# RENEWABLE ENERGY REVIEW: BARRIERS TO RENEWABLE ENERGY IN DEVELOPING COUNTRIES


by

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# ABSTRACT

## RENEWABLE ENERGY REVIEW: BARRIERS TO RENEWABLE ENERGY IN DEVELOPING COUNTRIES

Renewable energy has been a very trendy topic in recent decades not only in the developed world but also in the developing world. Considering the depleting fossil fuels and existential threats like Global Warming and Climate Change harnessing energy from renewable sources of energy is good bargain. In this study, first the renewable energy is reviewed in general and comprehensive information is provided for each major renewable source of energy. Second the barriers to the adoption of these renewable energy technology in developing countries are discussed and analyzed. Barriers found are compared by using the Analytical Hierarchy Process (AHP) as an analyzing tool. The most significant barriers for developing countries found are; Lack of financial mechanism, High Investment Requirement, Criminal and terrorist activities, Exclusion of environment externalities in cost, and Lack of standardization. Barriers like "Criminal and Terrorist activities" and Corruption, which have not been mentioned by many studies in the literature, are found to be very significant and moderately significant barrier respectively. The comparative analysis of this study with the existing literature shows that the achieved level of importance of the barriers differs when focusing on a particular region or country. For example, factors such as the political scenario in the country, economic situation, and geographical conditions have a different importance level for different regions or countries. The contribution provides general barriers for the adoption of renewable energy technology in developing countries around the world that could be used to help the government and investors take steps to help in removing or limiting the extent of these barriers.

# ÖZET

## YENİLENEBİLİR ENERJİ İNCELEME: GELİŞTİRİLEN ÜLKELERDE YENİLENEBİLİR ENERJİ BARİYERLERİ

Yenilenebilir enerji son yıllarda sadece gelişmiş ülkelerde değil aynı zamanda gelişmekte olan ülkelerde de oldukça popüler bir araştırma konusu olmuştur. Küresel ısınma ve iklim değişikliği gibi mevcut tehditlere karşı, tükenmekte olan fosil yakıtlar yerine yenilenebilir enerji kaynaklarından elde edilen enerjiyi kullanmak daha çevre dostu bir alternatiftir. Bu çalışmada, öncelikle yenilenebilir enerji kaynakları genel olarak değerlendirilmiş ve her bir yenilenebilir enerji kaynağı için kapsamlı literatür taraması yapılmıştır. İkinci aşamada ise gelişmekte olan ülkelerde yenilenebilir enerji teknolojisinin benimsenmesinin önündeki engeller analiz edilmiştir. Tespit edilen engeller Analitik Hiyerarşi Süreci (AHP) analiz aracı kullanılarak karşılaştırılmıştır. Gelişmekte olan ülkeler için en önemli engeller; finansal mekanizma eksikliği, yüksek mali yatırım gereksinimi, suç ve terörist faaliyetleri, çevresel etkenlerin maliyete dahil edilmemesi ve standardizasyon eksikliği olarak tespit edilmiştir. Bu çalışma kapsamında, literatürdeki birçok çalışmada yer almayan 'Suç ve Terör Faaliyetleri' ve 'Yolsuzluk' gibi engellerin sırasıyla çok önemli ve orta derece öneme sahip olduğu bulunmuştur. Bu çalışmanın bulguları mevcut literatürle karşılaştırılarak analiz edilmiştir. Karşılaştırmalı analiz sonuçlarına göre, belirli bir bölgeye veya ülkeye odaklandığında engellerin önem düzeyinin farklılaştığı belirlenmiştir. Örneğin, ülkedeki politik senaryo, ekonomik durum ve coğrafi koşullar gibi faktörler, değişik bölge veya ülkeler için farklı önem seviyelerine sahiptir. Bu çalışma, dünyanın dört bir yanındaki gelişmekte olan ülkelerde yenilenebilir enerji teknolojisinin benimsenmesi için hükümetlerin ve yatırımcıların bu engelleri ortadan kaldırılmasına yardımcı olabilecek niteliktedir.

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| | |
|---|---|
| [C] | Criteria Comparison Matrix |
| n | Number of criteria |
| $\{W_s\}$ | Weight sums vector |
| {W} | Criteria weight |
| $\sum$ | Summation |
| $\lambda$ | Average of the elements of {Consistency} |

# LIST OF ACRONYMS/ABBREVIATIONS

| | |
|---|---|
| $CO_2$ | Carbon dioxide |
| DOEE | Department of Environment and Energy |
| EGS | Enhanced Geothermal Systems |
| EU | European Union |
| EWEA | European Wind Energy Association |
| GHG | Greenhouse gases |
| GWEC | Global Wind Energy Council |
| $H_2S$ | Hydrogen sulfide |
| HEFA | Hydro-treated esters and fatty acids |
| HVO | Hydro-treated vegetable oil |
| IEA | International Energy Agency |
| IHA | International Hydropower Association |
| MSW | Municipal Solid Waste |
| NASA | National Aeronautics and Space Administration |
| NRDC | National Resources Defense Council |
| OECD | The Organization for Economic Co-operation and Development |
| OPEC | The Organization of the Petroleum Exporting Countries |
| PV | Photovoltaic |
| SEforALL | Sustainable Energy for All |
| SHERPA | Small Hydro Energy Efficient Promotion Campaign Action. |
| TFEC | Total final energy consumption |
| UN | United Nations |
| USA | United States of America |
| USEPA | United States Environment Protection Agency |
| WEC | World Energy Council |
| WEO | World Energy Outlook |
| WNA | World Nuclear Association |

# 1. INTRODUCTION

## 1.1. Problem Statement

The world is facing a possible existential threat and the reason for it is *Global Warming* or in other words Climate Change. Many researchers have suggested that warming of 11-12℃ would make the planet inhabitable and would completely destroy agriculture (Sebastian *et al.* 2017). There are many effects of global warming. It leads to a rise in the mean temperatures and temperature extremes. It also causes extraordinary weather events like ice melt or in other words Glaciers melt, increasing sea levels and ocean acidification, change in the behavior of plants and animals and harmful social effects (Bradford, 2017). The effect of Global warming has been felt in many famous regions of the world. The city of Venice in Italy, Key west region of Florida, The Rhone Valley in France, the city of Mumbai in India, the city of Rio de Janeiro in Brazil, Amazon region in South America, Yamal Peninsula in Russia, the state of Alaska and California in US, and Maldives are some of the regions affected (Moss *et al.*, 2018).

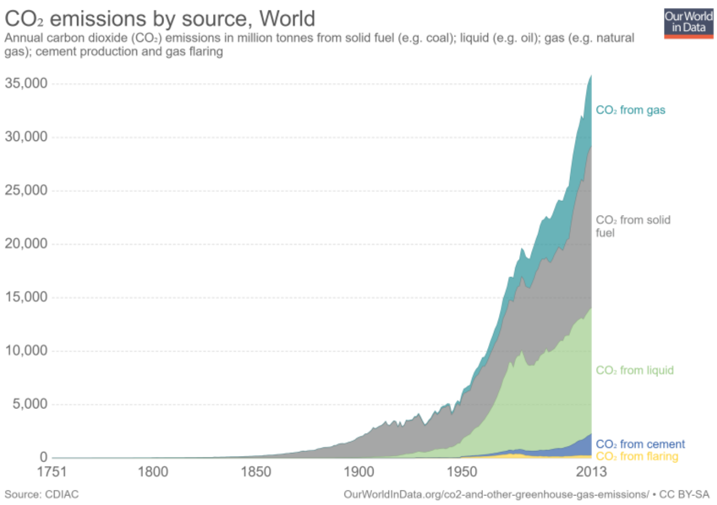



Figure 1.1. Carbon Dioxide Emissions by source
(Boden *et al.*, 2017)

Majority of the scientists that are experts in the field of climate agree that the *main cause* of the recent rise in global temperature is greenhouse emissions caused by expansion of humans (Oreskes, 2004). The process that is natural and causes the increase in temperature of earth's surface is known as greenhouse effect. Greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, ozone and some artificial chemicals such as chlorofluorocarbons (CFCs) (DOEE, Australian Government). Rise in the greenhouse gases emissions leads to rise in the greenhouse effect. *Figure 1.1* gives two important information: first that the main sources of carbon dioxide emissions is fossil fuels and second it shows that the consumption of the fossil fuels has increased exponentially over the last century. *Figure 1.2* shows the global average surface temperature over the last century. When we compare *Figure 1.1* and *Figure 1.2* we see that the increase in the global mean surface temperature is directly proportional to the increase in the consumption of fossil fuels. Hence it can be inferred that the *overuse of fossil fuel* is the primary contributor to climate change. The burning of fossil fuels also causes many other problems like Air Pollution, Water Pollution, Land Pollution and Health problems. Another problem with the fossil fuels is that they are not unlimited or in other words are renewed very slowly but the demand for energy is increasing by each passing day. But we cannot stop the use of fossil fuels because they are one of the main sources of energy, nearly 94% of energy is generated by fossil fuels (WEC, 2016), and energy is essential for humanity.

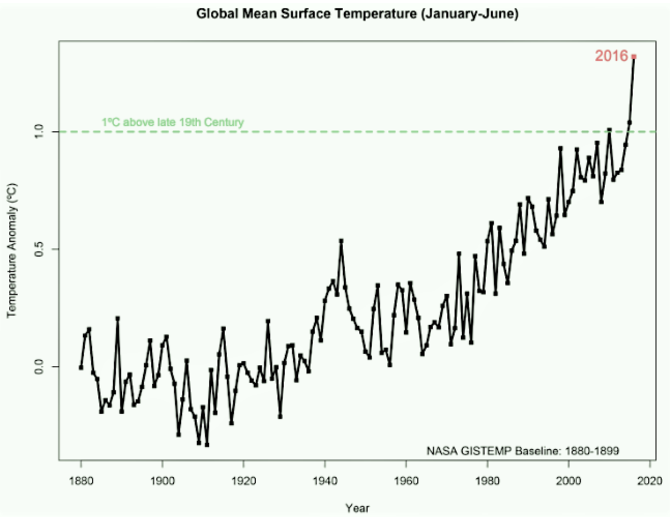



Figure 1.2. Global Average Surface Temperature
(NASA, 2016)

Another available possible source of energy for the replacement of fossil fuel is Renewable Sources of Energy namely: Solar, Wind, Hydro, Geothermal and Bio Energy. Other possible alternative is Nuclear Energy. *Figure 1.3* shows the lifecycle greenhouse emissions of different sources of electricity generation methods. It can clearly be seen that the fossil fuels are the main source of greenhouse gas emissions and the alternatives i.e. Nuclear Energy and Renewable sources of Energy have comparatively negligible emissions.

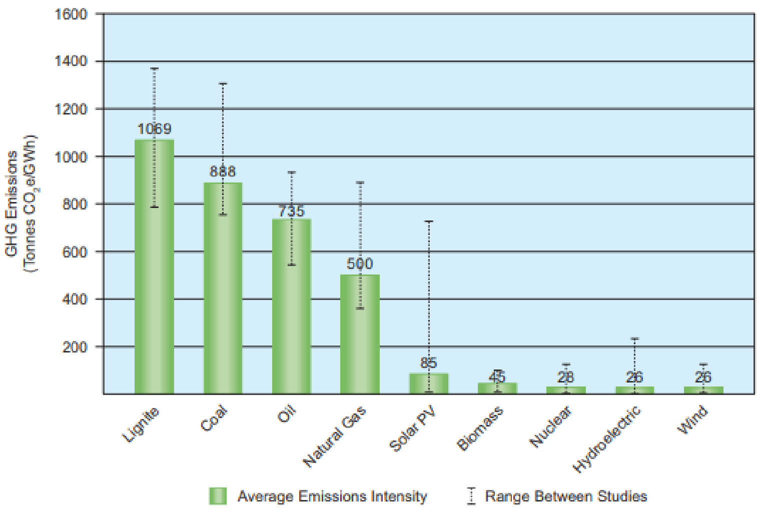



Figure 1.3. Lifecycle GHG Emissions Intensity of Electricity Generation Methods (WNA, 2011).

Nuclear Energy has one of the lowest emissions but it has many other problems. The major problem with it is that the power plants used to generate energy could also be used to produce nuclear weapon grade material, which has been seen in recent years. The possession of such weapons could risk nuclear exchange between countries during tensions or could land into the hands of terrorists which could be catastrophic for the world. Due to the spread of nuclear energy worldwide there has been increase in detonations by terrorists on such sites and lead to alarming situations (Jacobson, 2009). One other example for the disadvantage of nuclear energy is the case of Fukushima Daichi Nuclear disaster, Japan. The radiation contaminated a large part of the surrounding area and made it inhabitable. Therefore, Renewable sources of Energy is safest and best substitute to fossil fuels.

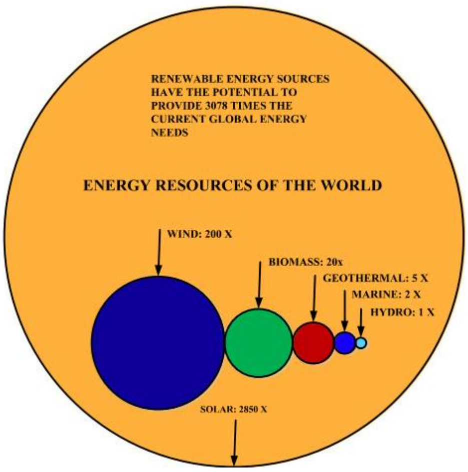



Figure 1.4. Energy Resources of the world (Ellaban *et al.*, 2014).

*Figure 1.4* shows the potential of the renewable resources. Theoretically, renewable resources could possibly provide 3078 times the present demand of energy in the world. Solar Energy alone could possible provide 2850 times the present demand of energy in the world. Wind could provide 200 times; Biomass 20 times, Geothermal 5 times, Marine or Ocean Energy 2 times and Hydro energy 1 time the present demand of energy in the world (Ellabban *et al.*, 2014).

Therefore, theoretically the world can solve two of its major problems, Energy need and Global warming, by substituting fossil fuels with these energy sources. Practically it would not be possible to get the mentioned potential but at least it shows a possibility to achieve the majority global energy need from these renewable energy sources.

### 1.1.1. The Paris Agreement

The Paris Agreement is a world initiative that brings all countries for a common goal to undertake extra-ordinary efforts in combating the problem of Climate Change and adjust to its consequences. This could not be done without the exalted backing in assisting the developing countries by the developed countries. 194 countries gathered in December, 2015 and signed this agreement.

The main objective of it is to reinforce the response of the world to the threat of rise in temperature globally during the last hundred years well below 2 °C above the level of the pre-industrial era and to engage in efforts to limit the increase in the temperature still lesser to 1.5°C. Furthermore, it means to fortify the capacity of nations to manage the effects of environmental change (UN, 2015). According to this agreement the developed countries were to provide funding to the developing countries to adopt the methods to lower carbon emissions.

It is a good effort but one of its main drawbacks is that it does not bind any nation. One of the recent setbacks is that the US has backed off from the agreement. The other thing is that the developing countries want more from the developed countries in terms of reduction in carbon emissions and vice versa. But still it is a positive step and the results of this agreement would be seen in the future. This study will locate the general hindrances related with the adoption of renewable energy in the developing nations.

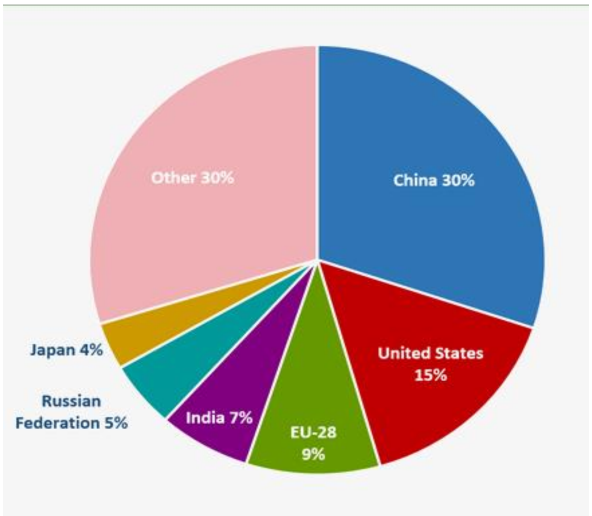



Figure 1.5. Carbon dioxide emissions from fossil fuel combustion and some Industrial Processes 2014 (Boden *et al.*, 2017).

## 1.2. Related Research

The topic of Renewable Energy is a very trendy one these days. Many research is being done and many have already been done on this topic. Some of these are giving general overview of all the sources of Renewable energy namely Solar, Wind, Bio, Hydro, and Geothermal, the research done by Ellaban *et al.* (2014) titled *"Renewable energy resources: Current status, future prospects and their enabling technology"* is one example of such research. Some have been specific to one source of Renewable energy, the research done by Frey *et al.* (2002) *"Hydropower as a renewable and sustainable energy resource meeting global energy challenges in a reasonable way"* is an example of this research. This research has been specific to Hydropower source of Renewable Energy. Many of the research have focused on availability and feasibility of renewable sources of energy in specific locations or regions of the world. Research done by Ahmad *et al.* (2010) titled *"Current Perspective of the renewable energy development in Malaysia"* is an example of a region specific research. There are many different types of research being done.

The research which are similar to this study would be related to the Barriers to Renewable energy. Even in this topic there are many different types of research. Some researchers are related to barriers for a particular renewable energy type like research done by Ohunakin *et al.* (2014) titled *"Solar energy applications and development in Nigeria: Drivers and Barriers"*, this research is also an example of region specific research. Some research is not bound to any region like the research done by Sen *et al.* (2016) titled *"Opportunities, barriers and issues with renewable energy development-A discussion",* this research talks about general barriers to renewable energy around the world. Many of the researchers have also researched by clubbing some regions together like the research done by Tania Urmee *et al.* (2008) titled *"Issues related to rural electrification using renewable energy in developing countries of Asia and Pacific"*. Correspondingly, in this study all the developing nations have been clubbed and the barriers to the appropriation of Renewable Energy in these nations are found.

The difference between the mentioned research and this research is that most of the research which are mentioned have either been region specific or renewable energy source specific whereas this research tries to cover developing countries from different regions of the world and tries to identify general barriers which most of these countries would have.

## 1.3. Aims and Objectives

The aim of this study is to *review Renewable Energy Resources and evaluate the major barriers to renewable energy in developing countries*. Information about renewable sources of energy is found from the literature. Relevant information is provided about the renewable energy and its major types. The next step was to find barriers that are obtained from a number of literatures and counterchecked with academicians and professionals with experience in their field of work, and then the ratings are established by using AHP to obtain an arguable result. This information is taken from professionals who have experience in at least one of the renewable source of energy. In order for the aim to be fulfilled five objectives are listed.

This research has the following objectives:

- To review the renewable sources of energy
- To find the barriers listed in the literature.
- To interview academicians and professionals who are working in this field and get their views on the found barriers and give their suggestions for any new barrier not listed in the list.
- Make the final list of barriers in the developing countries.
- To perform AHP on the results of the interview.

## 1.4. Scope and Limitations

The study provides a comprehensive overview of almost all the trending renewable sources of energy. It goes into every possible area where information could be vital for its adoption. It clubs all important information from different sources. Different definitions which are found in the literature are listed. Historical background of each renewable source is listed. Graphs showing the current situation is provided from Renewables Global Report. Benefits and limitations are listed that could help investors for taking a decision on investing in these renewable energy technologies.

Since, the topic of renewable energy has been a very trending topic in the last decade a lot of research have been done regarding it. The research has been done in many different areas which could be related to drivers for renewable energy technology or that which focuses on the technical aspects of the technology or barriers which hinder its adoption etc. This study centers around the zone of barriers to the selection of renewable power source and focuses on developing nations. The study also plays a great role in identifying the barriers for renewable energy sources in developing countries.

The research conducted in this area have mostly been either region specific like the study conducted by Luthra *et al.* (2015) titled "Barriers to renewable/sustainable energy technologies adoption: Indian perspective" that focuses on India or energy resource specific like the study conducted by Jagadeesh (2000) titled "Wind energy development in Tamil Nadu and Andhra Pradesh, India Institutional dynamics and barriers: A case study" that only focuses on Wind energy source. Very limited research is available which gives general barriers that considered grouping the developing countries and all the major renewable sources of energy. Since the study tries to accommodate the barriers which are common to all renewable sources of energy and are applicable to most of the developing countries, many barriers are omitted. These ignored barriers were either specific to a particular region or very specific to a particular renewable energy source.

Therefore, the limitations can be summarized as follows:

- Barriers which are region specific are mostly ignored and the focus has been on the general barriers, except barriers which the focus groups have deemed important.

- The significance of the barriers found in this research may not be applicable to each and every developing country since developing countries is a very vast group. The majority of the barriers listed would be applicable to many developing countries but their level of significance would differ.

### 1.5. Methodology

A thorough review of all renewable energy was conducted. Information like definition, history, current situation, and benefits and limitations were provided for each renewable energy considered in the study. The second part was to find the barriers which make it difficult for the implementation of renewable energy technology in developing nations. The barriers were found from the existing literature.

The barriers are then finalized in collaboration with academicians and experts from the industry. A pair wise comparison is done by the focus groups (10 experts from the industry). The interviewees were also asked in detail about their view on the barriers. After getting the results of the interview from the focus groups AHP was implemented and the barriers were ranked according to their respective weights. The barriers were then divided into very significant (VS), moderately significant (MS), somewhat significant (SS), and not so significant (NS), according to their respective weights. Coefficient of Variance (CV) was also calculated to understand how the experts differed in comparing the barriers.

### 1.6. Organization of the thesis

In the coming chapters, initially the Literature Review section is presented which covers two subtopics; Renewable Energy; Barriers to renewable energy in developing countries. In the Renewable energy section relevant information like the definition, historical background, current situation, benefits, and limitations is provided. In the barriers to renewable energy section studies related the barriers to renewable energy are explored and some major barriers in the literature are discussed.

In the third chapter, detailed information of the methodology used will be explained step by step, starting with the identification of barriers and formation of the groups. In the decision process, the Analytical Hierarchy Process (AHP) will be discussed. This section would also give insight on the professionals who were interviewed for the collection of the data. It would give details about the type of projects and the countries in which they had experience in. It would also highlight their number of years of experience.

Following the methodology chapter, the results and findings section will show the results obtained in this study. It will be followed by the discussion section in which the results would be commented on and comparison will be made between this study and previous studies done. A comparison between the experts would also be done in this section. A conclusion will be presented which would be stating the completion of the aim and objectives of this study together with the recommendations for further studies and improvements in this industry.

# 2. LITERATURE REVIEW

## 2.1. Renewable Energy

There are many definitions available for *"Renewable energy"* in the literature. Business Dictionary defines it as the energy which derived from resources that are naturally regenerative or are practically inexhaustible. This definition has a little flaw in it. It uses the term *"naturally regenerative"*, this term is also applicable for fossil fuels since they also regenerate but take thousands of years to do so. Frewin in his article titled *"Renewable Energy"* on Student Energy website gave a better definition. He defined it as "*the energy produced from sources that do not deplete or can be replenished within a human's life time"*. Shinn defines it as the energy which is constantly being replenished. A similar definition is quoted by Kasper from USEPA, *"resources that rely on fuel sources that restore themselves over short periods of time and do not diminish"*.

According to the Renewable Energy Policy Manual, those energy resources and technologies whose common characteristic is that they are non-deplete able or naturally replenishes are known as Renewable Energy resources (Armstrong *et al.*). Ellabban *et al.* (2014) gave a complete definition of Renewable Energy. He defined it as the energy sources that are continually replenished by nature and directly derived from sun (such as thermal, photo-chemical and photo-electric), indirectly from 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). This definition also closes all the drawbacks which the previous mentioned definitions had. It also clears a problem which would be stated in the following paragraph about the types of renewable energy.

There are many types of renewable sources of energy. According to the Renewable Energy Policy Manual and Frewin, there are five types of renewable energy sources namely Solar, Wind, Hydroelectric, Geothermal and Biomass. Some of the other research and articles like the research by Owusu *et al.* (2016), article by Mason for Environmental Science website and article by Shinn for NRDC website add Ocean or Tidal Energy as a form of renewable energy. On the other hand, research by Kasper classifies the renewable energy into three broad categories only, which are namely Solar, Wind and Hydropower. It considers Biomass to be an indirect source of solar energy since all the living beings get their energy from the sun. The researcher also makes the argument that not all the resources which we get from the biomass can necessarily be considered renewable. The researcher makes a statement which says *"if you harvest a renewable resource faster than it regenerates, it will not be able to renew itself over time"*, which shows the researcher's condition to consider biomass as a renewable source of energy.

