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Renewable Energy for a Sustainable Future

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ABSTRACT

Sustainable development becomes more and more important in recent years, since bold actions are necessary to ensure the needs of future generations. Using renewable sources for producing energy plays an important role to achieve sustainable development. Major global issues like depletion of sources and environmental concerns triggers the rapid development of these clean energy production systems. This paper focuses on the current status and future potentials of different renewable energy sources by considering various quantitative and qualitative factors that may affect the capabilities and significance of renewable energy systems such as the potential for power generation, availability issues, carbon dioxide emissions, capital costs, land requirements and social impacts. Furthermore, some of those factors are used for making comparisons between different technologies and systems, which are also discussed in the paper. The results and discussions reveal that these systems provide promising opportunities for people to access cheap, reliable and clean energy in the future, which is one of the key elements to sustain healthy ecosystems and human life. The recommendations and conclusions presented here will be beneficial to engineers, researchers, city planners and energy policy makers.

Keywords: Renewable energy, sustainability.

I. INTRODUCTION

The terms "sustainability and sustainable development" becomes more and more popular due to the serious problems faced by human kind such as the risk of depletion of sources and increasing human impact on environment. Sustainability can be described as maintaining welfare over a long-term [1] and the report of United Nations defines sustainable development as "The development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [2]. Therefore, human activities which have negative effects on the worlds' delicate balance can be determined as unsustainable activities. It is also an important point that considering not only environmental but also economic and social aspects must be taken into account together in order to achieve sustainability. Solving problems just considering one of these aspects is not enough to find sustainable solutions [3].

Increasing public awareness towards sustainability issues especially environmentally problems as well as the pressure from stakeholders and society to go green triggered companies to evaluate their entire value chain and set sustainability objectives. Many firms have performed major changes in their activities such as changes in distribution strategies and packaging methods in order to achieve those objectives [4].

Reducing the impacts related with energy consumption is one of the most effective efforts to achieve sustainability targets. This can be achieved either by using energy saving measures or using the power generated from renewable energy technologies. Since energy plays the major role in terms of sustainability, investing in renewable energy technologies have become attractive among investors, which is also an important step to provide cheap, reliable, ecological and accessible energy all around the world [5].

This paper focuses on introducing the main sustainability indicators for renewable energy technologies including potential power generation, availability of renewable sources, capital costs, land requirements, carbon-dioxide emissions, social acceptance and social impacts. It is mainly concentrated on hydro, wind, photovoltaic, geothermal, marine (wave & tidal) and bioenergy technologies which are used to generate power.

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II. SUSTAINABILITY INDICATORS

2.1. Potential Power Generation

The importance of renewable energy will definitely continue to grow in a world, where the demand for energy will be 56% more than today in 2040 [6]. Although renewable energy sector has already attracted many investors, the global energy status report of Renewable Energy Policy Network for the 21st Century [7] shows that renewable energy sector still has a long way to go. According to this report only 19% of global energy demand is provided by renewables in 2013. However, the report of U.S. Energy Information Administration [8] indicates that renewables is the fastest growing sector from now until 2035 projections. This clearly shows that this sector provides promising opportunities to meet the future energy demands.

Potential power generation is linked with the installed capacity of that specific technology, which indicates the amount of power that can be delivered under specific conditions. The amount of total installed capacity of renewable technologies that is used for worldwide power generation is 1560 GW. 1000 GW of this amount corresponds to the hydro-power capacity. Therefore, hydro-power can be identified as the locomotive renewable energy source for power production. However, it is also very important to consider annual growth rates in terms of installed capacity for each renewable source in order to evaluate the future of that technology. For example, although photovoltaic systems correspond to 8.9% of the total installed capacity for power generation among renewable technologies; photovoltaic market has the record in terms of annual installed capacity growing rates with 39% in 2013. Approximately 39 GW of installed capacity became operational in that year, which was about 100 GW in the end of 2012 [7]. Figure 1 demonstrates the annual growth rates of renewable energy capacities from the end of 2012 to the end of 2013.

