must support the wide spread of sustainable markets for the rapid development of RES. At this point, it is clear that the present and future growth will occur mainly in renewable energy and in some natural gas-based systems, and not common sources like coal or oil. The s progress of RESs can increase diversity in the electricity markets, contributing to obtain long-term sustainable energy, helping reduce local and global GHG emissions and promote attractive trade options to meet specific energy needs, particularly in developing countries and rural areas helping to create new opportunities.

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Tables:

Table 1.1. Renewable Electric Power Capacity (Top Regions/Countries in 2013) [9].

TECHNOLOGY	WORLD	EU-28	BRICS	CHINA	UNITED STATES	GERMANY	SPAIN	ITALY	INDIA
	[GW]								
Wind Power	318	117	115	91	61	34	23	8.6	20
Solar Energy PV	139	80	21	19.9	12.1	36	5.6	17.6	2.2
Solar Energy CSP	3.4	2.3	0.1	~0	0.9	~0	2.3	~0	0.1
Geothermal	12	1	0.1	~0	3.4	~0	0	0.9	0
Hydropower	1,000	124	437	260	78	5.6	17.1	18.3	44
Bioenergy	88	35	24	6.2	15.8	8.1	1	4	4.4
Ocean Power	0.5	0.2	~0	~0	~0	0	~0	0	0
Total Renewable Power Capacity	560	235	162	118	93	78	32	31	27

Table 1.2. Wind Power Global Capacity and Additions [9].

COUNTRY	TOTAL END 2012 [GW]	ADDED 2013 [GW]	TOTAL END 2013 [GW]
China	60.8/75.3	14.1/16.1	75.5/91.4
United States	60.0	1.1	61.1
Germany	31.3	3.2/3.6	34.3/34.7
Spain	22.8	0.2	23
India	18.4	1.7	20.2
United Kingdom	8.6	1.9	10.5
Italy	8.1	0.4	8.6
France	7.6	0.6	8.3
Canada	6.3	1.6	7.8
Denemark	4.2	0.7	4.8
Rest of World	41	7	48
World Total	283	35	318

Table 1.3. Wind Power Generation Technologies [9].

TECHNOLOGY	TYPICAL CHARACTERISTICS	CAPITAL COSTS [USD/kW]
Wind Onshore	Turbine size: 1.5-3.5 MW Capacity factor: 25-40%	925-1,470 (China and India) 1,500-1,950 (elsewhere)
Wind Offshore	Turbine size: 1.5-7.5 MW Capacity factor: 35-45%	4,500-5,500 (Global) 2,250-6,250 (OCDE)
Wind Onshore Small-scale	Turbine size: up to 100 kW Average: 0.85 kW (Global) 0.5 kW (China) 1.4 kW (United States) 4.7 kW (United Kingdom)	2,300-10,000(United States) 1,900 (China) 5,870 (United Kingdom)

Table 1.4. Solar PV Global Capacity and Additions [9].

COUNTRY	TOTAL END 2012 [GW]	ADDED 2013 [GW]	TOTAL END 2013 [GW]
Germany	32.6	3.3	35.9
China	7.0	12.9	19.9
Italy	16.4	1.5	17.6
Japan	6.6	6.9	13.6
United States	7.2	4.8	12.1
Spain	5.4	0.2	5.6
France	4.0	0.6	4.6
United Kingdom	1.8	1.5	3.3
Australia	2.4	0.8	3.3
Belgium	2.7	0.2	3.0
Rest of World	13.8	6.5	20.2
World Total	100	39	139

Table 1.5. Solar Energy Technologies [9].