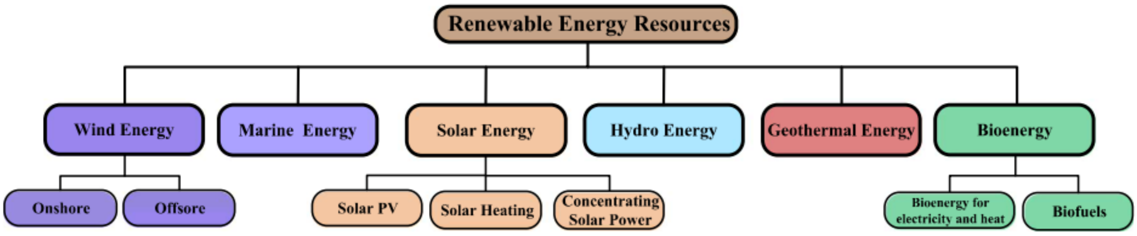



Figure 2. 1. Overview of Renewable energy resources (Owusu et al., 2016).

The distinction in the studies about the sorts of renewable sources of energy has been cleared by the research of Ellabban *et al.* (2014), in which the author has explained through the definition of renewable energy about the direct and indirect energy from sun. The direct energy from sun is referred to as Solar energy in most studies and the indirect energy is mentioned by their respective names, wind, hydropower and biomass. *Figure 2.1* gives an overview about the Renewable sources of energy. Marine Energy is the other name of Tidal Energy. *Figure 2.2* gives estimated renewable energy share of Global electricity production.

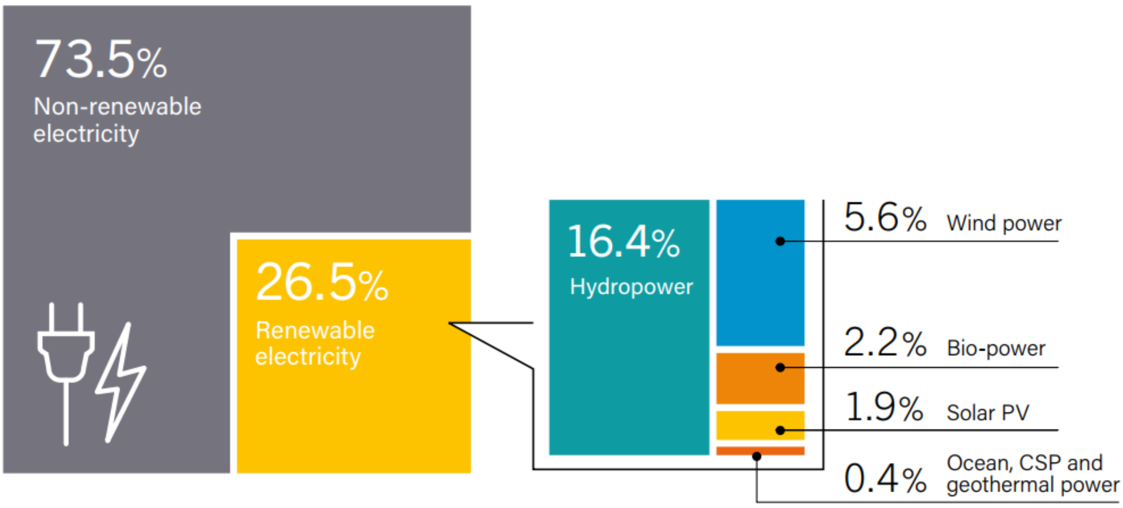



Figure 2. 2. Estimated Renewable Energy Share of Global Electricity Production, End-2017 (Renewables Global Report, 2018).

### 2.1.1. Solar Energy

The simplest form of definition of solar energy is given by the National Geographic; it is any type of energy generated by the sun. Tran (2016) defines solar energy as technologies that convert sun's heat or light to another form of energy for use. But these definitions of solar energy would also take many different types of renewable energy. Solar radiation reaching the earth is the main driving force of natural processes taking place on the earth and is the indirect source of all other renewable forms of energy, except geothermal and tidal (Owusuu *et al.,* 2016). Most of the research available in the literature has considered 'direct' solar energy as solar energy. The word 'direct' solar energy refers to the energy base for those renewable energy source technologies that draw on Sun's energy directly (Owusu *et al.*, 2016).

The utilization of sun based energy is not new to people. The historical backdrop of the utilization of sun oriented energy extends from seventh century B.C. to today. Theoretically solar energy was utilized by people as early as in seventh century B.C. (Richardson, 2018). As per historical text amid this time human utilized solar energy to light flames with the assistance of amplifying glass materials. Afterward, in the third century B.C. the Greek and Roman developments were known to bridle solar energy with the assistance of mirrors to light the lights for religious services (Richardson, 2018). Chinese people also known to have used it for the same purpose later in 20 A.D. Between 1$^{st}$ and 4$^{th}$ century A.D. Romans used to use the solar power for warming the bathhouses by having large south facing windows (U.S. Department of energy).

Another early use of solar energy in around 6$^{th}$ century B.C., which is as still well known today, is the idea of "sunrooms" in structures. The sunrooms had enormous windows to guide daylight to one concentrated zone. Some of the popular Roman bathhouses, particularly those which were arranged on the south-bound sides of structures, were sunrooms. Later during the 1200s A.D. the precursors of Pueblo Native Americans which were known as the Anasazi arranged themselves in south-bound dwelling places precipices to catch the sun's glow amid winter. (U.S. Department of Energy)

In late seventeenth and eighteenth century, researchers and scientists had achievement in utilizing daylight to control broilers for long voyages. They had likewise tackled the intensity of sun to create solar powered steamboats. (Richardson, 2018). In this way, it is exceptionally obvious that even before the period of solar panels energy from the sun was being utilized by people.

Solar Panel’s development was a step by step process which happened because of the contribution of various scientists. It began with the French Scientist 'Edmond Becquerel' who discovered that light could increase the generation of electricity when two metal cathodes were set into a conducting solution. This development was characterized as the "photovoltaic impact" and was compelling in later PV advancements with the component selenium. In the year 1883, after the revelation of the photoconductive capability of selenium by Willoughby Smith and further disclosure by William Grylls Adam and Richard Evans Day that Selenium creates power when presented to daylight, Charles Fritts developed the first solar cells which were made of selenium wafers. (Richardson, 2018)

The solar cells which are utilized today are not made of selenium. They are made of silicon. In 1954 Daryl Chapin, Calvin Fuller, and Gerald Pearson made the silicon photovoltaic (PV) cell at Bell Labs. This occasion was the one which denoted the genuine creation of PV technology since it was the first occasion when solar technology could really power an electric gadget for a few hours of multi day. The efficiency of the primary silicon solar cell that could convert light from the sun was four percent. This efficiency has expanded throughout the years and has come to 34.5%. This efficiency was accomplished by the analysts of South Wales University. (Richardson, 2018)

Numerous improvements occurred after the innovation of silicon based solar cell. In 1958 solar panels were beginning to be utilized in Satellites. First it was utilized to power the radios of Vanguard satellite-1. It was a 1-watt panel. Amid that year three additional satellites, Vanguard II, Explorer-III and Sputnik - 3, were propelled with PV equipped technology. In 1964 NASA propelled the first Nimbus spacecraft, a satellite which could keep running on 470-watt solar array. In 1966, NASA propelled the world's first Orbiting Astronomical Observatory, fueled by a one-kilowatt array. In 1973, the University of Delaware was in charge of developing the principal sun powered structure known as the 'Solar One'. (Richardson, 2018)

In 1981 Paul MacCready constructed Solar Challenger which was the principal air ship to keep running on power from the sun. Its first flight was over the English Channel from France to the U.K. In 1998, the remote-controlled solar plane known as the "Pathfinder" set a height record of 80,000 feet, NASA broke that record in 2001 when they had achieved 96,000 feet with their non-rocket aircraft. In 2016 Bertrand Piccard finished the initial zero-emissions flight around the world over with Solar Impulse 2 which is the world's biggest and most dominant solar-powered plane till date. (Richardson, 2018)

The cost of solar panel which had started with 300$ per watt in 1954 gradually came down to 100$ per watt in 1975 and today to 0.50$ per watt. Since the year 1980 the cost of solar panel is getting decreased by a rate of 10% consistently. This drop in cost is the reason for the developing prominence of solar energy and PV as a reliable energy source on the planet today. (Richardson, 2018).

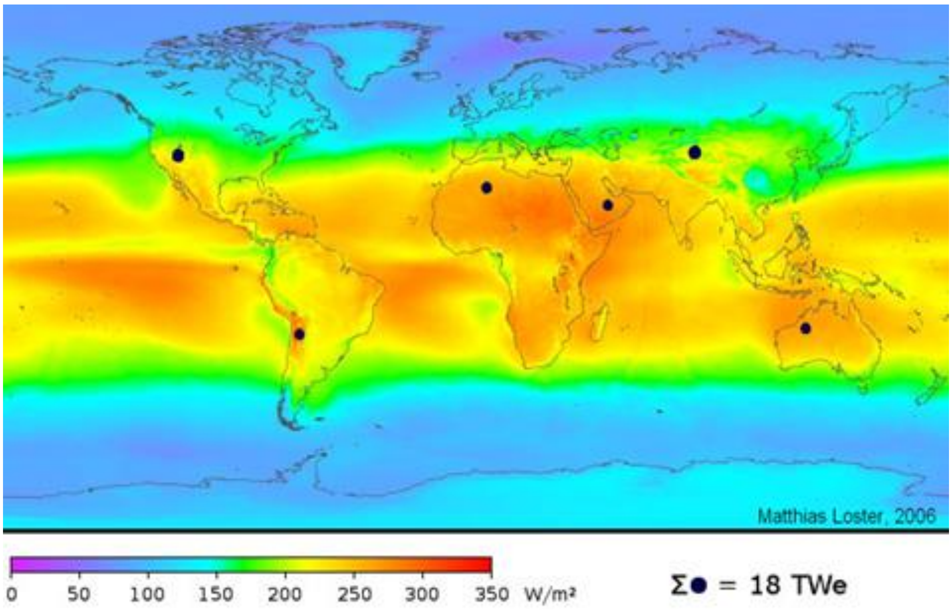



Figure 2. 3. Annual average solar irradiance distribution over the surface of earth (Kabir *et al.*, 2017).

Solar energy is a standout amongst the best choices to fulfill future energy need since it is predominant regarding accessibility, cost viability, availability, capacity, and efficiency contrasted with other renewable energy sources (Kannan *et al.* and Green *et al.*, 2016). About four million exajoules (1 EJ = 1018J) of solar energy reaches the earth yearly, ca. 5 × 104 EJ of which is professed to be effectively harvestable (WEO, 2012). *Figure 2.3* shows the annual average solar irradiance distribution over the surface of the earth. Research has demonstrated that the "dark spots" zones could give more than the whole world's all out essential energy demand, accepting that a transformation effectiveness as low as 8% is accomplished (Kabir *et al.*, 2017).

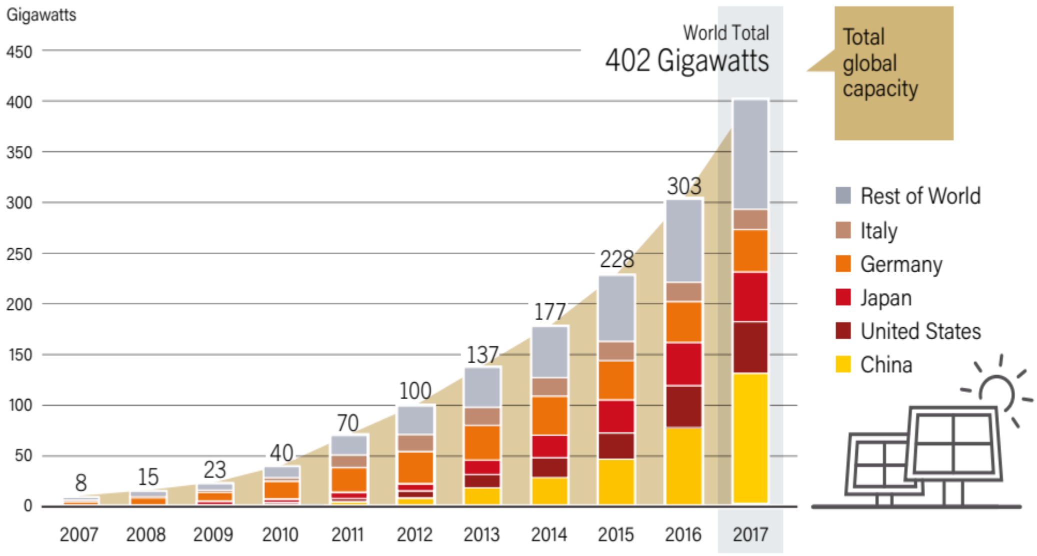



Figure 2. 4. Solar PV capacity, top 10 countries, 2017 (Renewables Global Report, 2018).

*Figure 2.4* shows the total global capacity of solar PVs. By 2017 the global capacity had reached 402 GW. *Figure 2.5* shows the solar PV capacity of top 10 countries. It is evident that China is fastest growing and with highest solar PV capacity

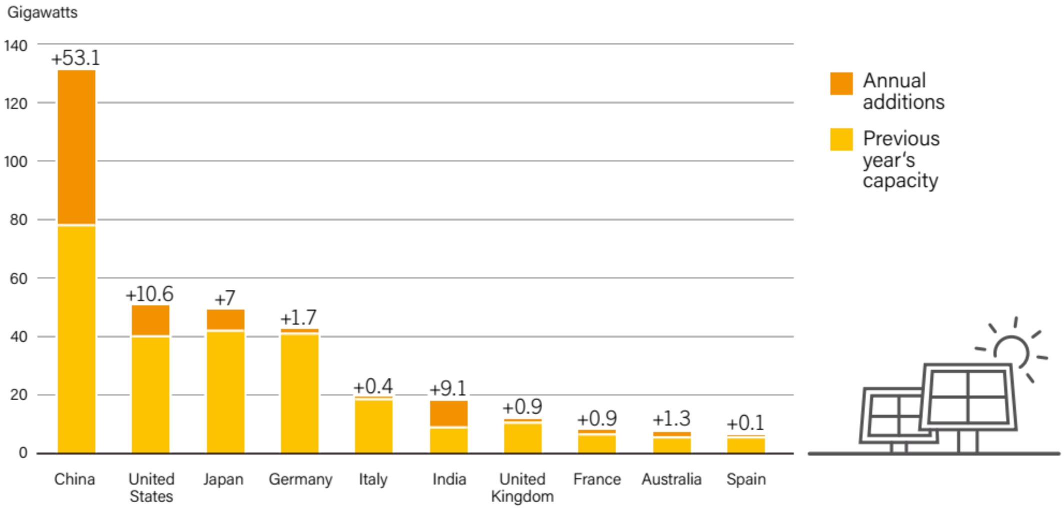



Figure 2. 5 Solar PV global capacity, by country or region 2007-2017 (Renewables Global Report, 2018).

Table 2.1 shows the efficiency of solar panels over the years. It is evident that the efficiency has increased significantly over the years. This shows that there is great potential for solar energy in the future.

Table 2. 1. Efficiency of solar panels over the years (U.S. Department of energy).

| **Year** | **Efficiency of Solar Panel** |
|---|---|
| 1954 | 04.00% |
| 1957 | 08.00% |
| 1958 | 09.00% |
| 1959 | 10.00% |
| 1960 | 14.00% |
| 1992 | 15.90% |
| 1999 | 33.33% |
| 2016 | 34.50% |

*Figure 2.6* shows the price and solar panel installations globally over the years. The price has reduced significantly and the installation has increased exponentially.

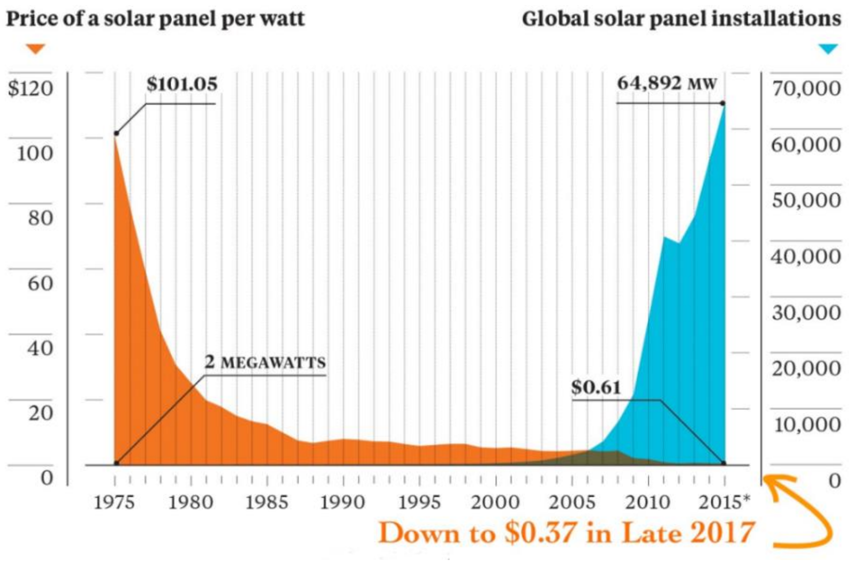



Figure 2. 6. Price and Solar power installations over the years (Bloomberg, 2017).

It is apparent that solar energy is a consistent power source that could give energy security and energy independence. This is a very big opportunity for all stakeholders who use energy and need energy (individuals, companies, nations etc.). In any case, solar power is being received as a natural and considerable part of power generation in many developed and developing nations for the satisfaction of their energy needs. However, solar energy comes with some benefits and limitations to it (Kabir *et al.*, 2017).

2.1.1.1. Benefits- It is verifiable truth that there isn't energy source contrasted with the energy potential from the sun. Most of the options in contrast to non-renewable energy sources are either direct source of energy from the sun or indirect sources. Theoretically the solar power is all that anyone could need to fulfill the energy needs of the whole world many fold. It is a sustainable as well as renewable source of energy. The world need not think about the extinction of this resource. Solar energy can be an option in contrast to the non-renewable energy sources which are mostly responsible for the emission of greenhouse gases. These greenhouse gases are responsible for Global Warming which is an existential threat for the world. Solar Power is viewed as a clean power source.

Machol detailed that the supplanting of non-renewable energy sources with renewable power source could limit untimely death rates, lost workdays, and lessen the general expenses for social insurance Power plants running on petroleum derivatives require a lot of water. The problem of water shortage and the drought caused by it can also be solved by substituting fossil fuels with solar power. Petroleum derivatives are principally motorized and capital escalated, solar power is viewed as labor intensive and hence can help in increasing the job opportunities. Though a high initial investment is required but solar power plants do not require a lot of operation cost.

Since the solar panels do not have any (mechanical) moving parts, they are free from noise pollution and are durable. This also implies they have a very low maintenance cost. Solar panels are additionally simple to introduce and can be introduced on housetops and mounted onto building dividers. Hence it can be regarded as flexible. Solar power systems are less inclined to huge scale breakdown since they are disseminated and made out of various individual solar arrays. (Kabir *et al.*, 2017). Hence, if any area of clusters were observed to be flawed, the rest could keep on working.

2.1.1.2. Limitations- With many benefits to solar power there are some limitations or in other words barriers to its adoption. One of the most significant barriers is the high initial investment cost (Kabir *et al.*, 2017). Though as of late the cost per watt of solar energy has gone down but still it is very expensive for average household. In 2016 when the price of solar power per watt was approximately 3.70$ in USA it would have taken around 13000$ (after 30% subsidy) for a household to install a 5kW solar energy system, which most of the households cannot afford.

The other significant barrier is the efficiency of solar panels. Most of the solar panels being used are having 10-20% efficiency. Though panels with more than 20% efficiency are available but their cost is high. Short battery lifetimes and the sheltered transfer of spent batteries are different worries with respect to solar energy systems (Kabir *et al.*, 2017). The batteries also require large spaces. Another issue with solar panels is that they are made of rare or valuable materials like silver, tellurium, or indium which are hard to recycle because very few facilities exist for doing it. Lack of skilled workers and Lack of technical know-how are other very significant barriers to solar energy adoption. Since it is a new technology not many trained professionals are available who can satisfy developing needs for establishment, support, investigation, repair, and assessment of solar power systems. Furthermore, the credibility of cracks inside the PV module, water interruption, vulnerability to dust, and algal development can incredibly bring down the performance of the system (Kabir *et al.*, 2017).

Other shortcomings of solar energy are that it is not solid source of energy in regions which have unsustainable climate or atmosphere conditions. Since it can only be harnessed amid the day it is most effective on bright days. Air pollution can also affect the effectiveness of the solar cells (Radivojevi *et al.*, 2015). Last but not the least large scale solar power plants require a large amount of area which is an important barrier especially for highly populated countries like India which have land scarcity.

### 2.1.2. Wind Energy

Wind energy refers to capturing the energy from moving air i.e. wind and converting it into electricity. National Geographic defines it as the energy produced by the movement of air and converted into power for human use. Hartviksen in an article on Student Energy website defines it as the technology that converts the air’s motion into mechanical energy usually for electricity production. The US Department of Energy gives a more detailed definition of Wind Power: *“It is a form of solar energy. Winds are caused by the uneven* *heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetative cover. This wind flow, or motion energy, when "harvested" by modern wind turbines, can be used to generate electricity".* Ellaban *et al.* (2014) define wind power as 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 art of harvesting wind power is not a new idea for the human civilization. Humans have been harvesting wind power since the time of the Pharaoh. The Egyptians in 3500 B.C. invented sail boats which were depended on the wind to travel. Even the use of wind mill is not new. In 2000 B.C., the Chinese use to use the wind mill to pump water. Between 500 A.D. and 900 A.D. the Persians enhanced the ability of the windmills. Now they were not only used to pump water but also to crush the grains. (Tajne, 2015)

These ingenious machines found in Persia were conveyed to different parts of the world including China and India where farmers utilized them to siphon water, pound grain and pulverize sugarcane. Autonomously the post mills emerged in England. In contrast to their Persian partners, which pursue a merry go round's way around a vertical axis, the conventional European windmill pursued a way around the horizontal axis. The whole assembly of the post mill, including the blades, axle, and milling cabin, lays on a vertical post. The mill arranged the post mill into the wind by swinging the whole windmill around the post, thus the name post plant. In 1137 A.D., William of Almoner designed and built the first mill in Leicester, England. (Pasqualetti *et al.*, 2004)

By 1300 A.D. the post mill had made inroads to rest of Europe. The Dutch transformed the mill into more power and elaborate mill called the 'Tower Mill'. It was invented in the year 1390 A.D. These recently overhauled mills could accomplish something beyond siphon water and crush grain. They reduced pepper and other spices, cocoa, colors, chalks and pigments. Timber mills utilized them as essential power for sawmills and the paper organizations utilized them to reduce wood mash to paper. Amid the golden time of European windmill, the Dutch alone utilized 10,000 tower mills. One source even estimated that the mills use to provide 25% of the industrial energy of Europe from 1300 A.D. till the entry of steam engine and cheap coal which was around 1800 A.D. (Pasqualetti *et al.*, 2004)

The demand for the windmills in Europe started to decline during the period of Industrial Revolution. But during the same time around mid-1800s the settlers started to establish windmills in the newly found continent of America. In the meantime, in 1850s the U.S. Wind Engine Company was built up by John Burnham and Daniel Halladay. Since the European mill was labor intensive and bulky, they construct the Halladay Windmill which was intended for the West American landscape.

In July, 1887 Professor James Blyth built the first electricity generating windmill in Glasgow, Scotland. He made three turbine plans and the last one is said to have powered his home for a long time. Amid that year Professor Charles Brush built up a 12kW wind turbine to charge 408 batteries kept in his mansion. The turbine was utilitarian for a long time and had a rotor distance across of 50m and 144 rotor blades (Tajne, 2015). Before the finish of the nineteenth century six million windmills were purportedly introduced all over America. The World Fair in Chicago had the participation of 15 windmill organizations with their turbine plans.

By the 1920s Wind turbines started to give power to a huge number of country areas over the Great Plains. The design by Professor Charles was very bulky and not commercially viable. Many different companies came up with different designs. Amongst them the most successful was Jacobs Wind Company, established by brothers Marcellus and Joe Jacobs in the year 1927. The firm created wind turbine generators which were utilized to control lighting and charge batteries on farms.

In 1931, the Russians developed first commercial power plant which utilized wind turbines to produce power. In 1941, to battle fuel deficiency the world's first megawatt-size wind turbine began activities in Vermont. Be that as it may, by the 1950s the majority of the wind turbines were closed down in Europe and America because of the entry of increasingly moderate fossil fueled stationary engines and widespread rural electrification.

Things changed when the cost of petroleum derivatives sky rocketed during the oil crisis of 1970s. This oil crisis again created interest in Wind turbines as an alternative. In 1971, the first seaward wind farm on the planet started its activity of the shoreline of Denmark. US Department of Energy is shaped in 1977 and the National Renewable Energy Laboratory started its activities. By the 1990s the world became more interested in renewable energy due to increasing public concern about the environmental issues like Global Warming.