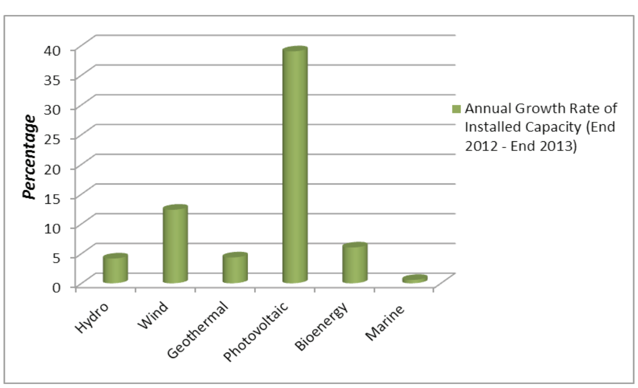

Figure 1. Annual growth rates of different renewable energy technologies

2.2. Availability Issues

Renewable energy systems may be the key for sustainable energy production, but it is important to assess the availability of renewable sources for the specific area, on which a renewable system is planned to be installed. The availability of renewable sources can be challenging to be evaluated, which requires many different factors to consider such as the weather conditions and the potential amount of specific sources. One of the most comprehensive researches related with this issue is undertaken by Dimakis et al [9]. This research introduces new strategies and tools for determining the availability of different renewable sources that may be useful for investors.

There is a difference between the installed capacity of any power plant and the actual output provided by this plant. This difference is defined as the capacity factor and plays a major role for power plant assessments. Although different factors may affect the capacity factor, main determinants for renewable energy systems are availability issues. For instance, it is only possible for solar panels to operate, if the sun shines. Consequently, the capacity factors of solar systems are approximately 10% in Germany and 20% in the state of Arizona depending on the amount of received solar radiation [10]. This clearly demonstrates the importance of the location of the area for renewable systems.

2.3. Energy Costs

Renewable energy systems are generally considered to have high initial costs, which is the main constraint for large-scale development of these systems. Thus, estimating the costs of such systems is a must for assessing technologies in terms of sustainability. In order to achieve this objective, comparing the capital costs and when possible levelized energy costs of different technologies gives the most appropriate results [11].

The power obtained by renewable energy technologies is highly dependent on factors such as the location of the site and the weather conditions, which lead to wide range of costs among different technologies. It is a fact that the maturity of the technology also plays a role in terms of the levelized energy costs. It is expected that the money spent for research and development of a technology is proportional with the maturity level of that technology. This means an increase of efficiency and a decrease of capital and/or operating costs comparing to the early phase of that technology. Another advantage of mature technologies is being more reliable. Proven technologies are generally preferred among investors in order to avoid the risks of unexpected results. It is also an important point that providing financial support as a government policy for research and development costs as well as providing incentives for investors accelerates the development of different technologies [12].

2.4. Land Requirements

Land use requirement for renewable energy production is an important factor, since the land available can be used for any other purpose that may be more profitable for the investor. Thus, considering area requirements is necessary to assess the sustainability indicators for renewable energy technologies. An efficient way to show the efficiency of land requirements for different systems is to indicate the area that is needed to generate 1 kW of power, which can be expressed as m^2/kW.

Area requirements of specific technologies can vary from site to site due to various factors including land topography, weather conditions and the size of the system to be installed [13]. There are also opportunities for dual land use. For example, using roof-integrated solar systems or installing wind turbines in agricultural lands reduces the need for extra space. The capacity of the system also plays a role by determining land requirements, since substations, access roads and any other relevant infrastructure necessary for power generation requires extra land. Therefore, small capacity power stations are generally less land efficient compared to high capacity ones. An example for this claim is provided by the research of Ong et al [14]. This research takes 192 different photovoltaic projects located in US into consideration. It is observed that photovoltaic power plants, which have a capacity between 1 MW and 20 MW requires 5 to 18% more land compared to the ones, which have a capacity more than 20 MW.

The laws of nature are also important while considering land requirements for different technologies. Although solar panels become more and more efficient to capture the solar energy, sun's rays are highly dispersed which increases the need for land in the case of solar technologies. On the other hand, geothermal technologies generally require less land, since large volumes of hot water or rock required is located underground. Therefore, they are generally indicated as one of the most efficient renewable energy technologies in terms of land occupation [15].

2.5. Carbon-dioxide Emissions

Carbon-dioxide (CO_2) is the most significant greenhouse gas, which is claimed to be the main determinant responsible for global warming. According to American Society of Mechanical Engineers [16], 65% of greenhouse gas emissions are linked with energy related activities. Thus, reducing CO_2 emissions must be a priority for investors, who are planning to finance new power plant projects. Negligible amounts of CO_2 are released into the environment during operation of most of the renewable energy technologies. However, it doesn't mean that they don't play a role in CO_2 emissions. Life-cycle analysis, which is the main tool for determining the carbon-footprint of any system, can be used to evaluate the role of renewable technologies [17].