TECHNOLOGY	TYPICAL CHARACTERISTICS	CAPITAL COSTS [USD/kW]
Solar PV (rooftop)	**Peak capacity:** 3-5 kW (residential); 100 kW (commercial); 500 kW (industrial) **Capacity factor:** 10-25% (fixed tilt)	**Residential costs:** 2,200 (Germany); 3,500-7,00 (U.S.A.) 4,260 (Japan); 2,150 (China) 3,380 (Australia); 2,400-3,000 (Italy) **Commercial costs:** 3,800 (United States); 2,900-3,800 (Japan)
Solar PV (ground-mounted; Utility-scale)	**Peak capacity:** 2.5-250 MW **Capacity factor:** 10-25% (fixed tilt) **Conversion efficiency:** 10-30%	1,200 -1,950 (typical global); As much as 3,800 including Japan. Averages: 2,000 (United States); 1,710 (China); 1,450 (Germany); 1,510 (India)

*LCOE- Levelized Cost of Energy

Table 1.6. Concentrating Solar Thermal Power (CSP) [9].

COUNTRY	TOTAL END 2012 [MW]	ADDED 2013 [MW]	TOTAL END 2013 [MW]
Spain	1,950	350	2,300
United States	507	375	882
United Arab Emirates	0	100	100
India	0	50	50
Algeria	25	0	25
Egypt	20	0	20
Morocco	20	0	20
Australia	12	0	12
China	0	10	10
Thailand	5	0	5
World Total	2,540	885	3,425

Table 1.7. Solar Energy Technologies [9].

TECHNOLOGY	TYPICAL CHARACTERISTICS	CAPITAL COSTS [USD/kW]
Concentrating solar thermal power (CSP)	Types: parabolic, trough, tower, dis Plant size: 50-250 MW (trough); 20-250 MW (tower); 10-100 MW (Fresnel) Capacity factor: 20-40% (so storage); 35-75% (with storage)	Trough, no storage: 4,000-7,300 (OCDE) 3,100-4,050 (not OCDE) Trough, 6 hours storage: 7,100-9,800 Tower: 5,600 (United States without storage) 9,000 (United States with storage)

*LCOE- Levelized Cost of Energy

Table 1.8. Geothermal Power Global Capacity and Additions [9].

	NET ADDED 2013	TOTAL END 2013
Top Countries By Total Capacity	[MW]	[MW]
United States	507	375
Philippines	0	100
Indonesia	0	50
Mexico	25	0
New Zealand	20	0
Top Countries By New Additions	[MW]	[MW]
New Zealand	196	0.9
Turkey	112	0.3
United States	84	3.4
Kenya	36	0.2
Philippines	20	1.9
Mexico	10	1.0
World Total	465	12

Table 1.9. Geothermal Power Technology [9].

TECHNOLOGY	TYPICAL CHARACTERISTICS	CAPITAL COSTS [USD/kW]
Geothermal Power	Plant size: 1-100 MW Capacity factor: 60-90%	Condensing flash: 1,900-3800 Binary: 2,250 - 2,200

Table 1.10. Hydro Power Global Capacity and Additions [9].

	NET ADDED 2013	TOTAL END 2013
Top Countries By Total Capacity	[GW]	[GW]
China	28.7	260
Brazil	1.5	86
United States	0.2	78
Canada	0.5	76
Russia	0.7	47
India	0.8	44
Top Countries By New Additions	[GW]	[GW]
China	28.7	260
Turkey	2.9	22
Brazil	1.5	86
Vietnam	1.3	14
India	0.8	44
Russia	0.7	47
World Total	40	1,000

Table 1.11. Hydropower Power Technologies [9].

TECHNOLOGY	TYPICAL CHARACTERISTICS	CAPITAL COSTS [USD/kW]
Hydropower (grid-based)	Plant size: 1 MW -18,000 MW Plant type: reservoir, run-of-river Capacity factor: 30-60%	Projects > 300 MW: 1,000-2,250 Projects 20-300 MW: 750-2,500 Projects < 20 MW: 750-4,000
Hydropower (off-grid/rural)	Plant size:0.1-1,000 kW Plant type: run-of-river, hydrokinetic, diurnal storage	1,175-6,000

Table 1.12. Ocean Power Technologies [9].