In 2000s the cost of power produced by Wind Turbines was 4 to 6 cents for each kWh. In 2001, Wind energy capacity had come to 24,800 MW and generated a revenue of approximately 7 billion U.S. Dollars. By 2006 the capacity increased to 74000 MW and the price reduced to 3 to 4 cents per kWh. By 2008 due to Paris World Accords the global wind energy installed capacity crossed 94000 MW. By 2009, By 2009, Wind energy gave 2% of the worldwide power requirement. In 2014, Wind Energy alone contributed 20-30% of the yearly power demand of countries like Denmark and Spain. Wind Energy market is developing quickly around the globe.

By the first decade of the 21st century wind power had turned into the best hope for future of alternative power. Of all the conceivable "new" sources of power it had surprisingly wound up as the most touted and quickest developing alternate source of energy in many nations like USA, Denmark, Germany and Spain. (Pasqualetti *et al.*, 2004)

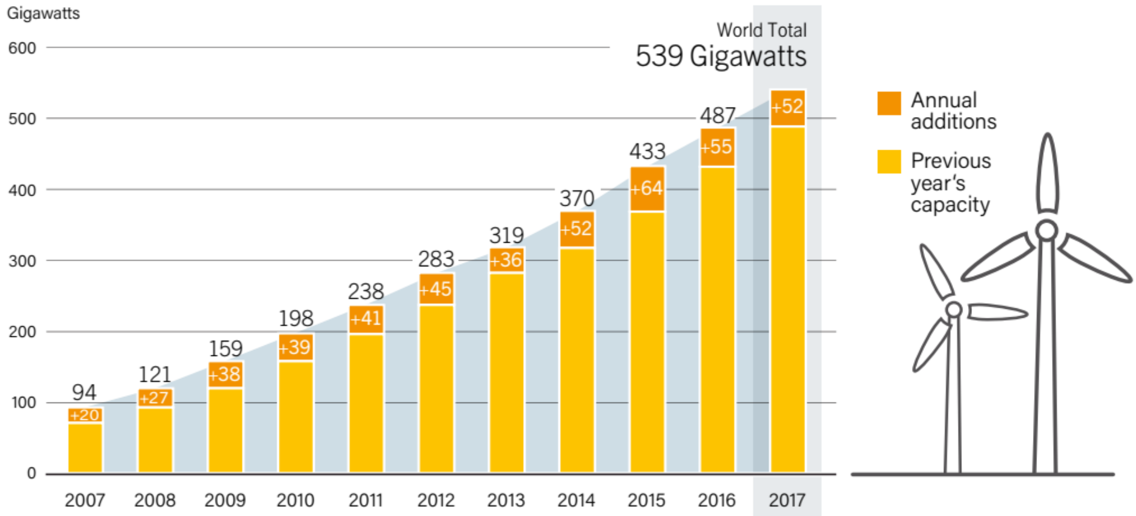



Figure 2. 7. Wind Power Global Capacity & Annual additions 2007-2017 (Renewables Global Report, 2018).

*Figure 2.7* shows the global capacity of wind power and annual additions. The total capacity reached 539 Gigawatts in 2017 which was an increase of 11% from the previous year. The annual addition declined from 2015 to 2017 is because of the decline of installation in Chinese Wind Sector.

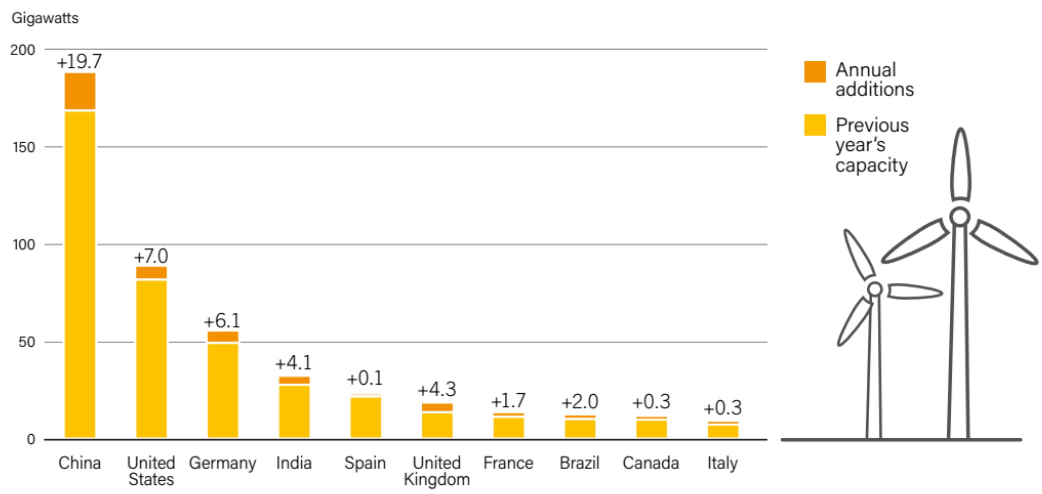
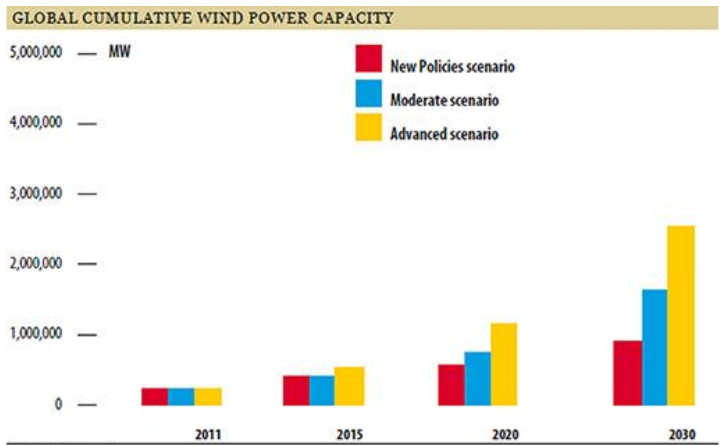



Figure 2. 8. Wind Power Capacity and Additions, Top 10 countries, 2017 (Renewables Global Report, 2018).

*Figure 2.8* shows the Wind power capacity and additions in top 10 countries of 2017. It can clearly be seen that China has surpassed every other competitor and is still growing at a better rate than other countries.




| | | 2011 | 2015 | 2020 | 2030 |
|---|---|---|---|---|---|
| **New Policies scenario** | | | | | |
| | [MW] | 237,699 | 397,859 | 586,729 | 917,798 |
| | [TWh/a] | 583 | 976 | 1,439 | 2,412 |
| **Moderate scenario** | | | | | |
| | [MW] | 237,699 | 425,155 | 759,349 | 1,617,444 |
| | [TWh/a] | 583 | 1,043 | 1,863 | 4,251 |
| **Advanced scenario** | | | | | |
| | [MW] | 237,699 | 530,945 | 1,149,919 | 2,541,135 |
| | [TWh/a] | 583 | 1,302 | 2,821 | 6,678 |

Figure 2. 9. Global cumulative wind power capacity to 2030 (GWEC, 2016).

In 2016, the GWEC delivered a progression of worldwide wind energy standpoint situations (GWEC, 2016) to look at the future potential for wind energy up to 2020, 2030 and 2050. They depended on following situation presumptions; a New Policies Scenario (NPS) in view of the projections by the International Energy Agency 2009 (IEA); An *IEA*

*450 Scenario* based on an optimistic interpretation of the implementation agreements in the Paris Climate Agreement; GWEC's Moderate Scenario (MS) mirrors a world which continues pretty much the manner in which it has for as far back as decade; GWEC's Advanced Scenario (AS) which utilizes progressively yearning suppositions about the capacity of wind vitality to deliver in excess of 33% of worldwide power request by 2030. *Figure* 2.9 shows the estimated increase in global cumulative wind power capacity based on the mentioned scenarios.

The development of wind is a significant hotspot for world's energy and has taken an instructing lead among renewable sources (Owusu *et al.*, 2016). Like Solar Energy it is also available everywhere and is unlimited.

2.1.2.1. Benefits- There are numerous advantages of utilizing wind energy. Most importantly, wind is a green source of energy and does not cause contamination like its petroleum product partners. The capability of Wind Energy is around multiple times more than the prerequisite of the whole human populace (Maehlum, 2018). It reduces the fossil fuel consumption. Wind Energy is free of expense and consequently can be utilized by anybody.

Wind Turbine does not require a lot of land. Consequently, they are not simply restricted to industrial scale installations; they can be introduced on a local scale. Numerous landowners introduce little, less ground-breaking turbines. They are mostly constructed in fields, on hills or out at sea. Wind Power can also be a very convenient source of energy for remote areas where the electricity lines have not reached.

Wind Energy is amongst the cheapest form of renewable energy resource. This cost is coming down every year and the governments have also started to provide more incentives in the form of subsidies. Wind control represents about 2.5% of absolute overall power generation, yet is developing at a promising rate of 25% every year as indicated by 2010 information (Maehlum, 2018).

Ellaban *et al.* (2014) listed some of the advantages of wind energy. It is a free source of energy, doesn't cause air or water contamination, wind farms are cheap to construct and the land around the wind farms can be utilized for different purposes.

2.1.2.2. Limitations- Wind is a fluctuating source of energy and isn't fit to meet the base load energy demand except if some type of energy stockpiling is used. The assembling and installation of wind turbines requires overwhelming forthright venture costs in both private and business applications (Maehlum, 2018). Good wind sites are located in remote areas and transmission lines are required to transfer the electricity to where it is required.

The clamor brought about by working coastal wind turbines, and their visual effect can be a noteworthy disturbance to individuals' lives (Lee *et al.*, 2011). The peril of wind turbines to birds is a worry to numerous animal lovers, as wind farms might be worked in the birds' natural surroundings. As the size of wind farm increases and becomes bigger, there are a few theories that they may cause changes in the nearby atmosphere (Leung *et al.*, 2012). Ellaban *et al.* (2014) likewise distinguished comparative limitations. As indicated by him the fundamental limitations are that it requires a lot of land and consistent huge measure of wind, can impact sly affect scenes, and needs better approaches to store energy.

Offshore Wind Farms which is new technology when compared to onshore wind farms can help eradicate most of the mentioned disadvantages. The wind blows harder and stronger in the sea and hence can be more reliable. Since they are built very far away from shore and human life, the noise and visual impact on the landscape can be ignored. But one more disadvantage comes with the offshore wind farms. Some of the research have found that they affect the lives of the sea animals. (Leung *et al.*, 2012)

### 2.1.3. Hydropower

Muise in an article on hydropower on Student Energy defined Hydropower as the conversion of energy from flowing water into electricity. Cambridge Dictionary also has a similar definition of hydropower. It defines hydropower as the production of electricity by the force of fast moving water. National Geographic also gives a similar definition of hydropower. It defines it as the electricity generated using the energy of moving water. OECD also gives a similar definition. It defines it as electricity generation using the power of falling water. International Hydro Power Association (IHA) defines hydropower as the power derived from the force of moving water widely used to produce electricity, among other useful purposes.

Origin an Australian website on energy gives a more elaborate definition of hydropower. It defines hydropower as the form of renewable energy that uses the water stored in dams, as well as flowing in rivers to create electricity in hydropower plants. Willie Scott of Bright Hub Engineering in an article titled "What is Hydropower Electricity? Definition Energy, Power Plant, Turbines" described hydropower as the producer of electricity which produces electricity by using a stored supply of water from a reservoir, which runs down large bore pipes known as penstocks, into water turbines located below the reservoir.

The US Department of Energy gives a refined and concise definition of Hydropower. It defines it as the harnessing of flowing water—using a dam or other type of diversion structure—to create energy that can be captured via a turbine to generate electricity.

The human civilization has been gathering water to perform labor for a large number of years. The Greeks had been utilizing water wheels for pounding wheat into flour over 2000 years prior. Other than the pounding of flour, it was additionally used to saw wood and power textile mills and manufacturing plants (U.S. Department of Energy). The National Geographic Channel explains the process followed by these Greek mills. It clarifies that the water wheels were put in streams and were utilized to get streaming water in cans situated around the wheels. The kinetic energy of the streaming water was along these lines used to transform the haggle it into mechanical energy which used to run the mills.

In a report by International hydropower affiliation titled "A short history of hydropower", China amid the Han Dynasty between 202 B.C. and 9 A.D. utilized excursion hammers which were powered by the vertical set water wheel were utilized to pound and structure grain, break ore, and in early paper-production.

There was very little improvement in this division from the time of Greeks and Chinese till mid-1770s. In mid 1770s, the advancement of the modern hydropower turbine starts to come to fruition when a French hydraulic and military specialist, Bernard Forest de Belidor composed a book of four volumes titled Architecture Hydraulique which portrayed the vertical axis and horizontal axis machines. The report by International hydropower affiliation likewise makes reference to Richard Arkwright who set up Cromford Mill in England's Derwent valley in 1771 to spin cotton and thus set up one of the world's first factory system. This factory had utilized hydropower as the energy source.

First half of the nineteenth century was the point at which the principal advancements occurred for the hydropower we know today. In the year 1820, the first turbine which was equipped for delivering around 6 horse power known as the Fourneyron reaction turbine was created by a French architect, Benoit Fourneyron (Duedney, 1981). This was trailed by the advancement of the main present day turbine known as the Francis turbine which was created by British-American Engineer James Francis in 1849. This turbine is as yet the most broadly utilized turbine today.

There were numerous different advancements in the turbine area in the next years. Some striking ones are the turbine created by American innovator Lester Allan Pelton who built up a drive water turbine otherwise called the Pelton wheel in 1870s and that created by Austrian Professor Viktor Kaplan known as the Kaplan Turbine, which was created in 1913 and was a propeller type turbine with adjustable blades.

In 1878, the main hydroelectric project was utilized to power a single lamp in the Cragside Country house in Northumberland, England. In the following four years the first plant to serve an arrangement of private and business clients was initiated in Wisconsin, USA. From that point forward, in 10 years several hydropower plants were operational. A portion of the spots wherein earliest hydropower plants constructed on the planet are Grand Rapids, Michigan (1880), Ottawa, Ontario (1881), Dolgeville, New York (1881), and Niagara Falls, New York (1881). They were utilized to supply power to mills and light a portion of the nearby structures.

Before the end of the nineteenth century the innovation began to spread the world over, with Germany beginning to deliver initial three stage hydroelectricity system in 1891, and the starting of first government owned plant by Australia in the Southern Hemisphere in 1895. In 1895, the world's biggest dam of that time known as the Edward Dean Adams Power Plant was constructed at Niagara Falls.

With an installed capacity of 500kW, a hydroelectric plant was based on the Xindian creek close to Taipei in the year 1905. This was before long pursued by the development of the principal station in the Yunnan Province of Mainland China, known as the Shilongba plan, constructed in 1910 and finished in 1912 with an introduced limit of 480kW. This arrangement is as yet operational with an installed capacity of 6MW.

In the first two quarters of the twentieth century USA and Canada drove the route in the field of hydropower designing. In the year 1936, the Hoover dam on the waterway Colorado turned into the world's biggest hydropower plant with a capacity of 1345 MW. In the year 1942, this record was broken by the Grand Coulee Dam which was worked with an installed capacity of 1974 MW in Washington. This Dam at present has an installed capacity of 6809 MW. Huge Hydropower developments were accomplished in Canada, the USSR and Latin America in 1960s through 1980s.

The advancement in the hydropower sector hindered like in some other sectors with the discovery of oil fields in the Middle East which scaled down the cost of oil. This was fortified by the costly expense of gaining land for hydropower ventures. These conditions demonstrated significant slowdown in the hydropower sector. This changed amid the oil crisis of 1973. It produced another enthusiasm for the production of power utilizing the running water. The rising energy costs had additionally started enthusiasm for to a great extent overlooked innovation that was not subject to the development of dams. As per an article by David Duedney written in September, 1981, amid the medieval times, before the dams ended up normal, water wheels fastened to freight ships secured in streams were generally being utilized to deliver power. These floating hydropower plants did not require costly and naturally problematic dams, a few nations began to endeavor to modernize this old system and asses its expenses.

In recent decades, Brazil and China have developed as world pioneers in the division of hydropower. The Itapúa Dam, which is straddling Brazil and Paraguay, was initiated in 1984 with a capacity of 12,600 MW. This Dam was additionally moved up to a capacity of 14000 MW and is just second to Three Gorges Dam which has a capacity of 22,500 MW and was initiated in 2008 in China. This section is summarized by Table 2.4.

Hydropower takes the greatest share of the renewable power source utilized on the planet today. In 2004, hydropower plants with a capacity of more than 10MW accounted for 90% of the total electricity by renewable source. The projects under development could expand the share of hydropower in production of power by renewable sources by 4.5% upon completion (Sims, 2008). Global additions to hydropower by the end of the year 2017 were estimated to be 19 GW bringing the absolute capacity to roughly 1114 GW. Despite the fact that this is a noteworthy addition however it has been the most reduced over the most recent five years. The main nations for total limit China, Brazil, Canada, The United States, Russian

Federation, India, and Norway-has stayed same in for quite a long while. These countries represented 63% of the total installed capacity at the end of the year (Renewables Global Report, 2018). *Figure 2.10* shows the hydropower global capacity of different countries. In 2017, the total generation, which varies according to annual hydrological conditions, was 4185 TWh worldwide. This was a 2% increase from the year 2016. There was also a 2% increase in the Global pumped storage capacity in 2017.

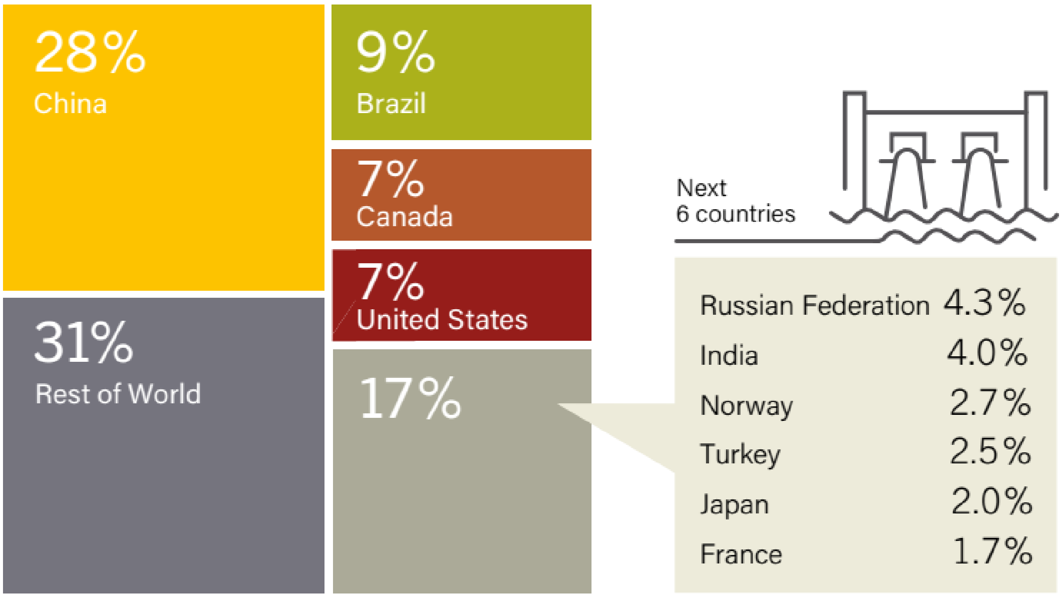



Figure 2. 10. Hydropower Global Capacity, Shares of Top 10 Countries and Rest of World, 2017 (Renewables Global Report, 2018).

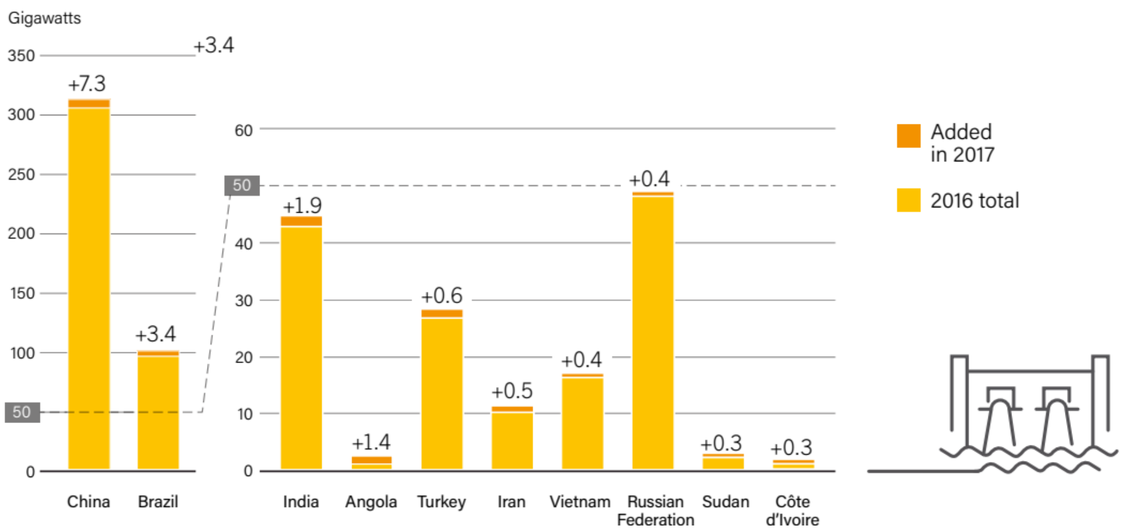



Figure 2. 11. Hydropower Capacity and Additions, Top 10 Countries for Capacity Added, 2017 (Renewables Global Report, 2018).

China remained a forerunner in commissioning new hydropower capacity. China represented 40% of new installations in 2017 and was trailed by Brazil, India, Angola and Turkey. Different nations that additionally included significant installations included Iran, Vietnam, the Russian Federation and Sudan. *Figure 2.11* demonstrates the hydropower capacity and increments of top 10 nations. (Renewables Global Report, 2018)

As indicated by Renewables Global Report the hydropower business is centered around the modernization and digitalization of the current and new facilities. In 2017, Sustainable Energy for All (SEforALL) and the International Hydropower Association (IHA) consented to an arrangement to counsel on the idea of a Hydropower Preparation Facility, which would help national governments in organizing potential hydropower ventures as per their surveyed manageability, before putting them out to tender to the private firms (Renewable Global Report, 2018). *Figure 2.12* gives an approximate idea of the potential of hydropower in different countries.

| | HEP Potential Theoretical (TWh/a) | Feasible HEP Potential Technical (TWh/a) | Feasible HEP Potential Economical (TWh/a) |
|---|---|---|---|
| Africa | 4,000 | 1,750 | 1,000 |
| Asia (incl.Russia,Turkey) | 19,300 | 6,700 | 3,600 |
| Australia | 600 | 270 | 105 |
| Europe (excl.Russia,Turkey) | 3,220 | 1,225 | 775 |
| North & Central America | 6,330 | 1,657 | 1,000 |
| South America | 7,020 | 2,720 | 1,600 |
| **World** | **40,470** | **14,322** | **8,080** |

Figure 2. 12. World Hydropower potential (Gürbüz, 2006).

<u>2.1.3.1. Benefits-</u> If we go by the definition of renewable energy as the technology which is non consumptive in the generation of energy then Hydropower can certainly be considered as a renewable source of energy but some of the individuals have the view that it is not a renewable source of energy because of the serious effect it has on the natural resources like fish (Frey *et al.*, 2002). Frey *et al.* (2002) rejected this as an issue of sustainability rather than renewability.

The thing that separates hydropower from other renewable sources of energy is that it leaves substantial positive legacies like canals, tunnels, dams, reservoirs, access roads etc. to future generations, as well as some negative ones like consumption of large quantities of land etc. (Frey *et al.*, 2002).

Hydropower is an abundant, clean and safe source of energy. It tends to be effectively put away in reservoirs and is generally reasonable approach to create power. It additionally offers recreational advantages like sailing, angling and so forth. (Ellaban *et al.*, 2014). U.S. Department of Energy additionally gives comparable advantages like Omar Ellaban in detail. Hydropower is energized by water, so it's a clean source of power for example it would not contaminate the air like power plants that consume petroleum products. It likewise creates various different advantages, for example, flood control, irrigation, and water supply. (U.S. Department of energy). The benefits of hydropower energy are categorized into three types- Economic, Social and Environmental.

(i) Economic Benefits: Hydropower gives low working and support costs, long life expectancy (50,100 years and that's only the tip of the iceberg), most noteworthy energy efficiency rate and dependable service. It incorporates demonstrated technology, makes business openings, and spares fuel. It additionally impels and cultivates local advancement (Yüksel, 2010)

Hydropower is a local source of energy which enables each state to create their very own power without being dependent on universal fuel sources. The power produced through it depends on the water cycle that is driven by sun along these lines making it a sustainable source of power and a more solid and moderate source than the non-renewable energy sources which are being drained. Some hydropower plants can rapidly go from zero capacity to highest yield which can give fundamental back up amid real power shock or disturbances (U.S. Department of energy). Hydropower also has other economic benefits like job creation, increased agriculture production and new business development (Bonneville Power Administration).