Life-cycle analyses show that renewable energy technologies are responsible for a far smaller amount of CO_2 emissions compared to other conventional methods except nuclear energy. Based on a recent research [18], nuclear energy is a competitive alternative to renewable technologies in terms of CO_2 emissions. This research also shows that nuclear, wind and solar technologies together are responsible for 20 times less greenhouse gas emissions per kWh than coal fired power plants.

CO_2 emissions of different technologies are quantitative factors that can be compared. By considering major quantitative sustainability indicators of renewable energy technologies, comparisons have been performed. These comparisons are indicated in table 1, which are based on a number of studies [13, 17, 19, 20]. For the comparisons of CO_2 emissions, land requirements and capital costs, maximum and minimum values, which are observed in different projects, are used. Data for the year 2011 is used for the total power generated from different renewable technologies.

Table 1. Major quantitative sustainability indicators for renewable energy technologies

Renewable Technology	Total electricity generation (TWh)	CO2 emissions (g CO_2 / kWh)	Land requirements (m^2 / kW)	Capital costs ($/ kW)
Hydro	3490	2 - 74.9	10 - 6500	750 - 6000
Wind	434	5.3 - 123.7	10 - 1200	925 - 6040
Geothermal	424	11 - 78	20 - 1000	1900 - 5500
Photovoltaic	69	9.4 - 300	10 - 500	1200 - 3800
Bioenergy	61	14.4 - 650	1000 - 6000	500 - 6500
Marine	2	10 - 50	10 - 300	5290 - 5870

It is observed that hydro-power is the main locomotive for power generation and marine technologies are still in an early stage of their development. However, maximum observed land requirement for marine technologies is less compared to the one for hydro-power.

2.6. Social Impacts & Acceptance

It is a fact that assessing social impacts of renewable energy technologies is as important as assessing the environmental and economic effects [21-23]. In order to assess social impacts, social acceptance of different technologies must be identified [24]. Thus, a comprehensive research on social acceptance is a must.

As stated by D'Souza and Yiridoe [25] "To be socially acceptable requires positive attitudes and feelings towards an object or issue under consideration". Therefore, positive attitude towards renewable energy technologies is definitely necessary. Cohen, Reichl and Schmidthaler [26] underline the observation of local opposition to some of renewable energy projects despite the fact that people are willing to use power generated by this kind of technologies. On the other hand, it is also stated that there are researches which show high levels of public support towards those projects. Based on these facts, assessing social acceptance of renewable energy technologies is not a simple task [13]. In table 2, studies by different researchers about various reasons of why people accept or don't accept renewable energy technologies are demonstrated.

Table 2. Positive and negative outcomes of renewable energy technologies from different studies

Study	Negative outcomes	Positive outcomes
[26]	- Diminished view sheds - Landscape intrusion - Ecosystem disturbance - Technical issues such as repair work - Decreased recreational opportunity and safety concerns (especially for wind farms) - Watershed damage - Noise and pollution during construction	- Greenhouse gas reduction - Decreased fossil fuel dependence - Place distinctiveness - Possible economic benefits - Energy supply security
[25]	- Concerns about potential changes in land scape - Visual aesthetics problems - Excess noise - Lack of transparency about future projects - Bias against some renewable technologies	- Economic development and growth - Contribution for creating employment opportunities - Population growth in some rural areas
[27]	- Maturity issues for some technologies - Environmental degradation - Damages suffered by the maritime storms	- Growth in local tourism - Use of a local generated energy - Economic benefits for locally-established installations
[28]	- Economic risks (uncertainty of feasibility) - Unproven technology	- Decreasing electricity costs - Improvement on human health
[29]	- Problems about (public or private) ownership - Lack of financial incentives - High investment costs compared to installations relying on the combustion of conventional fuels - Inefficiencies in the existing legal framework and bureaucratic problems or complex licensing - Technical complexities such as local geography - Problems for the selection of an appropriate application site - Lack of impartiality and suspicion towards investors	- Monetary benefits for nearby communities, - Economic boost to the entire region - Reliable energy supply
[30]	- Additional cost for raising the level of consumption of green electricity	- The impression of being clean, green and having low negative environmental impacts
[31]	- Sleep disruption and psychological distress	
[32]		- Have little or no negative impacts on residential property values

NIBMY (not in my backyard) is a popular term which is used to refer the resistance to a project that is unwanted by the local community due to potential economic losses and social conflict issues. On the contrary, the term PIMBY (please in my backyard) is used for neighboring communities, which consider the projects as opportunities for gaining economic, environmental and social benefits. These phenomena must be evaluated for assessing social acceptance [29].