TECHNOLOGY	TYPICAL CHARACTERISTICS	CAPITAL COSTS [USD/Kw]
Ocean Power (tidal range)	Plant size: <1 to >250 MW Capacity factor: 23-29%	5.290-5,870

Figures (Original version of each figure is also submitted separately):

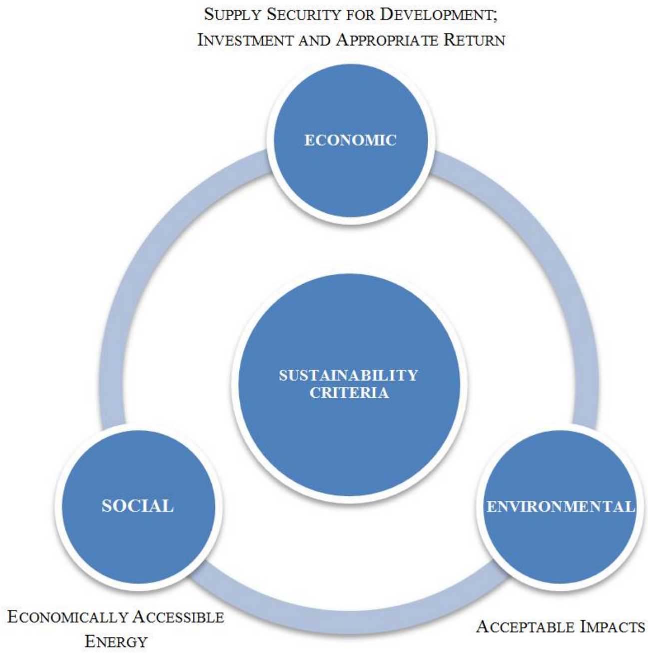

Figure 1.1. Sustainability in the electricity sector, adapted from [24].

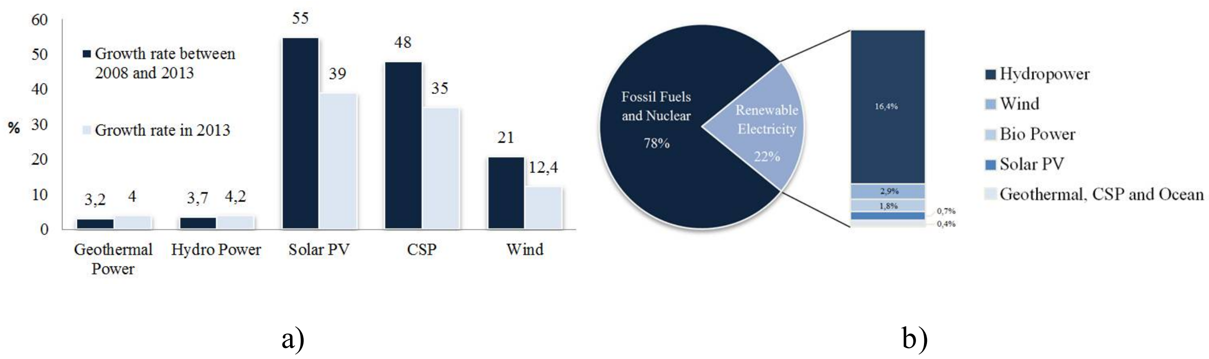

Figure 1.2. a) Average Annual Growth Rates of Renewables (2008 – 2013); b) Global Electricity Production (2013), adapted from [9].