(ii) Social Benefits: Yüksel (2010) has stated many social benefits of hydropower. Hydropower leaves water accessible for other uses, enhances the accessibility of the territory and its resources, improves the living conditions, and sustains livelihoods by providing fresh water and food supply. It also often provides flood protection and enhances recreation. It may also enhance navigation conditions. (Yüksel, 2010)

A hydropower facility produces a great deal of income from the utilization of a characteristic asset for example stream and questions definitely emerge about sharing of the incomes among the neighborhood networks, the administration, and financial specialist in the plant. Some countries allow the water rights to be owned whereas some allow it to be leased and yet in some other countries these rights are owned by the government. Apart from the legal provisions all the parties have to have the good will and cooperation of the local communities and hence the local communities get some share of the benefits that may in the form of job creation, improvement of roads and other infrastructure, sharing of revenues, and payment of local taxes (Koch *et al.*, 2002). Apart from the revenues, the water resources are also often shared among various sectors. It is shared with the farmers for irrigation. It is also shared with inland fisheries. It also helps in flood control, navigation, recreation and tourism, etc (Koch *et al.*, 2002). Some other indirect social benefits are that Hydropower helps in the water supply sanitation and health in downstream villages, and electrification of rural areas since the facility is mostly in rural areas

(iii) Environmental benefits: Hydropower delivers no pollutants aside from some GHG outflows. It improves air quality and creates no waste. It likewise abstains from draining nonrenewable fuel assets and frequently makes new freshwater biological systems with expanded profitability. Hydropower is likewise fundamental in increasing the knowledge and in improving administration of esteemed species because of study results. It hinders environmental change and neither devours nor dirties the water that it utilizes with the end goal of generation of power (Yüksel, 2010).

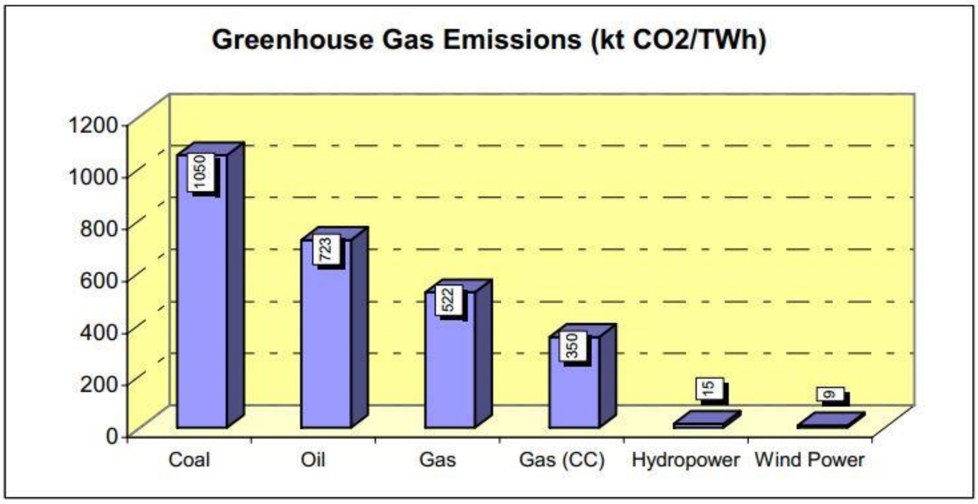



Figure 2. 13. Greenhouse gas emissions by different sources of energy (Gürbüz, 2006).

A Brochure titled “Hydropower and Environment” which was developed under SHERPA project, funded by the European Union also mentions some environmental benefits of hydropower. The presence of trash rack cleaning machine installed in Dams helps in the removal of anthropogenic waste from the water for free. Raising the river banks near to the diversion works and presence of a storage basins helps in protection from floods. (Gollessi *et al.*) *Figure* 2.13 shows the GHG for different sources of energy and it is clearly seen that emissions by hydropower are very negligible.

2.1.3.2. Limitations- Hydropower also has many limitations or disadvantages. It can cause flooding of surrounding communities and landscapes; can only be used where there is water supply; can have major ecological impact on local hydrology; and the best sites where the hydropower plant can be constructed have already been developed (Ellaban *et al.*, 2014). Like the benefits the limitations would also be categorized into three categories- Economical, Social and Environmental.

(i) Economical limitations: Hydropower requires high upfront investment, long-term planning, long-term agreements, multidisciplinary involvement, and it also often requires foreign contractors and funding. Hydropower also gets affected by precipitation (Yüksel, 2010). Dams are very expensive to build and must be built to a very high standard and this requires them to operate many decades to be able to become profitable. Therefore, the only economic disadvantages of hydropower are that it requires a high initial investment and requires decades to recover this investment. The other economical disadvantages that are worth mentioning are that the countries which have the maximum potential for hydropower are densely populated countries like India, Brazil etc. and the land prices are very expensive in these countries. Therefore, this is a major disadvantage of hydropower that it requires large amount of land for construction and mostly these lands are in areas which are already developed.

(ii) Social Limitations: Hydropower plants may require resettlement of neighborhood areas around the territory it is constructed. It might likewise require the land use examples to be adjusted. Waterborne illness vectors might be required to be checked. It can also restrict navigation. It also requires the management of competing water uses. (Yüksel, 2010)

Hydropower projects often necessitate the involuntary displacement of people from the area to be inundated (Koch, 2002). The expropriations of these people have become difficult in recent years. This is the result of too many instances where displaced populations were not treated fairly or humanely. This has given rise to public sympathy for these people and given rise to many protests. One example of such instance is the protests against the

Sardar Sarovar Dam in India which had also led to delays in the construction of this dam. Enormous water system extends that incorporate numerous trench with dormant water can prompt water-borne infections particularly in tropical regions (Koch, 2002). The subject of fisheries is both an ecological and social issue, the natural issue would be examined in the coming subtopic. The social viewpoint includes inland fisheries as a job, wellspring of protein in the eating regimen or a recreational asset (Koch, 2002).

(iii) Environmental limitations: Hydropower plants cause immersion of earthly living space, changes of hydrological routines, alteration of amphibian territories, and hindrances for fish movement and fish diversion. It likewise requires the management and monitoring of quality of water, temporary introduction of methylmercury into the food chain, species activities and populaces, and sediment composition and transport (Yüksel, 2010). Hydropower causes preoccupation of water which results in the alteration of natural surroundings because of intrusion of spatial and fleeting congruity of waterways, formation of boundary for fish entry, and demise of a specific level of fish going through the turbine and causes genuine ramifications on the aquatic ecosystem and the environment in general (Gollessi *et al.*). Hydropower can have negative effects on aquatic and riparian ecosystems, and these hindrances must have weighed against the points of interest (Koch, 2002).

### 2.1.4. Geothermal Energy

The term Geothermal originates from two Greek words ‘GEO’ and ‘THERM’. The Greek word ‘Geo’ means the earth and ‘Therm’ means heat from the earth. Geothermal energy is the energy derived from the heat of the earth (Bagher *et al.*, 2014). Many other authors defined geothermal energy in different words. Geothermal energy is the energy contained as heat in Earth’s interior (Barbier, 2002). Geothermal energy is heat that is stored in the subsurface and is a renewable resource that can be sustainably exploited (Limberger *et al.*, 2018). Geothermal energy is thermal energy produced naturally in the planetary interior, principally by the decay of radioisotopes of potassium, uranium and thorium (Younger, 2015).

Geothermal energy is the thermal energy stored in the underground, including any contained fluid, which is available for extraction and conversion into energy products

(Manzella, 2017). Geothermal energy resources are associated with a variety of geological settings, are available at temperatures ranging from a few tens of degrees to several hundred degrees and may be used for the provision of heat, power or both (Adams *et al.*, 2015).

The immediate utilization of geothermal energy is one of the most established, most flexible and normal type of use of geothermal vitality (Dickson *et al.*, 2005). The early history of geothermal direct use has been checked on for more than 25 nations in the Stories from a Heat Earth – Our Geothermal Heritage (Cataldi *et al.*, 1999), that archives geothermal use for more than 2000 years (Lund *et al.*, 2011). People have had a long history of utilizing geothermal vitality for heating, cooking, and washing (Limberger *et al.*, 2017)

The government of Alberta on its website as well as journal by Stober and Bucher (2013) titled *"History of Geothermal use"* has described the history of geothermal power and it will be used as a source for writing this section of the study. Geothermal energy is one of the oldest energy which used by human beings. There is archeological evidence that suggests that the earliest direct use of geothermal energy occurred at least 10,000 years ago by the indigenous peoples of North America who were drawn to hot springs for both spiritual and practical reasons (Govt. of Alberta). The hot springs were viewed by many in the indigenous communities of North America as sacred places and were considered as sites of healing; believing that soaking in warm spring water brought a wide range of health benefits. This attracted the people to the springs thus making them gathering side for different people and offering opportunities for trade, diplomacy and cultural exchange. It was also used by some people for mundane reasons like cooking food or providing refuge from winter (Govt. of Alberta). The people of ancient Greece and Rome also viewed hot springs as places of healing imbued with sacred power. Hippocrates (460-320 B.C.), a Greek physician, promoted the benefits of hot bathing. Pliny the Elder (23-73 B.C.), the Roman author, wrote about the particular benefits of hot mineral baths for people suffering from muscle, joint, or paralytic ailments. Shrines were built by Romans at hot springs that yield archaeological evidence that people sought to communicate with the gods. For example, at the shrine to the Roman goddess Minerva at Bath archaeologists have found 130 lead tablets upon which people had written various requests to the gods for assistance. (Govt. of Alberta)

Similar to the indigenous peoples of North America the Romans used geothermal energy for practical applications such as providing space heating for buildings. In the Roman Empire, the middle Chinese Dynasties and the Ottoman Empires spas have been focuses of balneological utilization of hot springs, where physical wellbeing and cleanliness have been joined with social and political discussion and advancement of the time (Stober *et al.*, 2013). Historical documents written by the Romans, Japanese, Turks, Icelander as well as people of Maori in New Zealand describe the occurrence and utilization of hot springs for cooking, bathing, and heating the house. Historical records of China on thermal springs which includes the therapeutic instructions and farming guides go back up to as far as the 4$^{th}$ and 6$^{th}$ century. An example for this is the diversion of thermal water to the field rice crops permits the first harvest already in March and resulted in three harvests in the year. In 1530, the temperature in underground mines increased with depth was realized by Agricola. In 1560, an account of the spas of southern Germany (“Badenfahrtbüchlein”) and instructions how to use them was published by Georgius Pictorius (Stober *et al.*, 2013). In 1818, French Engineer François Jacques de Larderel the Tuscan region of Italy pioneered a new way to extract boric acid from hot springs. Other people use to extract boric acid using fire to evaporate water François Jacques de Larderel was the first to harness the region’s geothermal energy to drive the process. The town that had grown around the industrial production of boric acid, Larderello, was also home to the first successful effort to produce electricity with geothermal energy.

In 1890, by completing district heating system early systematic geothermal heat utilization was accomplished in Boise, Idaho, USA. In1900, this system was copied by Klamath falls, Oregon, USA. In 1926, the use of geothermal well was started at Klamath Falls to heat green houses. (I. Stober *et al.*, 2013). In 1904, in the Larderello area of Tuscany, Italy, the beginning of the geothermal energy as we know today is marked by the first successful attempt to power light bulb with electricity converted from geothermal heat (Fridleifsson, 2001, DiPippo, 2015). In 1914 the first geothermal power plant went into operation in Larderello, Italy. It had a 250kW installed capacity. The installed capacity increased to 15MW in 1915 and was primarily driven by saturated steam. In 1920s, the use of warm water for warming homes and nurseries began in Reykjavik, Iceland. Geothermal warming of open structures and whole city regions pursued. In 1958, after the advancement in geothermal power in Italy and Iceland, New Zealand built its first geothermal plant in Waireki. In 1959, an experiment facility was built up in Pathe, Mexico. In 1960, California started the task titled "The Geysers", which involved 21 power stations with an aggregated capacity of 750MW (Stober *et al.*, 2013). Due to availability of alternate cheap sources of energy geothermal sector saw many setbacks. Many countries like Greece and Argentina shut down their geothermal facilities due to environmental and economic reasons. Then the oil crisis of 1973 renewed interests in alternate sources of energy. In 1980, Germany drilled deep wells for geothermal installations. Economic crisis followed by the collapse in prices of oil halted further development in geothermal sector. This halt was for a short period. Renewed interest in geothermal energy started when people came to know about dwindling fossil fuel resources. In the year 2003, Germany began first electrical energy creation from a geothermal source in Nuestadt-Glewe. In 2007 the geothermal wells of Landau and in 2009 the wells in Bruchsal that were bored in 1980s began to deliver electrical power.

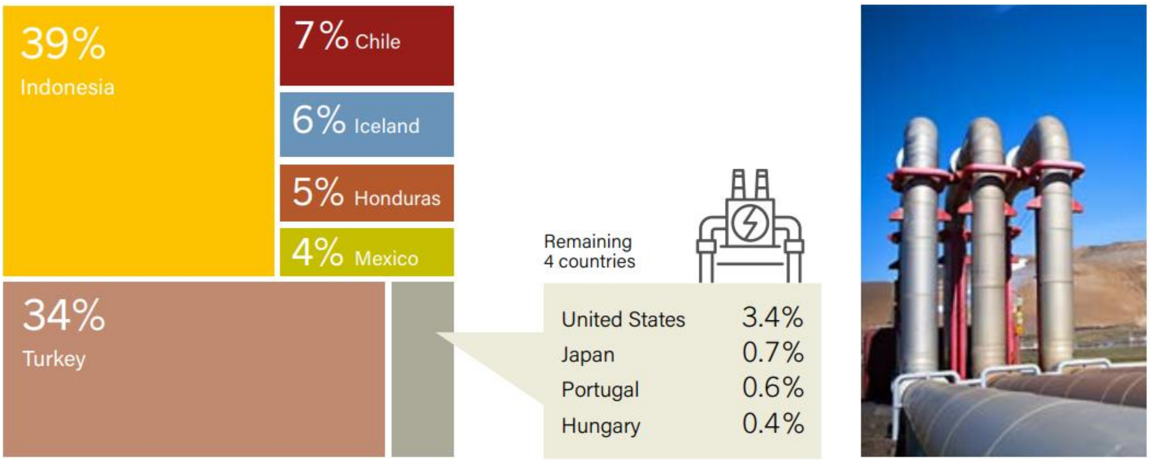



Figure 2. 14. Geothermal Power Capacity Global Additions, Share by Country, 2017 (Renewables Global Report, 2018).

Geothermal resources provide both electricity and thermal energy services. The total useful energy estimated in 2017 was 170TWh. Electricity and thermal energy have about equal share in this output. But the estimates of thermal energy consumption in other words direct use of geothermal energy is uncertain due to lack of data. Some geothermal plants provide both electricity and thermal output for various heat applications. Approximately 0.7GW of capacity of new geothermal power was added in 2017 which brought the total estimated capacity to 12.8 GW. Indonesia and Turkey are leading other nations in new installations. Together they account for 73% for new capacity during the year 2017. Other countries arranged in decreasing order of new capacity installations are as follows; Chile, Iceland, Honduras, Mexico, the United States, Japan, Portugal and Hungary (*figure 2.14*). *(Renewables Global Report, 2018)*

The countries with highest installed capacity, as of 2017, in decreasing order are as follows; the United States, the Philippines, Indonesia, Turkey, New Zealand, Mexico, Italy, Iceland, Kenya and Japan (*figure 2.15*).

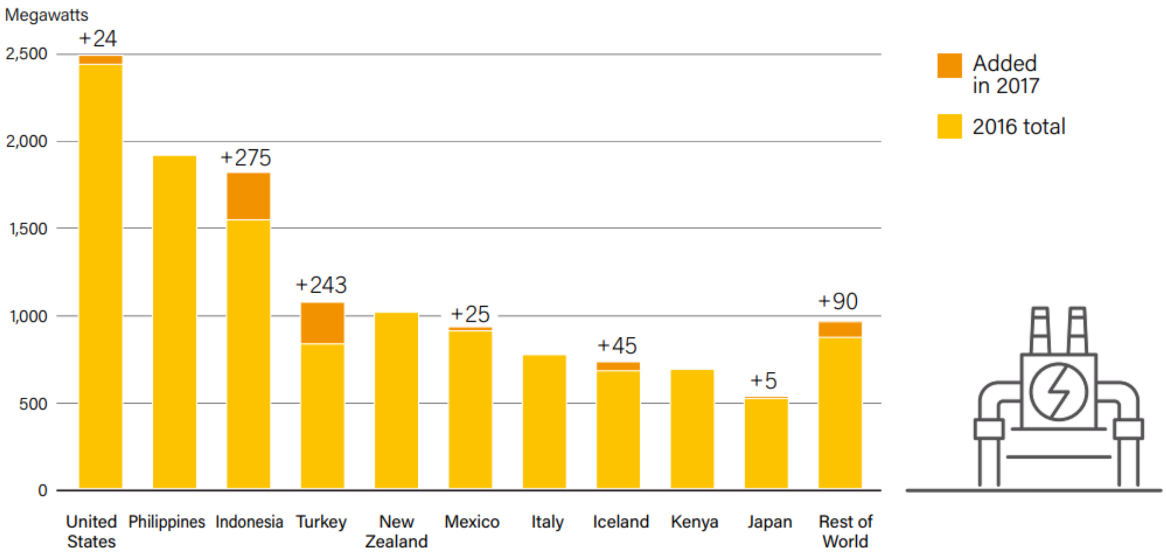



Figure 2. 15. Geothermal Power Capacity and Additions, Top 10 Countries and Rest of World, 2017 (Renewable Global Report, 2018).

New methods of resource exploration and extraction are assisting to overcome some of the economic and technical challenges that stand in the way of further development. Continuing innovation in technology especially in United States and Europe has raised the prospects of geothermal resources in the field of exploration and development that were out of reach. There has been significant development even in the areas with low geothermal gradient by reaching deeper in the earth and by better means of heat extraction. (Renewable Global Report, 2018)

There are many areas in which research has been going on, some worth mentioning research are as follows; US government funded research on enhanced geothermal systems (EGS) to enhance the technology; Ongoing research in Europe on deep geothermal extraction with the objective of improving these deep geothermal resources for combined heat and electricity production in more locations; Research on Emissions mitigation technologies to assess technical challenges and opportunities related to the capture and reinjection of $CO_2$ and $H_2S$ emissions; Iceland's CarbFix project which has made headway in tackling $CO_2$ emissions; Research in US regarding the production of geothermal energy from abandoned oil and gas wells or the abandoned mines to mitigate incremental drilling costs; The IEA has estimated geothermal production to be 5.8 EJ per year for heat (3.9% of projected world final energy for heat) and 1400 TWh per year for electricity (3.5% of projected world electricity production) for the year 2050 (Limberger *et al.*, 2018). IEA also estimates that if this production is achieved it could avoid emission of almost 900Mt per year of $CO_2$. *Figure 2.16* shows the likely case scenario for the growth of geothermal energy.

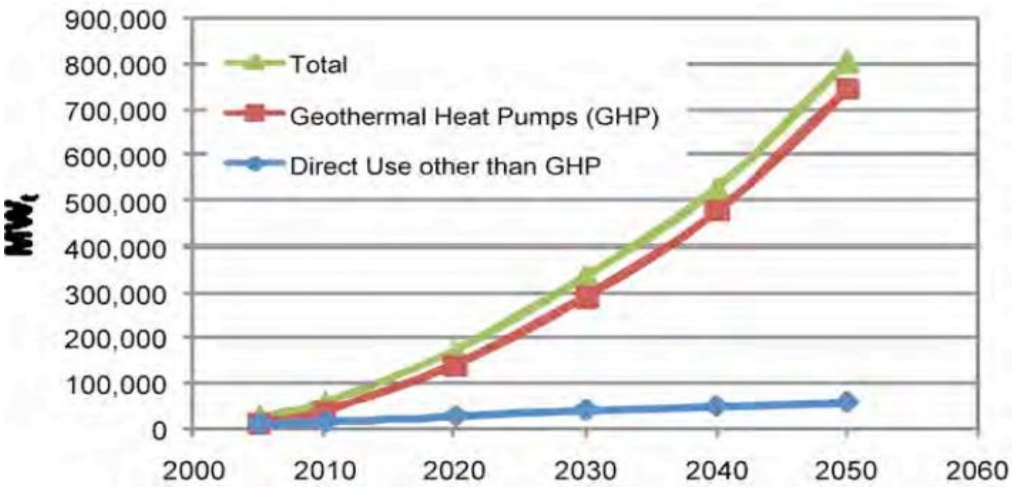



Figure 2. 16. Likely case scenario for growth in direct use and GHP installed capacity, (Fridleifsson et al., 2008).

Geothermal energy like the other renewable sources of energy has many advantages or benefits like reduction in GHG emissions etc. But also has many disadvantages like high cost etc.

<u>2.1.4.1. Benefits</u>- Geothermal energy provides an unlimited supply of energy and produces no air or water pollution (Ellaban *et al.*, 2014). Bagher *et al.* (2014) described many advantages of geothermal energy which are as follows: it is a renewable source of energy; it is relatively environmental friendly and does not produce pollution in the form of fumes although the drilling of earth's surface takes place. The surrounding environment is not harmed with the exception of the land acquired for the power plant and transport links; it can provide constant power unlike many other renewable sources of energy like wind power and solar power which rely on the weather conditions; reduction in the use of conventional polluting fuels like oil and coal; it can be used for electricity generation as well as for heating homes and offices; there is no wastage or generation of by products; maintenance cost of geothermal power plant is very less; it doesn't occupy a lot of space.

Greenhouse gas (GHG) emissions from the electricity generated by geothermal resource are only a fraction of the amounts coming from fossil fuel power plants and are almost same as most renewable energy sources such as hydro and solar energy (Chamorro *et al.*, 2012).

Renewables Global report has also mentioned some of the benefits of geothermal energy in the form of examples. The geothermal brine can contain relatively high penetration of rare earth minerals and metal, these rare materials can be extracted and could add value to geothermal resource attraction. An example for this is the case of SRI International located in United States is developing a technology, with US state and federal funding, to recover the valuable metal Lithium from geothermal brines with a rate of recovery exceeding 90%. Iceland and similar territories bordering the arctic are never known to be major source of fresh vegetables but Iceland has produced them with the aid of heat and lighting sourced from geothermal energy, and is in the final stages to export the produce to Europe.

R. Shortall *et al.* (2015) mentioned many indirect benefits of geothermal energy, which may or may not ultimately be achieved, and divided them into different themes which are as follows: Poverty; Health; Education; Natural Hazards; Demographics; Atmosphere; Land; Forests; Fresh water; Biodiversity; Economic development; Consumption and production patterns.

The positive impacts of geothermal energy on the theme of poverty are increase in the per capita income, salaries and social development initiatives, and provide affordable energy supply, higher living standards, improved food security and access of drinking water. On the theme of health, the positive impacts of it are improved sanitation and medical facilities, lower indoor air pollution, and Therapeutic uses. In the case of education theme geothermal could have is that it could indirectly facilitate the improvement of education facilities and school attendance. Geothermal does not have any positive impact on the theme of Natural Hazards.

In the case of demographics theme it can positively impact in bringing positive social change and increasing tourism. Displacement of GHG from other energy sources can be considered a positive impact by geothermal power on the theme of atmosphere. As was also mentioned before the positive impact on land theme is that geothermal requires very small land as compared to other sources of energy. It could positively impact the replacement of traditional biomass. On biodiversity theme it does not have any positive impact.

In the case of the theme "Economic development" geothermal can impact positively by providing increased energy security, lower climate dependence, high capacity factor, and direct, indirect, and induced economic activity and employment. The last theme namely Consumption and production patterns could be positively impacted by geothermal as waste heat can be cascaded or recaptured.

2.1.4.2. Limitations- The startup cost or development cost of geothermal energy can be expensive and due to the problem of corrosion even the maintenance cost could become high (Ellaban *et al.*, 2014). Some potential negative impacts of geothermal energy could be subsidence, landscape change, polluting waterways and air emissions (Ellaban *et al.*, 2014) like carbon dioxide and hydrogen sulfide.

The disadvantages of geothermal energy are as follows: Only few sites have the potential of geothermal energy; Most of the sites where it is produced, are far from markets or cities, where it needs to be consumed; The total generation potential of it is very low; There is always the possibility of eruption of volcano which is very dangerous; Installation costs is very high; No guarantee that the investment will bear fruit; May release some harmful, poisonous gases that can escape from the holes which were drilled during its construction (Bagher *et al.*, 2014).

Renewables Global Report (2018) also mentioned some of the disadvantages in its report. Geothermal energy as any other renewable source of energy has high upfront cost. By products like $CO_2$ and $H_2S$ are not welcomed by products. The $CO_2$ emission rate is usually low as compared with fossil fuels but in some cases it could significant and can even exceed the emission rates of coal powered plants. An example for this is geothermal power plants in Turkey.