It is also useful for investors to take studies performed on the issues of social acceptance into account. Table 3 is created in accordance with different researches, which are carried out to assess social acceptance.

Table 3. Different researches on social acceptance

Study	Country	Methodology	Aim of the research	Main results
[27]	Australia	Participatory action research	Investigating the social acceptance of geothermal technologies	Despite the limited understanding of geothermal technologies, they receive general support due to increasing popularity of renewable energy systems
[27]	Spain	Various participatory techniques	Assessing social acceptance of wind farm location	Main factors for local conflicts and opposition to wind farms are about the extensive land use and negative visual impacts
[33]	Australia	Face-to-face interviews	Studying the reasons of resistance to wind power and wind farms	Four common themes emerged that restrain the social acceptance of wind farms: Trust, distributional justice, procedural justice and place attachment
[27]	China	Survey questionnaire	Investigating social acceptance of solar energy technologies	High level of social acceptance for solar thermal technologies and low level of social acceptance for solar photovoltaic technologies are observed
[27]	Turkey	Survey questionnaire	Analyzing the level of understanding what clean energy means	The concept of clean energy is understood to a certain degree but more knowledge is required to foster social acceptance
[25]	Australia	Survey questionnaire	Evaluating predictor importance of key constructs in terms of social acceptance	Investing in consumer confidence is beneficial for social acceptance and a must for the widespread adoption of new renewable technologies
[27]	China	Survey questionnaire	Examining social acceptance of renewable energy installations in rural areas	Rural residents generally support renewable energy developments
[21]	Finland	Survey questionnaire	Investigating social acceptance towards renewable energy technology deployments in Finland	62% of all participants are willing to pay extra for using green energy and about 52.4% of all participants think that most of the investments in renewable energy must be carried out by public sector
[27]	Ethiopia	Face-to-face interviews	Assessing social acceptance of small photovoltaic systems for rural electrification	People think that photovoltaic systems have positive effects on family life and public security

III. CONCLUSIONS & RECOMMENDATIONS

Renewable energy systems are considered to be one of the most important technologies for achieving sustainable development goals. Many governments, companies and individual investors from all over the world are interested in investing renewable technologies not just for gaining long term economic advantages but also contributing to worldwide sustainability efforts. The popularity of renewable energy technologies will definitely continue, if potential investors are encouraged to invest in renewable energy technologies. Therefore, studies for determining sustainability indicators play a significant role.

Increasing carbon-footprint is an emerging issue, which is seriously dealt in developed countries by taking different measures such as increasing taxes for energy consumption generated from fossil fuel plants or providing incentives for consumers who have invested in renewable technologies for providing some or all of their energy needs. Furthermore, development and research efforts for these technologies cause a decrease of initial costs. These are important factors, which make renewable energy systems an attractive investment tool. In terms of social acceptance and impacts, every technology has its own problems and benefits, which must be seriously considered. It is necessary to propose solutions, in which perceived advantages of renewable technologies to local people are increased and negative impacts caused by those systems to local people are decreased. It is vital to improve the knowledge of general public about the potential advantages of renewable energy technologies and why brave steps must be taken in order to solve worlds' urgent problems such as CO_2 emissions. These actions can definitely change the opinion towards these technologies in a positive way.

For further research, multi-criteria analyses can be carried out in order to assess and compare the sustainability of different renewable energy technologies. This can provide the optimum solutions for deciding on the technology to be used on a specific area. It may be also useful to include concentrated solar power technology, which is considered to be a new and promising renewable technology for generating power.

To conclude, renewable energy technologies are becoming progressively popular each day. However, its share among the global energy production is still very small. Therefore, supporting worldwide efforts for increasing the share of renewable energy technologies in the global energy mix is very important. Renewable energy is a reliable key source for energy generation, which is capable of meeting the world's total energy demand and an excellent opportunity to provide innovative solutions for unsustainable problems.

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