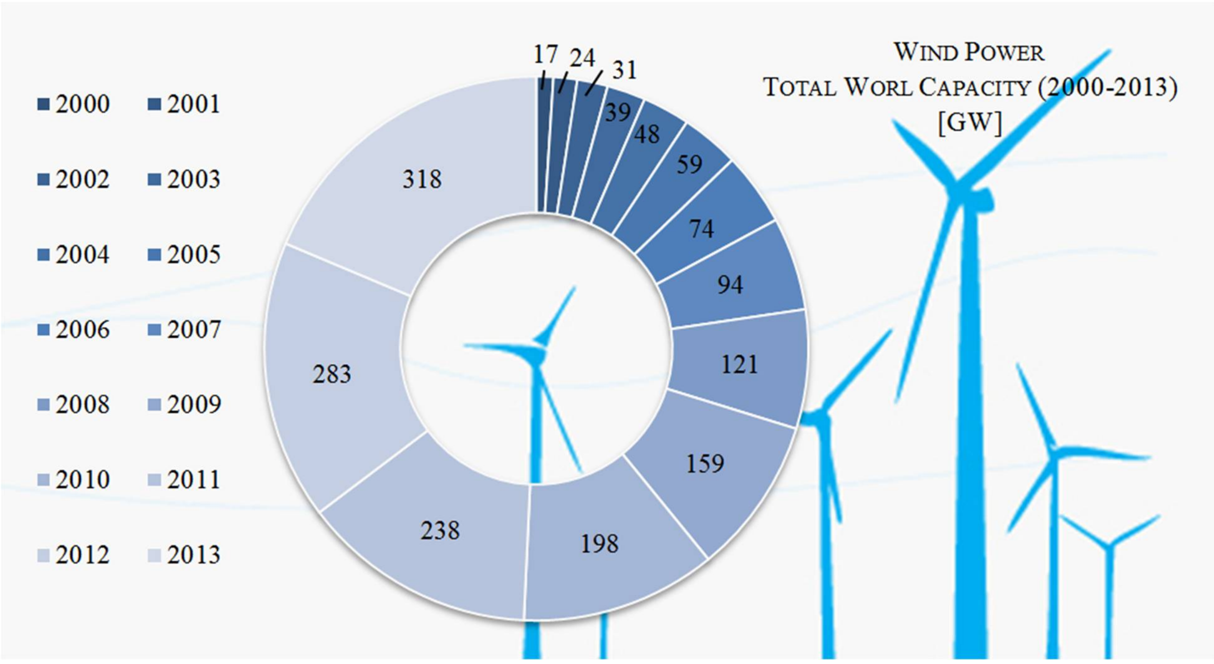

Figure 1.3. Wind power total world capacity (2000-2013), adapted from [15].