Like the indirect positive impacts Shortall *et al.* (2015) also mentioned indirect negative impacts in the same themes which were mentioned in the previous section. In the theme of poverty geothermal energy can have negative impacts like rising property prices and community displacement. On the theme of health, the negative impacts could be the odor nuisance, toxic gas emissions, water contamination and noise pollution. In the case of education theme, it can have a negative impact by causing sudden or unprecedented cultural change. On Natural Hazard theme the negative impact of geothermal power is that it can be the reason for induced seismicity, subsidence, and hydrothermal eruptions. It can cause negative cultural impact, resettlement, and livelihood displacement when looked at the Demographics theme. By looking at the atmosphere theme, Shortall *et al.* (2015) conclude that due to GHG, toxic and $H_2S$ emissions it can have a negative impact.

In the case of Land theme, the negative impact which geothermal energy can have are causing habitat loss, soil compaction and conflict with other land uses. It can cause deforestation and ecosystem loss when we look at the negative impact on forest theme. There could be a conflict with other energy uses and Contamination of shallow aquifers and other water bodies can be described as negative impacts on the theme of freshwater. It can also cause disturbance or habitat loss and loss of rare geothermal ecosystems.

On the Economic development theme, the negative impact of geothermal is that it fails to create many long-term jobs. In the end the consumption and production pattern theme geothermal energy can cause environmental contamination through the wastes it produces, it can also cause over exploitation, and the efficiency of the power plant could be compromised due to the high cost of turbines

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### 2.1.5. Biomass energy

Biomass is the plant material which is derived from the reaction between $CO_2$ in the air, water, and sunlight through the process of photosynthesis to produce carbohydrates that are the building blocks of biomass (McKendry, 2002). Some other authors differentiate from the mentioned definition of biomass as they also include animals in the sphere. Biomass is all organic matter which exists in the biosphere, whether of plant or animal origin, as well as those materials obtained through their natural or artificial transformation. Biofuels which are center to biomass energy are derived from biomass that include firewood, wood shavings, pellets, some fruit stones such as olives and avocados, as well as nutshells (Moreno *et al.*, 2019).

Other similar definitions found in the literature are as follows; Biomass is a renewable energy derived from animals and plant organic matter (Kamimoto); Biomass is a term to describe all organic matter, produced by photosynthesis, existing on the earth's surface (Sriram *et al.*, 2005); Biomass is a material derived from living or recently living organisms such as plants, animals and their byproducts (Mao *et al.*, 2015).

U.S. department of Energy also gives a similar definition. It defines it as an organic material that is derived from plants and animals, and it is a renewable source of energy. It further explains the process; biomass contains stored energy from the sun, which is stored by the plants by the process of photosynthesis. Chemical energy in biomass releases as heat when burned and it can also be converted to biofuel or biogas that can be burned as fuels. Biomass can be converted into three main types of products:

- electrical/heat energy,
- transport fuel,
- chemical feedstock. (McKendry, 2002)

There are four main types of biomass:

- woody plants,
- herbaceous plants/grasses,
- aquatic plants,
- manures. (McKendry, 2002)

Biomass energy is the 2$^{nd}$ oldest form of energy used by human civilization, second only to solar energy. The start of the use of biomass can be dated back to the time of the discovery of fire by the cavemen.

The cavemen used wood and other organic products to heat his cave and cook his food. In the form of wood, biomass energy had fueled the world's economy for thousands of years before the advent of more easily winnable coal and subsequently oil, gas and uranium (Lewis, 1981). This use of biomass can be termed as the traditional use of biomass which has been there for centuries.

The modern use of biomass is distinguished from the traditional use of biomass energy by its conversion into high-quality energy carriers, like electricity and biomass liquid fuels for transportation (Hoogwijk *et al.*, 2005). Biofuels like Bio-ethanol, Bio-oil, and Bio-methanol are example of fuels in the liquid form extracted from biomass. Landfill gas, Sewage gas, Biogas, and Syngas are examples of fuels extracted from biomass in the gaseous form. The information given further in this section is taken from the *website of timetoast*.

In 1700s, even before the commercialization of oil, biofuels were developed and being used. Biofuels were humans' first liquid fuels. Lights in Europe and America were lit up by vegetable oils and fat. Stoves powered by burning of alcohol were warming the houses. Therefore, they were a significant source of fuel for lighting and heating.

In Europe and America whale oil was used for running engines. In 1800s biofuels started to become cost competitive and their price dropped lower than the whale oil. This resulted in the increase in production of biofuels and reduction in hunting of whales. Table 2.6 gives the price and production of whale oil and biofuels in 1800s.

Table 2. 2. Price of whale oil vs biofuel in 1800s.

| **Product** | **Price (U.S. dollars/gallon)** | **Production per year (gallons/year)** |
|---|---|---|
| Whale oil | 1.30-2.5 | 18 million |
| Camphene and Alcohol | 0.50 | 150 million |
| Kerosene | 0.60 | 200 million |

In 1826, Samuel Morey invented the first spark-ignition piston using alcohol. In 1840, first commercially used biomass gasifier was built in France. In the year 1860, Nikolaus Otto developed Otto-cycle engine which was powered by ethanol. This can be considered a significant event as for the first time biofuels were used for generation of motion that is very much needed in factories and related businesses. Therefore, it increased their efficiencies and production capabilities. In 1880, Henry Ford used ethanol to power one of his first automobile known as the quadricycle.

In 1900, Germany creates the first large scale biofuels industry. Kaiser Wilhelm the monarch of Germany at that time encouraged the use of alcohol fuel from potatoes over oil use. By the year 1906, 72000 distilleries were producing 27 million gallons of biofuel. Ethanol fueled lamps, water heaters and other appliances were being used. Biofuels had become the primary source of energy for all homes and factories.

Another major event took place in the year 1906; the American President Teddy Roosevelt repealed the Distilled Spirit tax of 1862. Between the year 1912 and 1932 the production of alcohol slowed down in the United States due to the growth of prohibition movement. The fear of shortage of oil during the First World War motivated Henry Ford to create tractors and Model T's designed to burn alcohol as well as gasoline. With the intensives given by the government, production of biofuels became significant industry.

In 1912, Rudoph Diesel discovered that peanut, castor and palm oils can compete with "heavy" fuel obtained from petroleum. In 1925, Henry Ford envisions enough alcohol yields from crops such as potatoes that can drive the farm industry for 100 years. More and More machinery and cars started to use biofuels.

By the year 1927, many other countries also started the production of biofuels. Brazil and Philippines used the process of sugarcane to make alcohol biofuels to counter the high cost of gasoline import. Brazil also built its first biofuel plant in 1927. Brazil's consumption of ethanol was 7% of the total fuel consumption.

By the year 1932 almost 30 countries (mostly from the tropical areas and Europe) had tax incentives or mandatory ethanol blending programs. In 1939, Ford backed "Agrol" ethanol which was developed in Kansas for blending with gasoline but by then ethanol firms which were fighting with the oil industry were bankrupt. In the 1940s, the ethanol firms were reopened to help in the war effort, to make fuels, chemicals and rubber. The oil industry considered biofuel industry as a threat and thus tried to kill it.

In 1969, after 25 years of World War 2, the consumption of oil grew 5.5 folds due to supply of cheap oil from the Middle East. During this the oil producing nations (12 of them) formed OPEC to control oil prices and payments to producing countries. Availability of cheap oil from the Middle East lead to oil becoming the primary source of energy causing significant decline in the production of biofuels.

In 1973 Arab nations imposed oil embargo after their war with Israel which lead to the price of oil becoming quadrupled. This brought back interest in biofuels. Brazil mandated and subsidized ethanol blending and USA started to explore options of extracting ethanol from corn. The name biomass energy was given in 1976.

1980s is considered as the golden age of ethanol in US. The President of US at that time, Jimmy Carter, offered tax incentives for ethanol production. By the year 1984, 163 ethanol plants in US produced more than 595 gallons of ethanol which were used to mix with gasoline as an octane booster. Ethanol blend helped with the dwindling supplies of petroleum based fuels.

In the late 1980s the price of oil dropped to 12$ per barrel. This brought the ethanol industry to near bankruptcy. In 1990, the Clean Air Act was brought in the US, which barred lead and air toxics from gasoline and this led to the use of corn based ethanol blend as a popular alternative. Biofuel production especially from corn competed with food production and the issue of food vs fuel started to come up.

In 2007, United Nations agency calls for 5-year moratorium on food-based biofuels, fearing loss of valuable farmland which officially started the food vs. fuel debate. But problems like Climate Change, Global Warming and rising oil prices brought more interest to renewable plant based fuels. By 2009, the production of ethanol in USA reached 10.9 billion gallons.

In 2012 the total ethanol production in the world was 19.5 billion gallons. In the same year US through Renewable Fuel Standard mandated annual 18 billion gallons of fuel by 2014 and 36 billion by 2022. There are 40 other nations which have policies or mandates urging alternative fuel development. In 2013, the first commercial cellulosic ethanol plant was inaugurated. Today Biofuels are considered as a green and renewable source of energy.

There are many pathways to the conversion of bioenergy which are well established but there are some which are at the development, demonstration or commercial stages. In 2016, if we include the traditional biomass energy, biomass contributed an estimated 12.8% to the final energy consumption. Modern biomass energy on its own contributed 5% of the final energy consumption. *Figure* 2.17 show that the contribution of final energy consumption for heat in buildings and industry exceeds its use in electricity and transport, even when the use of traditional biomass energy is not included. But, the electricity sector has seen the maximum growth in the consumption of bioenergy. (Renewables Global Report, 2018)

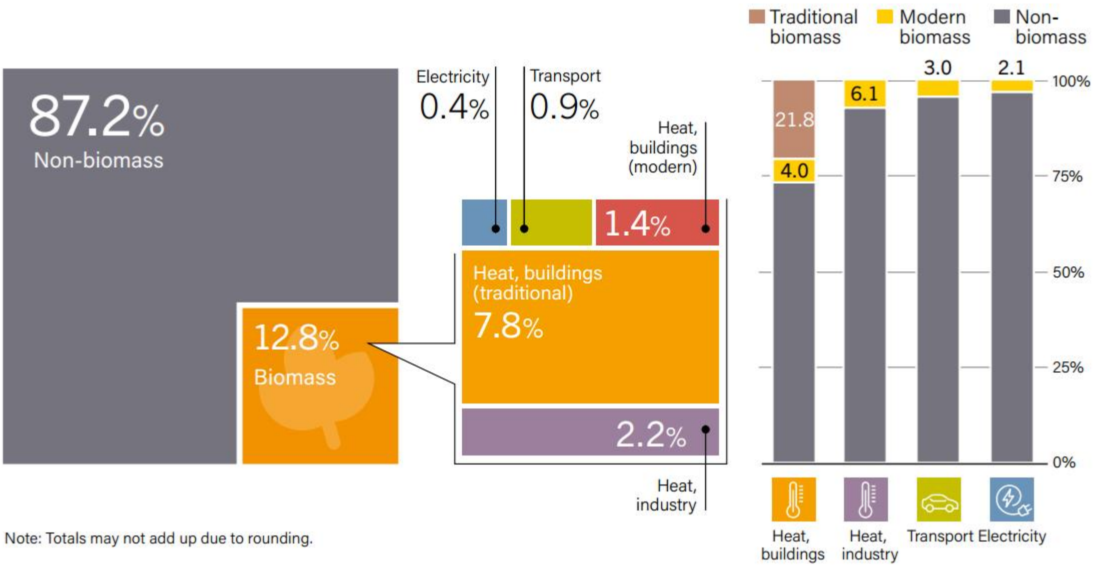


Figure 2. 17. Shares of Bioenergy in Total Final Energy Consumption, Overall and by End-Use Sector, 2016 (Renewables Global Report, 2018).

In the year 2017, a number of initiatives were taken to expand the development of sustainable bioenergy, which also included the establishment of Bio Future Platform, formed by a group of 20 countries. This Bio Future Platform was to promote the expansion of a sustainable bio economy, and the Sustainable Biofuels Innovation Challenge, which is part of the global Mission Innovation program and has 22 participating countries.

In 2017, several countries implemented policies to support the production and use of bioenergy. Brazil launched the RenovaBio initiative which is expected to lead to a significant increase in the production and use of bioenergy in the country. India also launched a major initiative to enhance the level of domestic production and use of biofuels which also includes the production of advanced biofuels by using agricultural residues. Whereas Europe was having a debate about the role of bioenergy in the EU Renewable Energy Directive since constraints are to be introduced on “food-based” biofuels. Similarly, uncertainties exist on the future of US Renewable Fuel Standard. These developments have significantly affected the bioenergy market

Modern biomass energy is expected to gain a significant share in the energy market in the future due to the expectation of reduction in cost of production and conversion, availability of resources in abundance, and expected increase in demand for $CO_2$ neutral fuels (Hoogwijk *et al.*, 2005). Various studies assume penetration levels of biomass in the future energy system in the order of 10% to about 50% of the total primary energy demand (Hoogwijk *et al.*, 2005). Further this section would be divided into three categories; bio-heat, bio-electricity, and bio-transport.

2.1.5.1. Bio-heat- The amount of traditional biomass use has grown slowly from 27.7 EJ in 2005 to an approximately 28.4 EJ in 2016. The share of traditional biomass energy in global energy consumption has been declining gradually for many years. It has dropped from 9.2% TFEC to approximately 7.8% in 2016.

In 2016, the modern biomass energy applications provided approximately 13.1 EJ of heat in TFEC, of which 7.9 EJ was used in industrial applications. 5.2 EJ of bio energy was consumed by residential and commercial sectors, which was mainly used for space heating in buildings. By the year 2017, the total installed heat capacity increased to approximately 314 GW thermal.

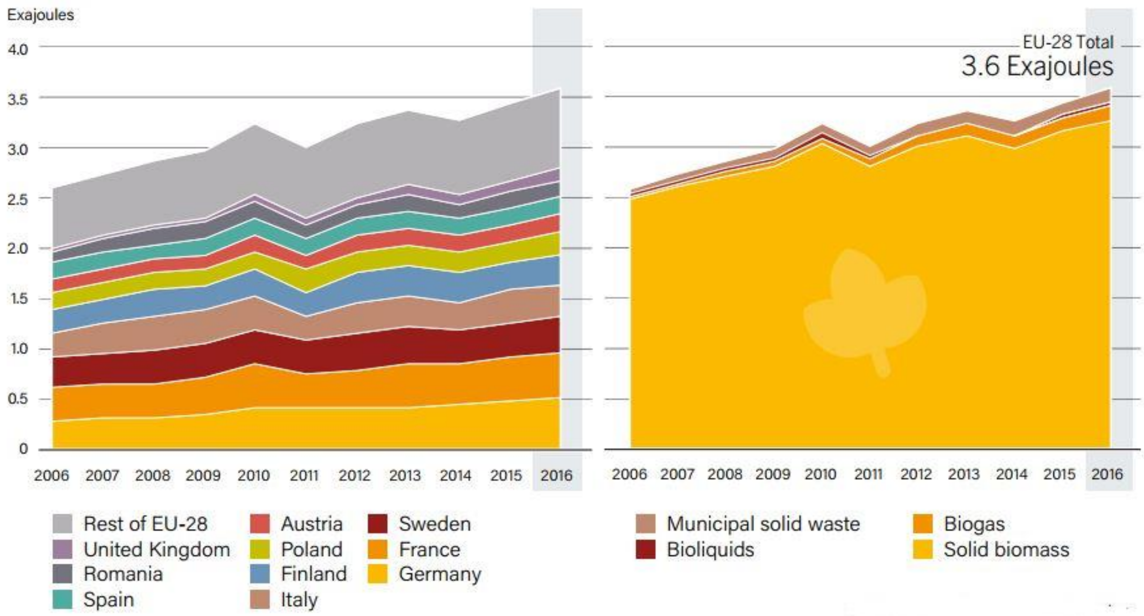


Figure 2. 18. Consumption of Heat from Bioenergy in the EU-28, by Country and Fuel Source, 2006-2016 (Renewables Global Report, 2018).

Europe has been the largest consumer of modern bio-heat by region. In order to meet the mandatory national targets under the Renewable Energy Directive, European countries have promoted the use of renewable heat in both buildings and industry. The estimated use of bio-heat by EU was 3.6 EJ in the year 2016; 91% of it was provided by solid biomass and 4% each was provided by biogas and municipal solid waste. *Figure* 2.18 shows the consumption heat from bioenergy in the EU.

2.1.5.2. Bio-electricity- Between 2016 and 2017, the capacity of electricity generation by biomass increased by 7% to 122 GW globally. China overtook USA as the largest producer of bio-electricity followed by Brazil, Germany, Japan, United Kingdom, and India. Figure 2.19 gives the global power generation by region between 2007 and 2017.

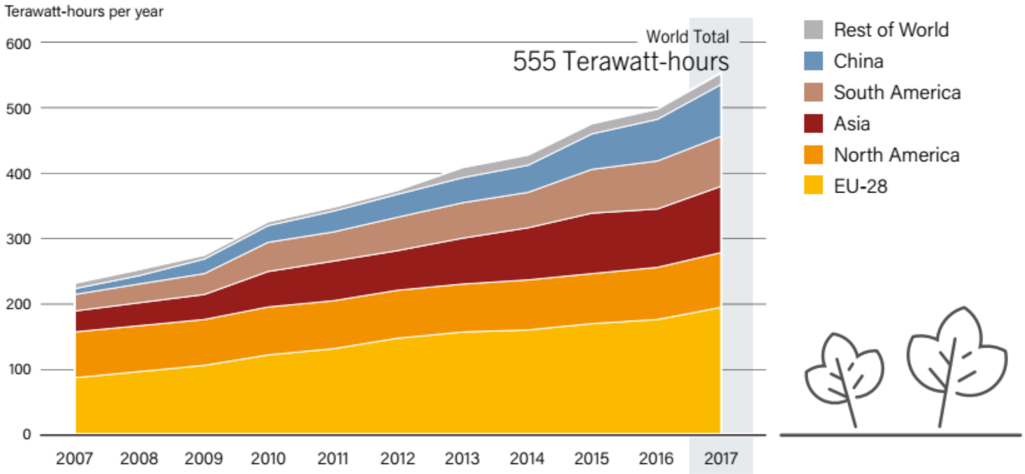


Figure 2. 19. Global Bio-Power Generation by Region, 2007-2017 (Renewables Global Report, 2018).

2.1.5.3. Bio-Transport- The production of biofuels is very concentrated with 80% of the production and use in US, EU and Brazil only. The production of biofuels rose by 2.5% to 143 billion liters, which is equivalent to 3.5 EJ, in 2017 when compared with 2016.

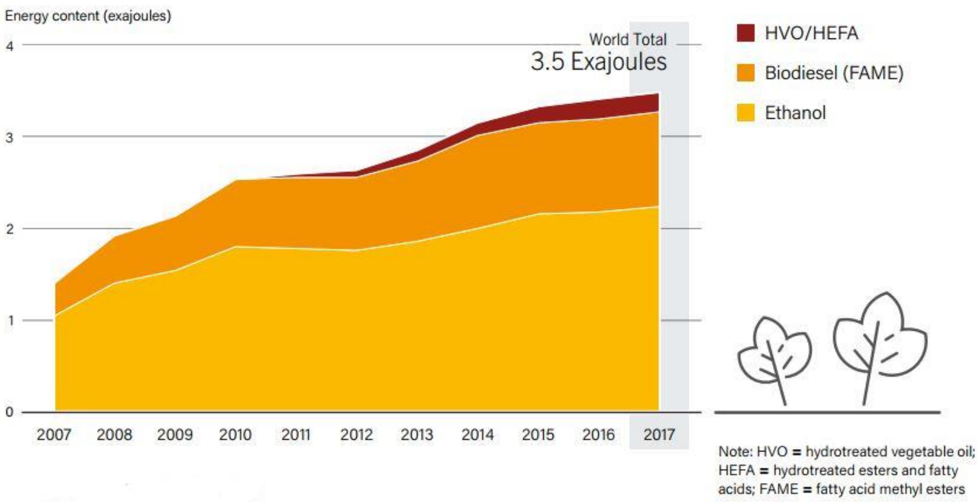


Figure 2. 20. Global Trends in Ethanol, Biodiesel and HVO/HEFA Production, 2007-2017 (Renewables Global Report, 2018).

The United States and Brazil remain the largest producer of biofuels followed by Germany, Argentina, China, and Indonesia (Renewables Global Report, 2018). The main biofuels produced were ethanol, biodiesel, and fuels produced by treating animal and vegetable oils and fats with hydrogen like hydrogen treated oil and hydrogen treated esters and fatty acids. There is also growing contribution of bio methane in some countries. *Figure 2.20* gives an overview of the global trends in these biofuels.

Biomass has been an energy which has been used since the discovery of fire. It has many benefits and like any other renewable energy many limitations. For example, one of the benefits of biomass is that it provides clean energy and helps in the reduction of GHG whereas one of the disadvantage is that the fuel for biomass i.e. the products which are used to generate bioenergy are used for many other purposes also like food, hence we can say that competing uses of biomass is a disadvantage.

2.1.5.4. Benefits- Renewables Global Report 2018 claims that there is an increasing consensus that if bioenergy is used in a sustainable manner then it can contribute to reductions in GHG and provide many environmental, social and economic benefits.

Biomass is an abundant and renewable source of energy and it can be used to burn waste products (Ellaban *et al.*, 2014). Renewables Global Report 2018 also mentioned some of the benefits of biomass; Biomass plays an expanded role in many low-carbon scenarios and can be specifically useful in the transport sector where other renewable energy may not be much useful.

Ellaban *et al.* also described potential benefits of biomass energy and divided them into two categories; environmental and economic. The environmental benefits are as follows; reduction on the dependency of fossil fuels and petroleum products which cause a lot of damage to the environment; lower the levels of GHG emissions; reduce the levels of smog and toxic chemical gas emissions; using the waste products which helps in reduction of the need for landfill sites. The economic benefits are as follows; it is relatively inexpensive source of energy; the energy sources that are distributed locally provide constancy and reliability; access to energy is more widely distributed; stability of prices; employment generation in rural areas; export potential of biomass and bioenergy technology; use of underutilized biomass resource as a renewable and inexhaustible source of energy.

Unlike fossil fuels which burn old biomass and convert it into new $CO_2$ that is the main cause of GHG emission and depletion of a non-renewable source, burning of new biomass contributes to no new $CO_2$ to the atmosphere because replanting harvested biomass ensures that CO2 is absorbed and returned for a cycle of new growth (McKendry, 2002).

Sriram *et al.* (2005) also listed many benefits of biomass energy which are as follows:

- It is an abundant, secure, environmental friendly, and renewable source of energy that does not add $CO_2$ to the atmosphere as it absorbs the same amount of carbon in growing as it releases when consumed as a fuel.
- It can be used to generate electricity with the same equipment or in the same power plants that are being used for burning fossil fuels.
- It is not associated with environmental impacts such as acid rain, mine spoils, open pits, oil spills, radioactive waste disposal or the damming of rivers.
- Biofuels are efficient, viable, and relatively clean burning.
- It is easily available and can be grown with relative ease in all parts of the world.

2.1.5.5. Limitations- Burning of biomass can cause air pollution and it may not be cost effective (Ellaban *et al.*, 2014). The research by Ellaban *et al.* (2014) also mentioned potential disadvantages or threats of biomass energy.

The environmental threats of biomass described by Ellaban *et al.* (2014) are as follows; use of protected land for its production; depletion of local water supplies; high demand for fertilizers, herbicides, and pesticides which could lead to an increase in air and soil pollution; possibility of contribution to climate change with increase in production of $CO_2$.; use of genetically engineered crops and micro-organisms could affect the ecosystem; reduction in biodiversity due to soil pollution and/or industrial cultivation of favored crop species; increase particulate carbon emissions from burning of wood.

Sriram *et al.* (2005) also listed many constraints of biomass energy which are as follows:

- It is an expensive source of energy, both in terms of producing biomass and converting it into biofuels, as large amount of biomass is required.
- On a small scale there could be most likely a net loss of energy as a lot of energy is required for growing plant mass. It is also difficult to store it in raw form.

- When the wastes of plant and animals are used for generation of energy, it cannot be used as fertilizers.
- The direct combustion of biomass can be harmful to the environment as burning biomass releases $CO_2$ that contributes to global warming and possible climatic change. Burning also creates soot and other air pollutants.
- Over-collecting wood can destroy forests. Soils bared of trees erode easily and do not hold rainfall that can cause an increase in runoff od rivers which can further cause flooding downstream.
- Biomass has less energy than a similar volume of fossil fuels.

## 2.2. Barriers to Renewable Energy in developing countries

UN categorizes the countries into three main categories namely developed, economies in transition, and developing countries. An example of developed country according to the classification by UN is United States of America, which is a part of G7 group and has one of the highest human development index. An example for the transition countries is Serbia, which is an eastern European nation, because of its economic structure being better than the developing countries but not up to the level of developed countries. The largest group among these category is of the developing countries and some examples for it are Turkey, India, Brazil, Qatar, Saudi Arabia, Pakistan etc. (UN, 2014)

Golic (2019) defines developed countries as *"Developed countries are technically and technologically advanced economies with a high human development index (HDI), high per capita income, modern infrastructure, highly developed own industrial production and economy, and a high standard of living"*, and developing countries as *"Developing countries are countries with low or medium human development index (HDI), low living standards, low per capita income, widespread poverty, and have underdeveloped industry and outdated infrastructure and are facing long periods of recession"*.

Faruk (2017) in the section of Key terms of the Handbook of Research on Economic, Financial, and Industrial Impacts on Infrastructure Development gives a definition for developing countries which is as follows: "*A developing country, also called a third world country, a less developed country or underdeveloped country, is a nation with a less* *developed industrial base and a low Human Development Index (HDI) relative to other countries".* There is another definition provided by Ifijeh *et al.* (2019): *"Sovereign states that are not yet highly industrialized relative to the industrialized ones and have low human development index".*

As for the transition economies Rees *et al.* (2008) sites the definition given by Hoskisson *et al.* (2000) which is as follows: *"An economy associated with a country that is committed to developing market mechanisms through the 'liberalization, stabilization and encouragement of private enterprise'"*. Most of the countries which come under this definition are Eastern European Countries (Rees *et al.*, 2008).

Barriers can be defined as man-made factors or attributes of factors that operate in between actual and potential RE development or use. It can be both intentional and unintentional. It prevents or hinders action, impedes progress or achievement in realizing potentials. (Verbruggen *et al.*, 2010)

Many barriers have been listed in the literature. These can be Financial Barriers, Technical Barrier, Market Barriers, Political or institutional Barriers, and Social and Environmental Barriers (Luthra *et al.*, 2015). Some of the barriers could be technologically specific, and some may region or country specific. General Barriers to the adoption of Renewable Energy technologies in the context of developing countries have been identified through an extensive review of the literature. A literature survey was conducted by searching key words like Renewable Energy Technology; Barriers to Renewable Energy Technology in developing countries; Barriers to Renewable Energy in African Countries; Barriers to Renewable Energy in developing countries of Asia; Google searches and Google Scholar databases were utilized. Since very few studies were conducted in the context of developing countries this study was forced to look at the studies which were conducted in different regions or specific countries.

Table 2.3 shows the studies found in the literature with the regions that they focused on. Some of the studies in the Table 2.3 have focused on one country only like Luthra *et al.* (2015) and Jagadeesh (2000) that focused on India; Mezher *et al.* (2012) that focused on Abu Dhabi; Nalan *et al.* (2009) and Kaya (2004) that focused on Turkey; Ahmad *et al.* (2011) that focused on Malaysia; Lokey (2009) that focused on Mexico; Ohunakin *et al.* (2014) that focused on Nigeria; and Pegels (2010) that focused on South Africa.

Some of the other studies had grouped countries like Patlitzianas *et al.* (2016) that focused on Arab States of the Gulf; Ahlborg and Hammar (2014) that focused on Tanzania and Mozambique; and Urmee *et al.* (2009) that focused on Asia and Pacific region. Some of the studies did not focus on a particular region and found general barriers to the adoption of renewable energy technology like Sen and Ganguly (2017); Painuly (2001); and Eleftheriadis and Anagnostopoulou (2015).

Table 2. 3. Studies conducted on Barriers to Renewable Energy in the literature.

| S. No. | Name | Author | Year | Regions focused |
|---|---|---|---|---|
| 1 | Barriers to renewable/sustainable energy technologies adoption: Indian Perspective | Luthra *et al.* | 2015 | India |
| 2 | Wind Energy development in Tamil Nadu and Andhra Pradesh, India Institutional dynamics and barriers-A case study | Jagadeesh | 2000 | India |
| 3 | Renewable Energy policy options for Abu Dhabi: Drivers and Barriers | Mezher *et al.* | 2012 | Abu Dhabi |
| 4 | Enhancing renewable energy in Arab states of the Gulf: Constraints and efforts | Patlitzianas *et al.* | 2006 | Arab States of the Gulf |
| 5 | Renewable Energy market conditions and barriers in Turkey | Nalan *et al.* | 2009 | Turkey |
| 6 | Renewable energy policies in Turkey | Kaya | 2004 | Turkey |
| 7 | Current perspective of the renewable energy development in Malaysia | Ahmad *et al.* | 2011 | Malaysia |
| 8 | Barriers to clean development mechanism renewable energy projects in Mexico | Lokey | 2009 | Mexico |
| 9 | Drivers and barriers to rural electrification in Tanzania and Mozambique-Grid extension, off grid, and renewable energy technologies | Ahlborg and Hammar | 2014 | Tanzania and Mozambique |
| 10 | Solar energy applications and development in Nigeria: Drivers and Barriers | Ohunakin *et al.* | 2014 | Nigeria |
| 11 | Renewable energy in South Africa: Potentials, barriers and options for support | Pegels | 2010 | South Africa |
| 12 | Issues related to rural electrification using renewable energy in developing countries of Asia and Pacific | Urmee *et al.* | 2009 | Asia and Pacific |

Table 2.3. Studies conducted on Barriers to Renewable Energy in the literature (Cont.).

| **S. No.** | **Name** | **Author** | **Year** | **Regions focused** |
|---|---|---|---|---|
| 13 | Opportunities, barriers and issues with renewable energy development- A discussion | Sen and Ganguly | 2017 | General |
| 14 | Barriers to renewable energy penetration; a framework for analysis | Painuly | 2001 | General |
| 15 | Identifying barriers in the diffusion of renewable energy sources | Eleftheriadis and Anagnostopoulou | 2015 | General |

The literature taken into account represents all the continents except for North America and Europe where majority of the countries are considered to be developed as per the United Nations. Assuming that the developing countries face somewhat similar barriers the relevant major barriers in the literature are explained as follows.

### 2.2.1. High Initial Cost

It could be in the form of acquiring land or importing technology or buying equipment. The technology can be imported from the more advanced countries, which is more efficient, but could be not economically viable when compared with its locally manufactured counterpart and thus would increase the investment requirement (Luthra *et al.*, 2015). The consumer behavior is in keeping the initial cost low instead of lowering the operation costs (Reddy *et al.*, 2004).

This barrier has been mentioned with many different names like High intial cost (S. Luthra *et al.*, 2015), High initial investment cost (Ohunakin *et al.*, 2014; Sen and Ganguly, 2017), Increased Initial Construction cost (Eleftheriadis and Anagnostopoulou, 2015), High capital cost (Urmee *et al.*, 2009; Nalan *et al.*, 2009), and Initial Capital cost (Patlitzianas *et al.*, 2006; Mezher *et al.*, 2012; Kaya, 2006).

### 2.2.2. Lack of Subsidies

There are some countries that have subsidized renewable energy by production payments or rebates. Rebates refer to the refunds that help in reducing the burden of cost of the technology or total installation cost on the investor. Rebates could also be given on the basis of the units installed (Sawin, 2003). There could be a potential improvement in the financial viability of business and affordability of services for renewable energy technology if any form of subsidy is provided (Nguyen *et al.*, 2010). This barrier has been mentioned with different names in the literature like Lack of subsidies (Luthra *et al.*, 2015; Ahlborg and Hammar, 2014; Kaya, 2006), Favor to conventional energy (Painuly, 2001), Fuel subsidy (Ahmad *et al.*, 2011), and Subsidies for competing fuels (Mezher *et al.*, 2012).

### 2.2.3. Inefficient Technology

Inefficient technology in other words technical risk implies that a technology underperforms or becomes obsolete before maturing (Luthra *et al.*, 2015). Site specific reasons could be present that would make it a technical risk which could provide a rational reason for its rejection (Painuly, 2001). Renewable technologies today are not financially competitive when compared with conventional technologies like Thermal power plants (Doner, 2007). Many studies have used different terms when mentioning it as a barrier like Inefficient technology (Luthra *et al.*, 2015), High technical losses (Ahlborg and Hammar, 2014), and Technology performance uncertainty/risk (Patlitzianas *et al.*, 2006; Mezher *et al.*, 2012).

### 2.2.4. Lack of Financial Mechanism

Many of the renewable energy technologies are in the development stage in the developing countries. There are many economic and financial issues that appear to be very crucial for the development of renewable energy technologies in the developing countries. There is not enough government effort on schemes or financing mechanisms to help in promoting the adoption of renewable energy technologies by the business family (Reddy, 2004). Lack of credit availability for buying renewable energy technologies is a major barrier for its adoption in developing countries (Painuly, 2001). Small and medium scale industries are the main group which faces lack of financial resources for adoption of renewable technologies but can contact with larger technology manufacturers and formal informal channels (Suzuki *et al.*, 2010). It has been mentioned as a barrier by many studies with different terms like Lack of financial mechanism (Luthra *et al.*, 2015; Nalan *et al.*, 2009), Difficulty in availing loans from banking institutions (Jagadeesh, 2000), Lack of proper lending facilities (Kaya, 2004), Lack of loan facilities (Ahmad *et al.*, 2011), and Lack of access of credit for the consumer (Urmee *et al.*, 2009; Painuly, 2001).

### 2.2.5. Lack of Consumer Awareness of Renewable Energy

Imperfect market is one of the most important barrier which indicates poor access to information when compared with conventional sources of energy. Newspapers and Magazines use to be the primary source of information (Luthra *et al.*, 2015). Consumers' lack of awareness about the costs and benefits of renewable energy technologies could result in a lack of interest and commitment in the promotion of them (Reddy, 2006). It has been mentioned with different terms in different studies like Lack of consumer awareness of technology (Luthra *et al.*, 2015), Lack of consumer acceptance of the product (Painuly, 2001), Change of mind among customers (Ahlborg and Hammar, 2014), Lack of awareness of technology (Jagadeesh, 2000), Lack of Awareness in social, rural, and environmental sectors (Mezher *et al.*, 2012), Lack of awareness and knowledge (Kaya, 2004), Lack of awareness and information (Ohunakin *et al.*, 2014), and Misinformation of local communities regarding Renewable energy benefits (Eleftheriadis and Anagnostopoulou, 2015).

### 2.2.6. Lack of political commitment and adequate government policies

There is a lot of potential in Renewable Energy technology and it cannot be fully harnessed without clear political vision and support of science and technology (Cherni *et al.*, 2007). Political instability, government intervention in domestic markets, corruption, and lack of civil society are major barriers to the adoption of renewable energy technology in developing countries (Brown, 2001). It has been mentioned as a barrier with different terms in different studies like Lack of Political commitment and Lack of adequate government policies (Luthra *et al.*, 2015), Bureaucratic problems (Kaya, 2004), Lack of transparency (Lokey, 2009), Lack of support from the government (Ohunakin *et al.*, 2014), Lack of policy mechanism (Nalan *et al.*, 2009), Lack of government policy and incentives (Ohunakin *et al.*, 2014), Absence of relative legal and policy framework (Mezhar *et al.*, 2012; Painuly, 2001), Lack of appropriate institutional infrastructure (Jagadeesh, 2000), and Unrealistic political commitment (Urmee *et al.*, 2009).

### 2.2.7. Lack of infrastructure

Infrastructure can be referred to as not only the physical facilities of transmission and distribution networks, but also required equipment and services required by the power companies (Luthra *et al.*, 2015). The limited participation of private sector and target linked programs have been unsuccessful to give motivation to the existing institutional mechanisms to be able to cater to the new markets (Blachndra, 2009). A strong infrastructure is required for many renewable energy technologies like Wind. This barrier also relates to the availability of infrastructure such as roads, connectivity to the grid, communication, and other logistics (Luthra *et al.*, 2015). The regulatory barrier gave way to problems in land acquisition and also problems in getting permission whereas lack of infrastructure facilities added to the cost (Reddy, 2006). Lack of infrastructure has been mentioned as a barrier with different terms like Lack of local infrastructure (Luthra *et al.*, 2015), Poor Grid (Jagadeesh, 2000), Utility interconnection requirement (Mezhar *et al.*, 2012), Lack of infrastructural support (Nalan *et al.*, 2009), and Limited rural infrastructure (Ahlborg and Hammar, 2014).

### 2.2.8. Need for backup or storage device

Most of the renewable sources like solar energy and wind energy are dependent on weather conditions and to ensure continuous supply backup or storage devices are required (Luthra *et al.*, 2015). It has been mentioned as a barrier in many studies using different terms like Need for backup or storage device (Luthra *et al.*, 2015), Backup system (Ahlborg and Hammar, 2014), Backup generator required (Nalan *et al.*, 2009), and Storage devices required (Ohunakin *et al.*, 2014).

### 2.2.9. Technological complexity

The renewable energy technologies are generally complex in nature (Luthra *et al.*, 2015). Wind energy is generated through the complex mechanism which involves rotation of the earth, heat energy from the sun, the cooling effects of oceans and the polar ice caps, temperature gradients between land and sea and physical effects of mountains and other obstacles (Kumar *et al.*, 2010). It was listed as a barrier by many studies but with different terms like Technological Complexity (Luthra *et al.*, 2015), Complex system (Jagadeesh, 2000), and Lack of technical information (Urmee *et al.*, 2009).

### 2.2.10. Lack of trained people and training institutes

In many developing countries there is a need for technically trained people and institutes to train them. There are many problems associated with it that includes rights of intellectual property (Luthra *et al.*, 2015). There is also a lack of guidance and technical support for operators that leads to inefficient exploitation of renewable resources (Rand *et al.*, 2008). This barrier has been mentioned in the literature with different terms by many studies like Lack of trained people and training institutes (Luthra *et al.*, 2015), Inadequate user training (Jagadeesh, 2000), Requirement of skilled human resources with specific trainings (Sen and Ganguly, 2017), and Inadequate scientific and technical personnel (Eleftheriadis and Anagnostopoulou, 2015).

### 2.2.11. Lack of Standardization

Lack of national technical standards and effective quality control units were identified as major institutional challenge to the adoption of renewable energy technology in households (Ohunakin *et al.*, 2014). In Wind Power industry, lack of standardization of the components which results from the wide range of in design features and technical standards causes manufacturing, servicing, and maintenance difficulties of the wind turbines (Jagadeesh, 2000). It also increases the commercial risk along with the negative perception about the technology (Painuly, 2001). It has been mentioned as a barrier by similar terms like Lack of standardization (Jagadeesh, 2000; Kaya, 2004), Lack of national technical standards (Ohunakin *et al.*, 2014), and Lack of standard and codes and certification (Painuly, 2001).

### 2.2.12. Transaction Cost

This is an extra cost which is paid in addition to the main cost. An example for this cost is cost of reaching environmentally conscious consumers (Nalan *et al.*, 2009). It may affect the economic viability of a project (Painuly, 2001). It is listed as a barrier by the same name in the literature by Urmee *et al.* (2009), Mezher *et al.* (2012), Nalan *et al.* (2009), and Painuly (2001).

### 2.2.13. Monopoly

Monopoly in the energy sector results in the lack of competition among suppliers and demanders. It also results in the reduction of the opportunities for free market entry and exit (Sen and Ganguly, 2017). Industries like electric, gas, and heat transmission grids within a given area are natural monopolies since network services are cost least when provided by a single operator (Baumal *et al.*, 1982). It has been mentioned as barrier with the same name by Ahmad *et al.* (2015), Lokey (2009), Pegels (2010), and Sen and Ganguly (2017).

### 2.2.14. Ecological Issues

The environmental cost of fossil fuel, hydroelectric, and nuclear energy consumption could push the world towards renewable sources of energy before scarcity becomes a major problem (Luthra *et al.*, 2015). The environmental problems which are associated with hydropower plants could be solved by afforestation, and the social problems could be addressed by sensitive, democratic, and participatory rehabilitation policies (Srivastava *et al.*, 2013). In wind power, sound and visual impact are two problems for the public health and community concerns. The environmental impacts related to solar energy are land use and loss of habitat, water use and the harmful raw materials used for the production of solar panels (Tsoutsos *et al.*, 2005). There are also potential environmental problems that can be associated with geothermal energy that includes air pollution, shortages of water, and water effluent disposal (Nalan *et al.*, 2009). It has been mentioned as a barrier by many studies but may use different words like Ecological issues (Luthra *et al.*, 2015), Environmental Barriers (Painuly, 2001; Nalan *et al.*, 2009) etc.

### 2.2.15. Exclusion of Environmental externalities

The true economic cost of power production by fossil fuels that take into account the environmental and social damage should be included (Mezher *et al.*, 2012). Lack of pricing policies do not take into account the real economic costs of environmental damage is a major barrier for fair competition between Renewable and Conventional sources of energy (Urmee *et al.*, 2009). It has been listed as a barrier by many studies some of them are Mezher *et al.* (2012), Patlitzianas *et al.* (2006), and Urmee *et al.* (2009).

### 2.2.16. Underinvestment in R&D

The renewable energy technologies are mostly in the development stage in the developing countries. Therefore, Lack of R&D work barrier is making adoption of renewable energy technologies difficult (Blachndra, 2009). Large investment required for research and development is one of the major barriers for renewable energy adoption in developing countries. Research and Development usually results in advantages that cannot be taken by private entities (Luthra *et al.*, 2015). There could be benefits that could attract the society at large but individual firms would not be able to realize the full economic benefits of their investments in Research and Development work (Brown, 2001). This can result in making the adaptation of the technology difficult (Painuly, 2001). It has been identified as a barrier by many studies using similar terms like Lack of R&D (Luthra *et al.*), Underinvestment in R&D programs (Sen and Ganguly, 2017), Lack of R&D culture (Painuly, 2001), and Lack of funding in R&D (Nalan *et al.*, 2009).

### 2.2.17. Faiths and Beliefs

There is general resistance to change that becomes a larger with the lack of capacity to understand, adopt and adapt the technologies for greater benefit (Cherni, 2007). The manufacturers of equipment may be not able to or not willing to give information because they would not be able to capture all the benefits (Reddy, 2004). This barrier has been listed in many studies by different terms like Faiths and Beliefs (Luthra *et al.*, 2015) and Cultural Mindset (Ahlborg and Hammar, 2014) etc.

### 2.2.18. Operation and Maintenance Cost

Renewable energy technologies are generally located in the remote and rural areas. The Operation and Maintenance cost are considerably high in developing countries due to lack of technically skilled personnel. Therefore, consumers may be reluctant for the adoption of the renewable energy technology for the fear of absence of technical support (Ohunakin *et al.*, 2014). It has been listed as a barrier with similar term like Operation and Maintenance cost (Ohunakin *et al.*, 2014), High operation and Management cost (Kaya, 2004), and Increased Maintenance Costs (Eleftheriadis and Anagnostopoulou, 2015).

There are many other barriers listed in the literature like Lack of sufficient market base (Luthra *et al.*, 2015; Patlitzianas *et al.*, 2006), Lack of paying capacity (Luthra *et al.*, 2015; Ahlborg and Hammar, 2014), Lack of positive track records (Jagadeesh, 2000); Nalan *et al.*, 2009), Lack of financial stability and commercial market (Jagadeesh, 2000; Mezher *et al.*, 2012), Competition between land uses (Nalan *et al.*, 2009; Ohunakin *et al.*, 2014), Donor dependency (Ahlborg and Hammar, 2014; Urmee *et al.*, 2009), Criminal activities (Ahlborg and Hammar, 2014; Ohunakin *et al.*, 2014), Unavailability of topographic data (Sen and Ganguly, 2017; Urmee *et al.*, 2009), etc.

The existing studies in the literature have found the barriers to the adoption of renewable energy sources by either selecting a particular country like the study by Mezher *et al.* (2012) that selects Malaysia or by grouping countries that are geographically close to each other like the research by Patlitzianas *et al.* (2006) that grouped the Arab Gulf States. However, there is not any study that has tried to find the barriers by grouping countries according to their development status even though most of the barriers mentioned by individual studies of the developing countries have a lot in common. Therefore, this study aims to identify the barriers to the adoption of renewable energy sources common in developing countries which is a major gap in the literature.

# 3. METHODOLOGY

The objective of the study is to review the renewable energy sources and to find the barriers which hinder their adoption in developing countries. The research question for this study formed by taking into consideration the objectives is as follows; *"What factors hinder the adoption of renewable energy technology in developing countries even though their advantages are significant?"* The first objective of the study has been met in the previous sections. This study has given relevant details about each of these five types of renewable energy resources. It has defined each of the renewable sources of energy, their historical use, advantages and disadvantages. It has also briefly explained the current situation of these renewable sources of energy.

For the accomplishment of the objective an extensive literature review was conducted. Literature review could be divided into two parts. The first part dealt with the reviewing of Renewable energy sources for which many journals and articles are researched to review each renewable resource namely-solar, wind, hydropower, geothermal, and biomass energy. This objective of the study was achieved in the previous sections. The previous sections tried to explain every aspect of each renewable resource like their definitions, history, current and future prospects, and benefits and limitations.

The second part of the literature review focused on the barriers to the adoption of these renewable sources of energy in developing countries. Many research which have already been done to find the barriers are reviewed. The studies were selected from across the continents. These barriers were then listed and adding or subtracting of any of the barriers which could have been left out was done in collaboration with the academicians and experts. Then these barriers were forwarded to experts who have considerable experience in working with one or more renewable source of energy. Furthermore, the barriers are weighted and ranked to obtain very significant, moderately significant, somewhat significant and not so significant barriers to renewable energy adoption in developing countries The details will be provided in further sections.

Finally, the AHP on the data received from the experts was implemented. By using AHP the weighted average of the barriers and divided them into major, intermediate, and least significant barriers were calculated. Further in this section, a link of the background and the method adopted will be constructed to make justification from previous literatures.

The methodology section would be divided into three sections which are as follows:

- *Identification of barriers:* This section would list the barriers which were identified by having a review of the previous literatures and the final list of barriers.
- *Interview of experts:* This section would discuss about the methods which were used to get the data from the experts.
- *AHP:* This method would explain the AHP process.
- Codes for experts and barriers and information about the experts.

### 3.1. Identification of barriers

The identification of barriers to renewable energy development in developing countries is based on literature review from previous studies conducted on barriers to renewable energy. 15 peer-reviewed research studies are examined and have been listed in Table 2.3. The main reason for selecting these 15 studies was that they were the individual cases of the barriers in developing countries i.e. they represented the barriers of a particular developing country or a group of developing countries located geographically close to each other. The studies selected included at least one country from each continent except for Europe and Australia since the countries part of these continents are considered to be either developed countries or countries in transition according to the UN classification. Majority of the studies selected are not limited to a particular renewable source and barriers identified from them are common between various countries. For this a frequency column is created to attain the similarity between the selected studies.

This frequency reveals most common barriers to the development of renewable energy in developing countries. The 15 selected studies reveal a total of 116 barriers, obtained from the literature review. The barriers found in the previous section are tabulated and shown in Tables 3.1. The frequency of each barrier is calculated and high initial capital has the highest number of frequency (11 out of 15) followed by lack of subsidies (10 out of 15), less efficiency (8 out of 15), and financial mechanisms (7 out of 15). There are many barriers like lack of consumer awareness of technology, unable to meet electric demand alone, etc. which have been mentioned only once out of fifteen studies.