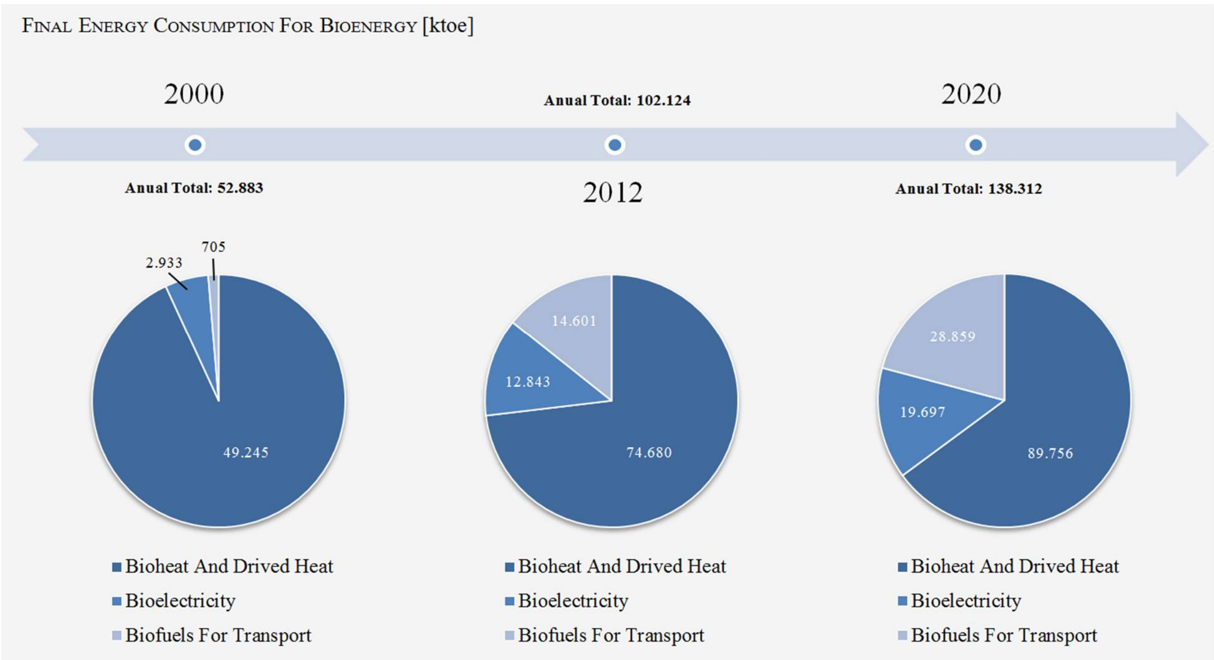

Figure 1.4. Final energy consumption for Bioenergy in EU, adapted from [47].

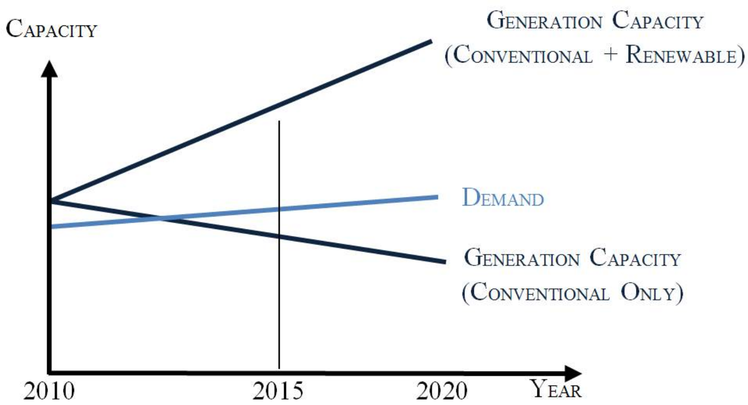

Figure 1.5. Development and future trend of generation capacity, demand and wholesale electricity market price in Central Europe from 2010, adapted from [48].

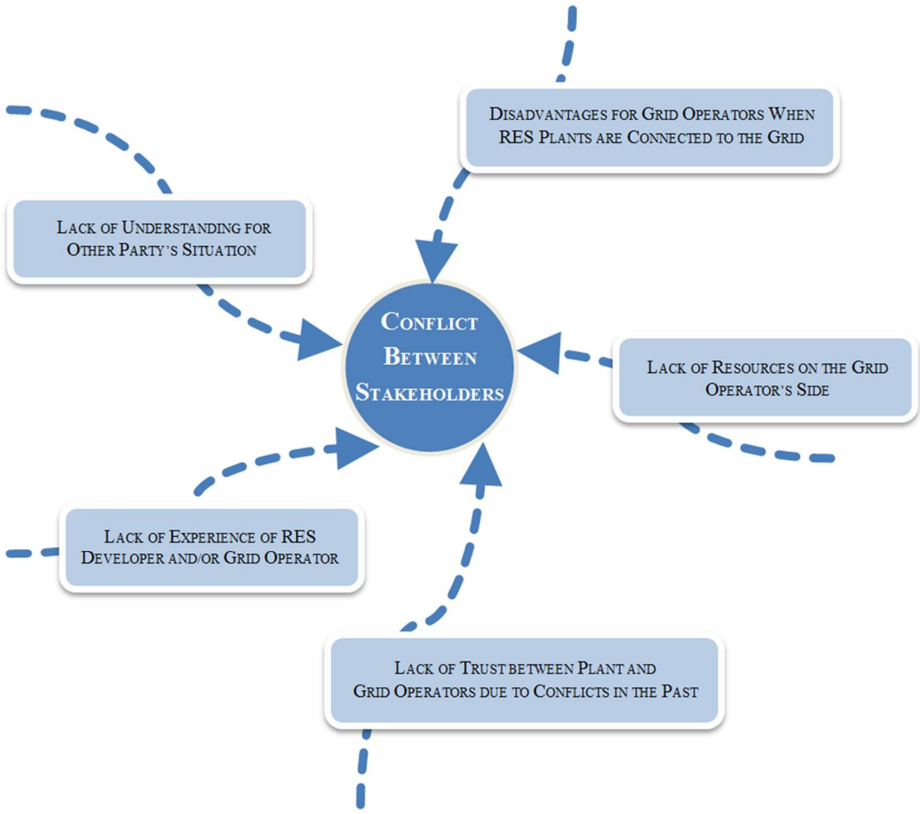

Figure 1.6. Main reasons in the EU 27 for issue "Lack of communication", adapted from [49].