Table 3. 1. Barriers with Their Frequencies.

| **S.No.** | **Barriers** | **Authors** | **freq.** |
|---|---|---|---|
| **1** | High initial capital cost | Luthra et al. (2015); Mezhar et al. (2012); Nalan et al. (2009); Kaya (2004); Ahmad et al. (2011); Ohunakin et al. (2014); Pegels (2010); Urmee et al. (2009); Sen and Ganguly (2017); Painuly (2001); Eleftheriadis and Anagnostopoulou (2015); | 11 |
| **2** | Lack of financing mechanism | Luthra et al. (2015); Jagadeesh (2000); Nalan et al. (2009); Kaya (2004); Ahmad et al. (2011); Urmee et al. (2009); Painuly (2001); | 7 |
| **3** | Transmission and Distribution losses | Luthra et al. (2015); | 1 |
| **4** | Inefficient technology | Luthra et al. (2015); Ahlborg and Hammar (2014);; | 2 |
| **5** | Lack of subsidies | Luthra et al. (2015); Jagadeesh (2000); Mezhar et al. (2012); Patlitzianas et al. (2006); Kaya (2004); Ahmad et al. (2011); Ahlborg and Hammar (2014);; Urmee et al. (2009); Painuly (2001); Eleftheriadis and Anagnostopoulou (2015); | 10 |
| **6** | Lack of consumer awareness of technology | Luthra et al. (2015); | 1 |
| **7** | Lack of sufficient market base | Luthra et al. (2015); Patlitzianas et al. (2006); | 2 |
| **8** | Unable to meet electricity power demand alone | Luthra et al. (2015); | 1 |
| **9** | Lack of paying capacity | Luthra et al. (2015); Ahlborg and Hammar (2014); | 2 |
| **10** | Need for backup or storage device | Luthra et al. (2015); Ahlborg and Hammar (2014); Nalan et al. (2009); Ohunakin et al. (2014); | 4 |
| **11** | Unavailability of solar radiation data | Luthra et al. (2015); | 1 |
| **12** | Lack of IT enablement | Luthra et al. (2015); | 1 |
| **13** | Lack of awareness of technology | Luthra et al. (2015); Jagadeesh (2000); Mezhar et al. (2012); Kaya (2004); Ahmad et al. (2011); Ohunakin et al. (2014); Eleftheriadis and Anagnostopoulou (2015); | 7 |
| **14** | Less efficiency | Luthra *et al.* (2015); Jagadeesh (2000); Patlitzianas *et al.* (2006); Nalan *et al.* (2009); Ahlborg and Hammar (2014); Pegels (2010); Sen and Ganguly (2017); Painuly (2001); | 8 |

Table 3. 1. Barriers with Their Frequencies (Cont.).

| **S.No.** | **Barriers** | **Authors** | **freq.** |
|---|---|---|---|
| **15** | Technology complexity | Luthra *et al.* (2015); Jagadeesh (2000); Mezhar *et al.* (2012); Urmee *et al.* (2009); | 4 |
| **16** | Lack of research and development work | Luthra *et al.* (2015); | 1 |
| **17** | Lack of trained people and training institutes | Luthra *et al.* (2015); Jagadeesh (2000); Sen and Ganguly (2017); Eleftheriadis and Anagnostopoulou (2015); | 4 |
| **18** | Lack of local infrastructure | Luthra *et al.* (2015); Jagadeesh (2000); Mezhar *et al.* (2012); Nalan *et al.* (2009); Ahlborg and Hammar (2014); | 5 |
| **19** | Lack of national infrastructure | Luthra *et al.* (2015); Jagadeesh (2000); Mezhar *et al.* (2012); Nalan *et al.* (2009); | 4 |
| **20** | Scarcity of natural and renewable resources | Luthra *et al.* (2015); | 1 |
| **21** | Geographical conditions | Luthra *et al.* (2015); | 1 |
| **22** | Ecological issues | Luthra *et al.* (2015); Nalan *et al.* (2009); Painuly (2001); | 3 |
| **23** | Lack of experience | Luthra *et al.* (2015); Jagadeesh (2000); Patlitzianas *et al.* (2006); | 3 |
| **24** | Rehabilitation controversies | Luthra *et al.* (2015); Ahlborg and Hammar (2014); Lokey (2009); | 3 |
| **25** | Faiths and Beliefs | Luthra *et al.* (2015); Lokey (2009); Ahlborg and Hammar (2014); | 3 |
| **26** | Lack of Political commitment | Luthra *et al.* (2015); Kaya; Lokey (2009); Ohunakin *et al.* (2014); Urmee *et al.* (2009); | 5 |
| **27** | Lack of adequate government policies | Luthra *et al.* (2015); Jagadeesh (2000); Mezhar *et al.* (2012); Nalan *et al.* (2009); Ohunakin *et al.* (2014); Painuly (2001); | 6 |
| **28** | Lack of public interest litigations | Luthra *et al.* (2015); | 1 |
| **29** | Rising cost of land for installing wind turbines | Jagadeesh (2000); | 1 |
| **30** | Unplanned addition of windfarms | Jagadeesh (2000); | 1 |
| **31** | Improper Maintenance | Jagadeesh (2000); | 1 |
| **32** | Costlier than Conventional power systems | Jagadeesh (2000); | 1 |

Table 3. 1. Barriers with Their Frequencies (Cont.).

| S.No. | Barriers | Authors | freq. |
|---|---|---|---|
| **33** | Account life-cycle costs | Jagadeesh (2000); | 1 |
| **34** | Lack of positive track records | Jagadeesh (2000); Nalan *et al.* (2009); | 2 |
| **35** | Lack of project implementation models | Jagadeesh (2000); | 1 |
| **36** | Lack of financial stability and commercial market | Jagadeesh (2000); Mezher *et al.* (2012); | 2 |
| **37** | Lack of funding for technology development | Jagadeesh (2000); | 1 |
| **38** | Lack of Adequate financial resources | Jagadeesh (2000); Mezher *et al.* (2012); Patlitzianas *et al.* (2006); Ahmad *et al.* (2011); Ahlborg and Hammar (2014); Urmee *et al.* (2009); Eleftheriadis and Anagnostopoulou (2015); | 7 |
| **39** | Lack of standardization | Jagadeesh (2000); Painuly (2001); Kaya; Ohunakin *et al.* (2014); | 4 |
| **40** | Mismatch between locally manufactured components and imported parts | Jagadeesh (2000); | 1 |
| **41** | Reliability of overall system | Jagadeesh (2000); | 1 |
| **42** | Lack of coordination among research groups | Jagadeesh (2000); | 1 |
| **43** | Rigidity in instructions and a centralized planning process | Jagadeesh (2000); Ohunakin *et al.* (2014); Lokey (2009); | 3 |
| **44** | Restrictions on sitting and construction | Mezher *et al.* (2012); | 1 |
| **45** | Liability insurance requirements | Mezher *et al.* (2012); | 1 |
| **46** | Difficulty of fuel risk assessment | Mezher *et al.* (2012); | 1 |
| **47** | Transactions cost | Urmee *et al.* (2009); Mezher *et al.* (2012); Nalan *et al.* (2009); Painuly (2001); | 4 |
| **48** | Exclusion of environmental externalities in the cost | Mezher *et al.* (2012); Patlitzianas *et al.* (2006); Urmee *et al.* (2009) | 3 |
| **49** | Coordination between users, policy makers, planners and manufacturers | Patlitzianas *et al.* (2006); Kaya; Painuly (2001); | 3 |
| **50** | Failure to quantify economic development | Nalan *et al.* (2009); | 1 |
| **51** | User mechanism service network | Nalan *et al.* (2009); | 1 |

Table 3. 1. Barriers with Their Frequencies (Cont.).

| S.No. | Barriers | Authors | freq. |
|---|---|---|---|
| **52** | Social compatibility | Nalan *et al.* (2009); | 1 |
| **53** | Lack of distribution mechanisms | Nalan *et al.* (2009); | 1 |
| **54** | User support | Nalan *et al.* (2009); | 1 |
| **55** | Needs assessment | Nalan *et al.* (2009); | 1 |
| **56** | Unavailability of wind speed data | Nalan *et al.* (2009); | |
| **57** | Competition between land uses | Nalan *et al.* (2009); Ohunakin *et al.* (2014); | 2 |
| **58** | High operation and maintenance cost | Kaya; Ohunakin *et al.* (2014); Eleftheriadis and Anagnostopoulou (2015); | 3 |
| **59** | Lacking internalization of external costs | Ahmad *et al.* (2011); | 1 |
| **60** | Trade barriers | Ahmad *et al.* (2011); Lokey (2009); Ahlborg and Hammar (2014); Painuly (2001); Eleftheriadis and Anagnostopoulou (2015); Nalan *et al.* (2009); | 6 |
| **61** | Monopoly | Ahmad *et al.* (2011); Lokey (2009); Pegels (2010); Sen and Ganguly (2017); | 4 |
| **62** | Financially in-competitive | Lokey (2009); | 1 |
| **63** | Lack of transparency | Lokey (2009); | 1 |
| **64** | Lack of organizational organizations | Ahlborg and Hammar (2014); | 1 |
| **65** | Top-down management in energy-sector | Ahlborg and Hammar (2014); | 1 |
| **66** | Low institutional quality | Ahlborg and Hammar (2014); | 1 |
| **67** | Incompatible donor policies | Ahlborg and Hammar (2014); | 1 |
| **68** | Lack of co-investments | Ahlborg and Hammar (2014); | 1 |
| **69** | High costs of diesel | Ahlborg and Hammar (2014); | 1 |
| **70** | Donor dependency | Ahlborg and Hammar (2014); Urmee *et al.* (2009); | 2 |
| **71** | In-sufficient rural financial institutions | Ahlborg and Hammar (2014); | 1 |
| **72** | Administrative costs in small off-grid systems | Ahlborg and Hammar (2014); | 1 |

Table 3. 1. Barriers with Their Frequencies (Cont.).

| **S.No.** | **Barriers** | **Authors** | **freq.** |
|---|---|---|---|
| **73** | Lack of consistency between RE projects | Ahlborg and Hammar (2014); | 1 |
| **74** | Lack of local engagement | Ahlborg and Hammar (2014); | 1 |
| **75** | Criminal activities | Ahlborg and Hammar (2014); Ohunakin *et al.* (2014); | 2 |
| **76** | Change of mind among customers | Ahlborg and Hammar (2014); | 1 |
| **77** | Gender issues | Ahlborg and Hammar (2014); | 1 |
| **78** | Low access to required materials | Ahlborg and Hammar (2014); | 1 |
| **79** | High technical losses | Ahlborg and Hammar (2014); | 1 |
| **80** | Low capacity of solar PV systems | Ahlborg and Hammar (2014); | 1 |
| **81** | Lack of private sector involvement | Kaya; Ahmad *et al.* (2011); Ahlborg and Hammar (2014); Pegels (2010); Painuly (2001);Eleftheriadis and Anagnostopoulou (2015); | 6 |
| **82** | Scattered population | Ahlborg and Hammar (2014); | 1 |
| **83** | Traditional houses | Ahlborg and Hammar (2014); | 1 |
| **84** | Natural reserves and national parks | Ahlborg and Hammar (2014); | 1 |
| **85** | Seasonal droughts/cyclones | Ahlborg and Hammar (2014); | 1 |
| **86** | Variability and intermittency of radiation | Ohunakin *et al.* (2014); | 1 |
| **87** | Grid unreliability | Ohunakin *et al.* (2014); | 1 |
| **88** | Ineffective quality control of products | Ohunakin *et al.* (2014); | 1 |
| **89** | Specific technology needs | Pegels (2010); | 1 |
| **90** | Lack of institutional capacity | Urmee *et al.* (2009); | 1 |
| **91** | Underinvestment in R&D programs | Sen and Ganguly (2017); Painuly (2001); Nalan *et al.* (2009); | 3 |
| **92** | Unavailability of topographic data | Sen and Ganguly (2017); Urmee *et al.* (2009) | 2 |
| **93** | Compensation | Sen and Ganguly (2017); | 1 |

Table 3.1. Barriers with Their Frequencies (Cont.).

| S.No. | Barriers | Authors | freq. |
|---|---|---|---|
| **94** | Underinvestment | Sen and Ganguly (2017); | 1 |
| **95** | Highly controlled energy sector | Painuly (2001); | 1 |
| **96** | Restricted access of technology | Painuly (2001); | 1 |
| **97** | Missing market infrastructure | Painuly (2001); | 1 |
| **98** | Economically not viable | Painuly (2001); | 1 |
| **99** | High discount rates | Painuly (2001); | 1 |
| **100** | High payback period | Painuly (2001); Eleftheriadis and Anagnostopoulou (2015); | 2 |
| **101** | Problems in realizing financial incentives | Painuly (2001); | 1 |
| **102** | Unstable macro-economic environment | Painuly (2001); | 1 |
| **103** | Lack of Operation and Maintenance facilities | Painuly (2001); | 1 |
| **104** | Lack of entrepreneurs | Painuly (2001); | 1 |
| **105** | System constraints | Painuly (2001); | 1 |
| **106** | Lack of consumer acceptance of the product | Painuly (2001); | 1 |
| **107** | Lack of social acceptance for some RETs | Painuly (2001); | 1 |
| **108** | High risk perception | Painuly (2001); | 1 |
| **109** | Lack of infrastructure | Painuly (2001); | 1 |
| **110** | Local opposition to construction of wind farms | Eleftheriadis and Anagnostopoulou (2015); | 1 |
| **111** | Local opposition to installations of PV | Eleftheriadis and Anagnostopoulou (2015); | 1 |
| **112** | Lack of domestic manufacturing industry | Kaya (2004); Painuly (2001); Eleftheriadis and Anagnostopoulou (2015); | 3 |
| **113** | Island are not linked to the main electricity grid | Eleftheriadis and Anagnostopoulou (2015); | 1 |
| **114** | Grid capacity | Eleftheriadis and Anagnostopoulou (2015); | 1 |
| **115** | Lack of stable energy policy | Eleftheriadis and Anagnostopoulou (2015); | 1 |
| **116** | Delays in the issuance of building permits | Eleftheriadis and Anagnostopoulou (2015); | 1 |

Amongst the 116 barriers some of the barriers are merged according to their similarity to obtain a high frequency factor. A new name is given to some of the barriers to generalize its meaning. High initial capital cost, rising cost of land for installing wind farms, lack of adequate financial resources, financially in-competitive, administrative costs in small off-grid systems, underinvestment, and high payback period are combined to make a new barrier *"High investment requirements"*. Lack of financial stability and commercial market, lack of co-investments, liability insurance requirements, donor dependency, and in-sufficient rural financial institutions are merged into the barrier *"Lack of financial mechanisms"*. Lack of subsidies, difficulty of fuel risk assessment, and high discount rates are merged to form a new barrier *"Policy of Subsidies"*.

Improper maintenance and Lack of Operation and Maintenance facilities are merged with *"High operation and maintenance cost"*. Account life-cycle costs and Lacking internalization of external costs are merged with *"Exclusion of environmental externalities in the cost"*. User mechanism service network, transmission and distribution losses, and lack of distribution mechanisms are merged with *"Transaction cost"*.

Lack of local engagement, Lack of awareness of technology, change of mind among customers, lack of consumer acceptance of the product, lack of consumer awareness of technology, and Lack of social acceptance for some RETs are merged to form a new barrier *"Lack of awareness of Renewable Energy"*. User support and scattered population are merged with *"Lack of sufficient market base"*. Costlier than Conventional power systems and economically not viable barriers are merged with *"Lack of paying capacity"*. Lack of entrepreneurs is merged with *"Lack of private sector involvement"*. Low access to required materials and restricted access to technology are merged with *"Trade Barriers"*. Lack of consistency between RE projects, reliability of overall system, and ineffective quality control of products are merged with *"Lack of positive track records"*.

Inefficient technology, Unable to meet electricity power demand alone, less efficiency, technology complexity, mismatch between locally manufactured components and imported parts, high risk perception, high technical losses, low capacity of solar PV systems, variability and intermittency of radiation, and specific technology needs are merged to form a new barrier *"Inefficient and complex technology"*. Lack of research and development work, lack of project implementation models, and lack of funding for technology development are merged with *"Underinvestment in R&D programs"*.

Lack of organizational organizations, low institutional quality, lack of experience, lack of coordination among research groups, and lack of institutional capacity are merged with *"Lack of trained people and training institutes"*. Lack of local infrastructure, lack of distribution mechanism, lack of national infrastructure, grid unreliability, and grid capacity are merged with *"Lack of infrastructure"*. Underinvestment is merged with *"Lack domestic manufacturing industry"*.

Gender issues, competition between land uses and traditional houses, are merged with *"Faiths and Beliefs"*. Local opposition to construction of wind farms and local opposition to installations of PV are merged with *"Rehabilitation Controversies"*. Unavailability of solar radiation data, Geographical conditions, unavailability of topographic data, seasonal droughts/cyclones, and unavailability of wind speed data are combined to form a new barrier *"Unavailability of topographic and/or geographical information"*. Scarcity of natural and renewable resources and natural reserves and national parks are merged with *"Ecological issues"*.

Highly controlled energy sector is merged with *"Monopoly"*. Lack of transparency, system constraints and delays in the issuance of building permits are combined to form a new barrier *"Corruption"*. Lack of Political commitment, lack of adequate government policies, unplanned addition of windfarms, lack of stable energy policy, and coordination between users, policy makers, planners and manufacturers are combined to form a new barrier *"Lack of Political commitment and government policies"*. Top-down management in energy-sector and restrictions on sitting and construction are merged with *"Rigidity in instructions and a centralized planning process"*.

After the merging process all the barriers which had a frequency factor less than 4, except for the barriers *"Criminal or terrorist activities"* and *"Corruption"*, were ignored. These two barriers were included in collaboration with the academicians. This study considered them important barriers and they were included although their frequency factor is less than 4. The total number of critical barriers identified after this process are 28 down from 116.

The resulting list of barriers was further divided into groups with collaboration with the academicians. Table 3.2 shows the groups and the barriers included in those groups. Tables 3.3 shows the updated barriers with their frequencies.

Table 3. 2. Groups and the barriers.

| **Groups** | **Barriers** |
|---|---|
| **Economic and Financial Barriers** | High investment requirements |
| | Lack of financial mechanism |
| | Policy of subsidies |
| | High operation and maintenance cost |
| | Exclusion of environment externalities in cost |
| | Transaction cost |
| **Market Barriers** | Lack of awareness of Renewable energy |
| | Lack of sufficient market base |
| | Lack of paying capacity of consumers |
| | Lack of private sector involvement |
| | Trade barriers |
| | Lack of positive track records |
| **Technical Barriers** | Need for backup or storage devices |
| | Inefficient and complex technology |
| | Underinvestment in R&D |
| | Lack of trained people and training institutes |
| | Lack of infrastructure |
| | Lack of domestic manufacturing industries |
| **Social, Cultural and Environmental Barriers** | Faiths and Beliefs |
| | Rehabilitation controversies |
| | Criminal or terrorist activities |
| | Unavailability of topographic and/or geographical information |
| | Ecological issues |
| **Political and Government Barriers** | Monopoly |
| | Corruption |
| | Lack of standardization |
| | Lack of Political commitment and government policies |
| | Rigidity in instructions and Centralized planning process |

Table 3. 3. Final list of barriers with their groups and frequency.

| **S.No.** | **Barriers** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **freq.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Economic and Financial Barriers** | | | | | | | | | | | | | | | | | |
| **1** | High investment requirements | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 13 |
| **2** | Lack of financial mechanism | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | | ✓ | | | ✓ | | ✓ | | 9 |
| **3** | Policy of subsidies | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | ✓ | | | ✓ | | ✓ | ✓ | 10 |
| **4** | High operation and maintenance cost | | ✓ | | | | ✓ | | | | ✓ | | | | ✓ | ✓ | 5 |
| **5** | Exclusion of environment externalities in cost | | ✓ | ✓ | ✓ | | | ✓ | | | | | ✓ | | | | 5 |
| **6** | Transaction cost | | | ✓ | | ✓ | | | | | | | ✓ | | ✓ | | 4 |
| **Market Barriers** | | | | | | | | | | | | | | | | | |
| **7** | Lack of awareness of Renewable energy | ✓ | ✓ | ✓ | | | ✓ | ✓ | | ✓ | ✓ | | | | | ✓ | 8 |
| **8** | Lack of sufficient market base | ✓ | | | ✓ | ✓ | | | | ✓ | | | | | ✓ | | 5 |
| **9** | Lack of paying capacity of consumers | ✓ | ✓ | | | | | | | ✓ | | | | | ✓ | | 4 |
| **10** | Lack of private sector involvement | | | | | | ✓ | ✓ | | ✓ | | ✓ | | | ✓ | ✓ | 6 |
| **11** | Trade barriers | | | | | ✓ | | ✓ | ✓ | ✓ | | | | | ✓ | ✓ | 6 |
| **12** | Lack of positive track records | | ✓ | | | ✓ | | | | ✓ | ✓ | | | | | | 4 |
| **Technical Barriers** | | | | | | | | | | | | | | | | | |
| **13** | Need for backup or storage devices | ✓ | | | | ✓ | | | | ✓ | ✓ | | | | | | 4 |
| **14** | Inefficient and complex technology | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ | | ✓ | ✓ | ✓ | ✓ | | 10 |
| **15** | Underinvestment in R&D | ✓ | ✓ | | | ✓ | | | | | | | | ✓ | ✓ | | 5 |
| **16** | Lack of trained people and training institutes | ✓ | ✓ | | ✓ | | | | | ✓ | | | ✓ | ✓ | | ✓ | 7 |
| **17** | Lack of infrastructure | ✓ | ✓ | ✓ | | ✓ | | | | ✓ | ✓ | | | | ✓ | ✓ | 8 |
| **18** | Lack of domestic manufacturing industries | | | | | | ✓ | | | | | | | ✓ | ✓ | ✓ | 4 |

Table 3. 3. Final list of barriers with their groups and frequency (Cont.).

| **S.No.** | **Barriers** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **freq.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Social, Cultural and Environmental Barriers** | | | | | | | | | | | | | | | | | |
| **19** | Faiths and Beliefs | ✓ | | | | ✓ | | | ✓ | ✓ | ✓ | | | | | | 5 |
| **20** | Rehabilitation controversies | ✓ | | | | | | | ✓ | ✓ | | | | | | ✓ | 4 |
| **21** | Criminal or terrorist activities | | | | | | | | | ✓ | ✓ | | | | | | 2 |
| **22** | Unavailability of topographic and/or geographical information | ✓ | | | | ✓ | | | | ✓ | | | ✓ | ✓ | | | 5 |
| **23** | Ecological issues | ✓ | | | | ✓ | | | | ✓ | | | | | ✓ | | 4 |
| **Political and Government Barriers** | | | | | | | | | | | | | | | | | |
| **24** | Monopoly | | | | | | | ✓ | ✓ | | | ✓ | | ✓ | ✓ | | 5 |
| **25** | Corruption | | | | | | | | ✓ | | | | | | ✓ | ✓ | 3 |
| **26** | Lack of standardization | | ✓ | | | | ✓ | | | | ✓ | | | | ✓ | | 4 |
| **27** | Lack of Political commitment and government policies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | ✓ | | ✓ | | ✓ | ✓ | 11 |
| **28** | Rigidity in instructions and Centralized planning process | | ✓ | ✓ | | | | | ✓ | ✓ | ✓ | | | | | | 5 |

### 3.2. Interview of Experts

The experts were selected according to their experience in developing countries. Most of the experts who were willing to give interview were from India. A comparison between the experts of India and other experts from other countries has been done in the discussion section to understand the difference.

From the barriers identified in the literature, an interview format was created where the interviewees which were selected on the basis of their experience in Renewable Energy Technology and their experience in developing countries. In the interview the interviewees were asked to make a pair wise comparison between the groups first and then the barriers in respective groups.

A scale of 1-7 was provided where 1 stands for equally preferred, 2 stands for equally to moderately preferred, 3 for moderately preferred, 4 for strongly preferred, 5 for strongly to very strongly preferred, 6 for very strongly preferred, and 7 for extremely preferred. Table 3.4 shows the scale for pair wise comparison. This scale is used for the process of AHP that will be explained in separate section.

Table 3. 4. Scale used for pair wise comparison.

| Code | Linguistic variables |
|---|---|
| **1** | Equally preferred |
| **2** | Equally to moderately preferred |
| **3** | Moderately preferred |
| **4** | Strongly preferred |
| **5** | Strongly to very strongly preferred |
| **6** | Very strongly preferred |
| **7** | Extremely preferred |

To show how the scale worked, an example will be provided. For e.g. let's take the barriers High investment requirement and High operation and maintenance cost. If the interviewee thinks that they were equally important then he/she would highlight the number 1. If he/she thinks that "High investment requirements" is a much stronger barrier than the "High operation and maintenance cost" then he/she would highlight any number from 2-7, according to how strong he thinks the barrier is than the other, which is nearer to "High investment requirements". If he/she thinks that "High operation and maintenance cost" is a much stronger barrier, then he would highlight any number from 2-7 but in this case nearer to the "High operation and maintenance cost".

### 3.3. Analytical Hierarchy Process (AHP)

AHP is defined as "a decision making model that aids us in making decisions in our complex world" (Saaty, 1988). It is a multi-criteria decision making method and was introduced by Saaty in 1970s. The full form of AHP is "Analytical Hierarchy Process", here the word "Hierarchy" is important as AHP is a process that involves hierarchy of the goal to the alternatives linking them. On the fundamental level AHP works by establishing priorities for alternatives and criteria that is used to judge the alternatives (Saaty, 2001).

AHP has many uses for decision making some of them are mentioned below (Saaty, 1988):

1. Design a form that represents a complex problem.
2. Measure priorities and choose among alternatives.
3. Measure the consistency.
4. Predict a cost/benefit analysis.
5. Formulate a cost/benefit analysis.
6. Design forwards/ backward planning.
7. Analyze conflict resolution.
8. Develop resource allocation from the cost/benefit analysis.

The most essential task in making decision is to select the factors, in this case barrier, that are important for particular decision. This study utilizes AHP for the ranking performed by the experts. The barrier groups involved in the study included Economical and Financial Barriers, Market Barriers, Technical Barriers, Social, Cultural and Environmental Barriers, and Political and Government Barriers. AHP is utilized in this study since there is not any direct dependency between Economical and Financial Barriers, Market Barriers, Technical Barriers, Social, Cultural and Environmental Barriers, or Political and Government Barriers.