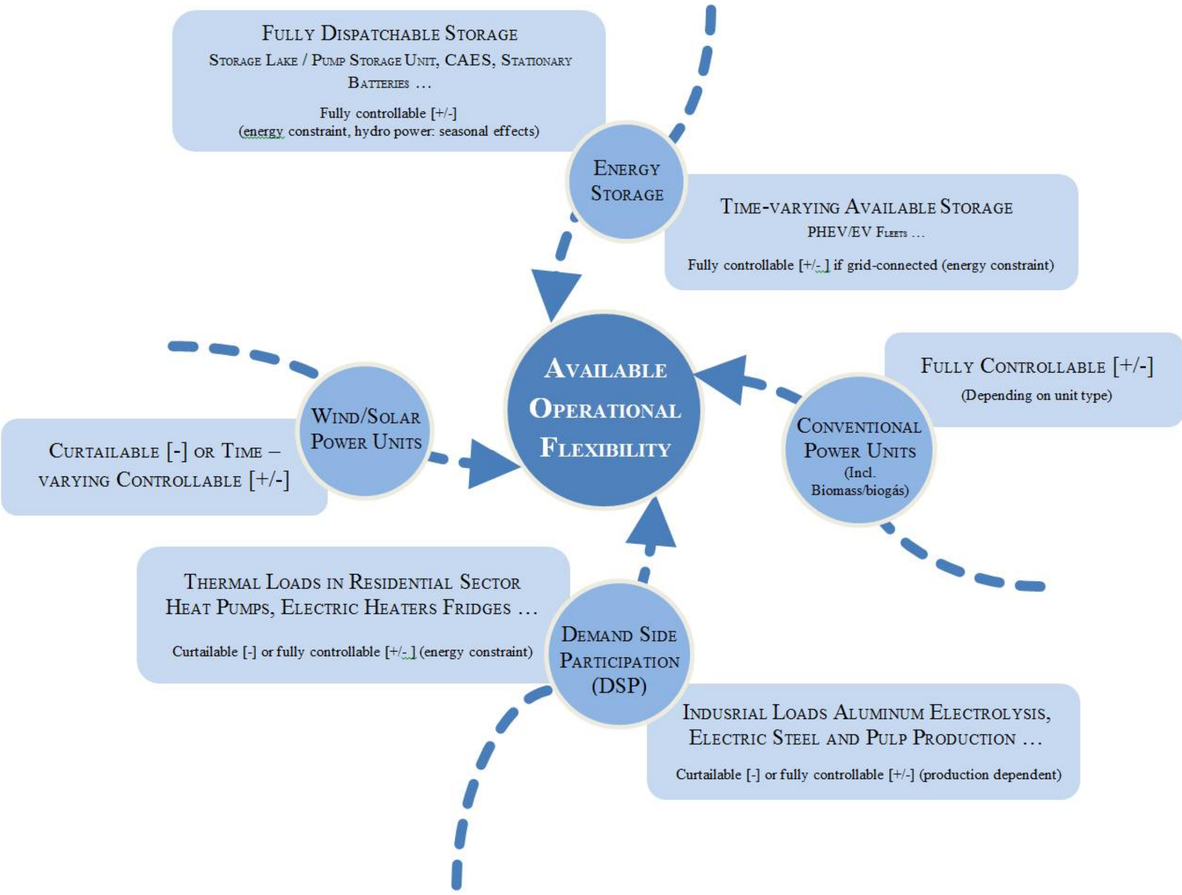

Figure 1.7. Sources of Operational flexibility in power systems, adapted from [50].