The other motivation of using AHP for this study is because AHP has the higher general awareness. The hierarchal structure of AHP is intuitively more understandable for inexperienced users and because of its simplicity it is more suitable for an illustration and evaluation of group aggregation techniques (Ossadnik *et al.*, 2016). There have been many articles from renewable energy sector which have used AHP technique for their research.

Mardani *et al.* (2015) reviewed 54 different studies from more than 20 high ranking journals in the field of renewable and sustainable energy that were published between 2003 and 2015. They developed a table that illustrates how often different decision making models; AHP, FAHP, ANP, VIKOR, TOPSIS, F-TOPSIS, PROMETHEE, integrated methods, and other methods are used in application areas in the field of sustainable and renewable energy. Table 3.5 shows the frequencies of the decision making techniques in renewable and sustainable energy. Out of the 54 studies 14 of them used AHP as a decision making technique. If advanced form of AHP like VIKOR and ANP are also considered, then 19 of the 54 studies in renewable and sustainable energy used the technique in their respective research.

Table 3. 5. Summary of applications of the DM techniques (Mardani *et al.*, 2015).

| DM Techniques | Frequency Based on Sustainable Energy | Frequency Based on Renewable Energy | Total |
|---|---|---|---|
| **AHP and FAHP** | 8 | 6 | 14 |
| **VIKOR and ANP** | 1 | 4 | 5 |
| **TOPSIS and F-TOPSIS** | 4 | 2 | 6 |
| **PROMETHEE** | 3 | 3 | 6 |
| **Other techniques** | 3 | 8 | 11 |
| **Integrated methods** | 8 | 4 | 12 |
| **Total** | 27 | 27 | 54 |

There are many other studies which are directly related to this research which have used AHP as a decision making tool for their research. Some studies with similar research area which have also applied AHP are as follows; Luthra *et al.* (2015) paper titled "Barriers to renewable/sustainable energy technologies adoption: Indian perspective"; Ghimire and Kim (2018) paper titled "An analysis on barriers to renewable energy development in the context of Nepal using AHP"; Amer and Daim (2011) paper titled "Selection of renewable energy technologies for a developing county: A case of Pakistan"; Karatayev *et al.* (2016) paper titled "Renewable energy technology uptake in Kazakhstan: Policy drivers and barriers in a transitional economy"; Wijayatunga *et al.* (2006) paper titled "Strategies to overcome barriers for cleaner generation technologies in small developing power systems: Sri Lanka case study"; Sindhu *et al.* (2017) paper titled "Solar energy deployment for sustainable future of India: Hybrid SWOCAHP analysis". All these studies have used AHP as a decision making tool for their respective research that are similar to this research.

The AHP arranges the factors in a hierarchy structure that first undergo priority derivation for the performance of the alternatives. The priorities are then derived based on the pairwise assessments using judgement. A weighting and adding process is used in the end to obtain the overall priority for the alternatives to the goal (Saaty, 2001). The pairwise assessment is conducted with the help of a matrix. Table 3.6 shows the matrix. As it can be seen the matrix will contain a diagonal of 1's since when similar criteria would obviously have same importance. The process of AHP in steps is further explained.

Table 3. 6. Matrix of Importance Relationship between the Criteria

| | **n1** | **n2** | **n3** | **n4** |
|---|---|---|---|---|
| **n1** | 1 | … | … | … |
| **n2** | … | 1 | … | … |
| **n3** | … | … | 1 | … |
| **n4** | … | … | … | 1 |

**Step 1:** The first step is to do a pair wise comparison of all the factors using the scale below:

Table 3. 7. AHP Fundamental Scale (Saaty, 1977)

| **Intensity of Importance** | **Definition** |
|---|---|
| 1 | Equal Importance |
| 3 | Moderate importance of one over another |
| 5 | Essential or strong importance |
| 7 | Demonstrated importance |
| 9 | Absolute/Extreme importance |
| 2, 4, 6, 8 | Intermediate values |

A similar scale has been used that has been mentioned in the previous section. The scale was provided to the interviewees for the pair wise comparison of each barrier, which has also been mentioned in the previous section. If an activity "i" has one of the intensity for importance, which is given in Table 3.7, assigned in when compared to an activity "j", then "j" gets the reciprocal value of the assigned value to "i" (Saaty, 1977). The upper part of the matrix is basically the reciprocal of the lower part of the Criteria Comparison matrix [Table 3.8].

**Step 2:** The next step is to sum all the columns of the Criteria Comparison matrix.

Table 3. 8. Summation of the Columns of the Criteria Comparison Matrix.

| | **n1** | **n2** | **n3** | **n4** |
|---|---|---|---|---|
| **n1** | 1 | … | … | … |
| **n2** | … | 1 | … | … |
| **n3** | … | … | 1 | … |
| **n4** | … | … | … | 1 |
| **Sum Columns** | ∑ (column 1) | ∑ (column 2) | ∑ (column 3) | ∑ (column 4) |

**Step 3:** The next step is to normalize the criteria comparison matrix by dividing each element of the column with the sum of that column. The sum of each column in the normalized matrix should be 1.

Table 3. 9. Normalized Criteria Comparison Matrix.

| | **n1** | **n2** | **n3** | **n4** |
|---|---|---|---|---|
| **n1** | 1/∑ (column 1) | ./ ∑ (column 2) | ./ ∑ (column 3) | ./ ∑ (column 4) |
| **n2** | ./ ∑ (column 1) | 1/∑ (column 2) | ./ ∑ (column 3) | ./ ∑ (column 4) |
| **n3** | ./ ∑ (column 1) | ./ ∑ (column 2) | 1/∑ (column 3) | ./ ∑ (column 4) |
| **n4** | ./ ∑ (column 1) | ./ ∑ (column 2) | ./ ∑ (column 3) | 1/∑ (column 4) |
| **Sum Columns** | 1 | 1 | 1 | 1 |

**Step 4:** The next step is to find the mean of each row of the normalized criteria comparison matrix.

Table 3. 10. Normalized Criteria Comparison Matrix with the Criteria Weights.

| | **n1** | **n2** | **n3** | **n4** | **Criteria Weights** |
|---|---|---|---|---|---|
| **n1** | 1/∑ (column 1) | ../ ∑ (column 2) | ../ ∑ (column 3) | ../ ∑ (column 4) | Mean_1 |
| **n2** | ../ ∑ (column 1) | 1/∑ (column 2) | ../ ∑ (column 3) | ../ ∑ (column 4) | Mean_2 |
| **n3** | ../ ∑ (column 1) | ./ ∑ (column 2) | 1/∑ (column 3) | ../ ∑ (column 4) | Mean_3 |
| **n4** | ../ ∑ (column 1) | ../ ∑ (column 2) | ../ ∑ (column 3) | …1/∑ (column 4) | Mean_4 |
| **Sum Columns** | 1 | 1 | 1 | 1 | |

The means of each row of the normalized comparison matrix is the criteria weight for that particular criterion. The determination of the criteria weights is significant as it makes the decision making easier. The aim of AHP is also justified to make decision for a complex problem. The higher the criteria weight the more significant the criteria are considered.

**Step 5:** The next step is to check the consistency ratio of the ranking. The consistency ratio (CR) of a pairwise comparison matrix is the ratio of its consistency index μ to the corresponding Random Index (RI) (Saaty, 2004).

Determination of weight sums factor: $(Ws) = [C](W)$ (3.1)

Consistency vector calculation: Dot product (Consistency) = (Ws) ● (1/W) (3.2)

λ: Average of the elements of (Consistency)

Calculating the consistency index (CI): CI = (λ-n) / (n-1), (3.3)

where n = number of criteria

Finally, Consistency ratio: (CR) = CI/RI, (3.4)

where RI= Random Index

Maintaining the consistency is considered a priority in AHP. The inconsistency magnitude split of 90% and 10% was given by Saaty (1988). This split meant that the consistency ratio obtained has to be less than 10% (0.01) for the data to be consistent. If the consistency ratio comes out to be higher than desired, then Saaty (2004) stated steps to be taken. These steps are as follows:

1. The first step is to find the most inconsistent judgement in the matrix.
2. The second step is to determine the range of values to which that specific judgement can be changed for improvement of the inconsistency
3. The third step is to ask the decision maker, in this case the expert interviewed, to consider changing his judgement to a value that is more appropriate value in the range.

### 3.4. Codes for experts and barriers and information about the experts.

For ease experts and barriers have been given codes. Table 3.11 shows the codes for experts. Table 3.12 shows the codes for barriers. The information about the experts is provided in Table 3.13.

Table 3. 11. Experts with their respective codes.

| Experts | Abbreviation |
|---|---|
| Expert 1 | E1 |
| Expert 2 | E2 |
| Expert 3 | E3 |
| Expert 4 | E4 |
| Expert 5 | E5 |
| Expert 6 | E6 |
| Expert 7 | E7 |
| Expert 8 | E8 |
| Expert 9 | E9 |
| Expert 10 | E10 |

Table 3. 12. Barriers with their respective codes.

| Barriers | Abbreviation |
|---|---|
| **Economic and Financial Barriers** | **B1** |
| High investment requirements | B11 |
| Lack of financial mechanism | B12 |
| Policy of subsidies | B13 |
| High operation and maintenance cost | B14 |
| Exclusion of environment externalities in cost | B15 |
| Transaction cost | B16 |
| **Market Barriers** | **B2** |
| Lack of consumer awareness of Renewable energy | B21 |
| Lack of sufficient market base | B22 |
| Lack of paying capacity of consumers | B23 |
| Lack of private sector involvement | B24 |
| Trade barriers | B25 |
| Lack of positive track records | B26 |
| **Technical Barriers** | **B3** |
| Need for backup or storage devices | B31 |
| Inefficient and complex technology | B32 |
| Underinvestment in R&D | B33 |
| Lack of trained people and training institutes | B34 |
| Lack of infrastructure | B35 |
| Lack of domestic manufacturing industries | B36 |
| **Cultural, Social and Environmental Barriers** | **B4** |
| Faiths and Beliefs | B41 |
| Rehabilitation controversies | B42 |
| Criminal or terrorist activities | B43 |
| Unavailability of topographic and/or geographical information | B44 |
| Ecological issues | B45 |
| **Political and Government Barriers** | **B5** |
| Monopoly | B51 |
| Corruption | B52 |
| Lack of standardization | B53 |
| Lack of Political commitment and government policies | B54 |
| Rigidity in instructions and Centralized planning process | B55 |

Table 3. 13. Information about the experts.

| **Expert** | **Work Experience** | **Countries in which experience gained** | **Renewable Energy sector** |
|---|---|---|---|
| **E1** | 15 | India, Sudan | Solar Energy |
| **E2** | 12 | USA, UK, Turkey | Hydropower, Bioenergy |
| **E3** | 25 | India | Hydropower |
| **E4** | 15 | India | Wind Energy |
| **E5** | 7 | Nigeria, Kenya | Solar Energy |
| **E6** | 15 | India, Uzbekistan | Hydropower |
| **E7** | 28 | East Timor, Indonesia, Australia, Middle East, Sudan, UK | Solar Energy |
| **E8** | 7 | Syria, Turkey, France, Tunisia | Solar Energy |
| **E9** | 13 | India | Solar Energy |
| **E10** | 20 | India | Solar Energy |

# 4. RESULTS AND FINDINGS

The data is collected from 10 experts from the Renewable Energy industry which have considerable experience in one or more of the renewable energy sectors. The information about the experts has already been provided in the previous section. The data is collected from the experts through a questionnaire which has been provided in the Appendix. A total of 28 barriers are gathered and are classified into five groups that are as follows:

(i) Economic and Financial Barriers
(ii) Market Barriers
(iii) Technical Barriers
(iv) Cultural, Social and Environmental Barriers
(v) Political and Government Barriers

The weights, separately for each expert, of the barriers of each group and their respective barriers are listed (Table 4.1). Then the weights of the barriers are normalized by multiplying the weight of each group with the weights of the barriers in that group. The average of the normalized weights by each expert is taken to get the normalized mean weight (Table 4.2).

The barriers are ranked according to their respective normalized mean weights. The barriers are then divided into four categories according to their significance. The barriers with normalized mean weight above 0.05 are considered very significant. Barriers with normalized mean weight between 0.03 and 0.05 are considered moderately significant. Those with normalized mean weight between 0.01 and 0.03 are considered somewhat significant and below 0.01 are considered not so significant.

To understand the variation of the experts' opinion to the rating of the barriers, coefficient of variance (CV) is calculated. To find the coefficient of variation the standard deviation of each barrier from the data received from the interviewees is calculated and divided by the average mean weights of each barrier to find the CV for that barrier. Therefore, CV can be defined as the ratio of the standard deviation to the mean of the original values (Sorensen (2002), Reed *et al.* (2002)). Variation degree of less than 1 is considered as low variance and that greater than 1 is considered as high variance. Table 4.3 give the results of all the above mentioned analysis.

Table 4. 1. Category wise weights for each barrier group and the barriers.

| | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 | E9 | E10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **B1** | 0.50 | 0.15 | 0.21 | 0.50 | 0.45 | 0.10 | 0.50 | 0.52 | 0.46 | 0.46 |
| **B2** | 0.24 | 0.04 | 0.04 | 0.07 | 0.07 | 0.04 | 0.05 | 0.23 | 0.09 | 0.06 |
| **B3** | 0.06 | 0.06 | 0.09 | 0.26 | 0.06 | 0.16 | 0.07 | 0.12 | 0.05 | 0.15 |
| **B4** | 0.10 | 0.25 | 0.40 | 0.06 | 0.20 | 0.43 | 0.16 | 0.08 | 0.26 | 0.26 |
| **B5** | 0.10 | 0.51 | 0.26 | 0.11 | 0.22 | 0.27 | 0.22 | 0.05 | 0.14 | 0.08 |
| | | | | | | | | | | |
| **B11** | 0.24 | 0.07 | 0.30 | 0.31 | 0.32 | 0.16 | 0.24 | 0.41 | 0.26 | 0.24 |
| **B12** | 0.46 | 0.18 | 0.16 | 0.27 | 0.29 | 0.06 | 0.41 | 0.24 | 0.43 | 0.41 |
| **B13** | 0.14 | 0.40 | 0.08 | 0.04 | 0.11 | 0.04 | 0.09 | 0.12 | 0.06 | 0.09 |
| **B14** | 0.06 | 0.18 | 0.35 | 0.06 | 0.17 | 0.29 | 0.04 | 0.06 | 0.04 | 0.04 |
| **B15** | 0.06 | 0.10 | 0.06 | 0.23 | 0.04 | 0.31 | 0.17 | 0.15 | 0.14 | 0.17 |
| **B16** | 0.04 | 0.06 | 0.05 | 0.09 | 0.08 | 0.15 | 0.05 | 0.03 | 0.08 | 0.05 |
| | | | | | | | | | | |
| **B21** | 0.15 | 0.13 | 0.08 | 0.06 | 0.23 | 0.06 | 0.06 | 0.05 | 0.06 | 0.06 |
| **B22** | 0.07 | 0.04 | 0.08 | 0.35 | 0.19 | 0.10 | 0.05 | 0.10 | 0.05 | 0.05 |
| **B23** | 0.19 | 0.17 | 0.20 | 0.28 | 0.43 | 0.17 | 0.34 | 0.22 | 0.34 | 0.34 |
| **B24** | 0.04 | 0.24 | 0.42 | 0.10 | 0.04 | 0.38 | 0.12 | 0.18 | 0.12 | 0.12 |
| **B25** | 0.50 | 0.21 | 0.04 | 0.04 | 0.06 | 0.04 | 0.31 | 0.40 | 0.31 | 0.31 |
| **B26** | 0.04 | 0.21 | 0.18 | 0.17 | 0.04 | 0.26 | 0.12 | 0.03 | 0.12 | 0.12 |

Table 4. 1. Category wise weights for each barrier group and the barriers. (Cont.)

| | **E1** | **E2** | **E3** | **E4** | **E5** | **E6** | **E7** | **E8** | **E9** | **E10** |
|---|---|---|---|---|---|---|---|---|---|---|
| **B31** | 0.06 | 0.29 | 0.04 | 0.05 | 0.03 | 0.04 | 0.04 | 0.10 | 0.04 | 0.04 |
| **B32** | 0.03 | 0.07 | 0.10 | 0.30 | 0.13 | 0.12 | 0.17 | 0.10 | 0.17 | 0.17 |
| **B33** | 0.36 | 0.29 | 0.37 | 0.38 | 0.07 | 0.30 | 0.41 | 0.30 | 0.41 | 0.41 |
| **B34** | 0.29 | 0.11 | 0.18 | 0.13 | 0.24 | 0.17 | 0.21 | 0.30 | 0.21 | 0.21 |
| **B35** | 0.09 | 0.18 | 0.26 | 0.10 | 0.45 | 0.28 | 0.09 | 0.04 | 0.09 | 0.09 |
| **B36** | 0.16 | 0.05 | 0.06 | 0.04 | 0.07 | 0.09 | 0.07 | 0.16 | 0.07 | 0.07 |
| | | | | | | | | | | |
| **B41** | 0.07 | 0.08 | 0.30 | 0.15 | 0.26 | 0.26 | 0.08 | 0.21 | 0.08 | 0.08 |
| **B42** | 0.15 | 0.23 | 0.34 | 0.46 | 0.06 | 0.40 | 0.09 | 0.07 | 0.09 | 0.09 |
| **B43** | 0.54 | 0.09 | 0.05 | 0.07 | 0.49 | 0.07 | 0.58 | 0.54 | 0.58 | 0.58 |
| **B44** | 0.05 | 0.21 | 0.11 | 0.06 | 0.14 | 0.04 | 0.07 | 0.13 | 0.07 | 0.07 |
| **B45** | 0.20 | 0.39 | 0.20 | 0.27 | 0.05 | 0.23 | 0.19 | 0.05 | 0.19 | 0.19 |
| | | | | | | | | | | |
| **B51** | 0.04 | 0.11 | 0.31 | 0.05 | 0.04 | 0.34 | 0.05 | 0.17 | 0.05 | 0.05 |
| **B52** | 0.15 | 0.07 | 0.11 | 0.12 | 0.26 | 0.37 | 0.16 | 0.04 | 0.16 | 0.17 |
| **B53** | 0.43 | 0.18 | 0.05 | 0.42 | 0.47 | 0.06 | 0.42 | 0.38 | 0.42 | 0.41 |
| **B54** | 0.23 | 0.32 | 0.34 | 0.16 | 0.14 | 0.11 | 0.10 | 0.12 | 0.10 | 0.10 |
| **B55** | 0.15 | 0.32 | 0.20 | 0.24 | 0.09 | 0.12 | 0.27 | 0.28 | 0.27 | 0.28 |

Table 4. 2. Normalized weights for barriers and the average of weights.

| | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 | E9 | E10 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **B11** | 0.118 | 0.011 | 0.062 | 0.153 | 0.144 | 0.016 | 0.122 | 0.212 | 0.120 | 0.111 | 0.107 |
| **B12** | 0.228 | 0.027 | 0.032 | 0.136 | 0.133 | 0.006 | 0.206 | 0.125 | 0.197 | 0.188 | 0.128 |
| **B13** | 0.071 | 0.060 | 0.017 | 0.020 | 0.049 | 0.004 | 0.046 | 0.062 | 0.029 | 0.042 | 0.040 |
| **B14** | 0.030 | 0.027 | 0.071 | 0.028 | 0.078 | 0.029 | 0.019 | 0.031 | 0.016 | 0.017 | 0.035 |
| **B15** | 0.031 | 0.015 | 0.013 | 0.114 | 0.018 | 0.031 | 0.086 | 0.078 | 0.064 | 0.078 | 0.053 |
| **B16** | 0.019 | 0.010 | 0.010 | 0.047 | 0.034 | 0.015 | 0.024 | 0.016 | 0.036 | 0.022 | 0.023 |
| | | | | | | | | | | | |
| **B21** | 0.037 | 0.005 | 0.004 | 0.004 | 0.015 | 0.002 | 0.003 | 0.013 | 0.005 | 0.003 | 0.009 |
| **B22** | 0.017 | 0.002 | 0.004 | 0.023 | 0.012 | 0.004 | 0.003 | 0.023 | 0.005 | 0.003 | 0.010 |
| **B23** | 0.046 | 0.007 | 0.008 | 0.018 | 0.029 | 0.006 | 0.016 | 0.052 | 0.029 | 0.020 | 0.023 |
| **B24** | 0.011 | 0.010 | 0.018 | 0.007 | 0.003 | 0.014 | 0.006 | 0.042 | 0.010 | 0.007 | 0.013 |
| **B25** | 0.122 | 0.009 | 0.002 | 0.003 | 0.004 | 0.001 | 0.015 | 0.093 | 0.027 | 0.018 | 0.029 |
| **B26** | 0.010 | 0.009 | 0.008 | 0.011 | 0.003 | 0.010 | 0.006 | 0.007 | 0.011 | 0.007 | 0.008 |
| | | | | | | | | | | | |
| **B31** | 0.003 | 0.016 | 0.004 | 0.012 | 0.002 | 0.007 | 0.002 | 0.012 | 0.002 | 0.005 | 0.007 |
| **B32** | 0.002 | 0.004 | 0.009 | 0.078 | 0.007 | 0.019 | 0.011 | 0.012 | 0.009 | 0.025 | 0.018 |
| **B33** | 0.022 | 0.016 | 0.033 | 0.099 | 0.004 | 0.049 | 0.027 | 0.036 | 0.020 | 0.061 | 0.037 |
| **B34** | 0.018 | 0.006 | 0.016 | 0.034 | 0.014 | 0.027 | 0.014 | 0.036 | 0.011 | 0.031 | 0.021 |
| **B35** | 0.005 | 0.010 | 0.023 | 0.026 | 0.025 | 0.046 | 0.006 | 0.004 | 0.004 | 0.013 | 0.016 |
| **B36** | 0.010 | 0.003 | 0.005 | 0.012 | 0.004 | 0.015 | 0.005 | 0.019 | 0.004 | 0.011 | 0.009 |

Table 4. 2. Normalized weights for barriers and the average of weights. (Cont.)

| | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 | E9 | E10 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **B41** | 0.007 | 0.020 | 0.120 | 0.009 | 0.052 | 0.109 | 0.012 | 0.016 | 0.020 | 0.020 | 0.039 |
| **B42** | 0.015 | 0.056 | 0.137 | 0.029 | 0.013 | 0.172 | 0.014 | 0.006 | 0.023 | 0.023 | 0.049 |
| **B43** | 0.053 | 0.022 | 0.022 | 0.004 | 0.101 | 0.031 | 0.093 | 0.041 | 0.150 | 0.148 | 0.067 |
| **B44** | 0.005 | 0.052 | 0.043 | 0.004 | 0.029 | 0.017 | 0.011 | 0.010 | 0.017 | 0.017 | 0.020 |
| **B45** | 0.020 | 0.095 | 0.080 | 0.017 | 0.009 | 0.097 | 0.031 | 0.004 | 0.050 | 0.050 | 0.045 |
| | | | | | | | | | | | |
| **B51** | 0.004 | 0.056 | 0.080 | 0.006 | 0.010 | 0.091 | 0.011 | 0.009 | 0.007 | 0.004 | 0.028 |
| **B52** | 0.015 | 0.035 | 0.028 | 0.014 | 0.057 | 0.100 | 0.035 | 0.002 | 0.022 | 0.013 | 0.032 |
| **B53** | 0.043 | 0.093 | 0.012 | 0.047 | 0.103 | 0.016 | 0.093 | 0.020 | 0.060 | 0.032 | 0.052 |
| **B54** | 0.022 | 0.162 | 0.088 | 0.018 | 0.030 | 0.030 | 0.021 | 0.006 | 0.014 | 0.008 | 0.040 |
| **B55** | 0.015 | 0.162 | 0.051 | 0.027 | 0.019 | 0.032 | 0.060 | 0.014 | 0.039 | 0.022 | 0.044 |

Table 4. 3. Normalized weights with their respective ranks and variance.

| Barrier code | Barrier | Weight | Rank | Standard Deviation | Coefficient of Variance (CV) | Variation Degree |
|---|---|---|---|---|---|---|
| **B11** | High investment requirements | 0.107 | 2 (VS) | 0.0620 | 0.5796 | LOW |
| **B12** | Lack of financial mechanism | 0.128 | 1 (VS) | 0.0808 | 0.6323 | LOW |
| **B13** | Policy of subsidies | 0.040 | 9 (MS) | 0.0219 | 0.5489 | LOW |
| **B14** | High operation and maintenance cost | 0.035 | 13 (MS) | 0.0218 | 0.6265 | LOW |
| **B15** | Exclusion of environment externalities in cost | 0.053 | 4 (VS) | 0.0357 | 0.6762 | LOW |
| **B16** | Transaction cost | 0.023 | 17 (SS) | 0.0122 | 0.5242 | LOW |
| **B21** | Lack of consumer awareness of Renewable energy | 0.009 | 25 (NS) | 0.0107 | 1.1811 | HIGH |
| **B22** | Lack of sufficient market base | 0.010 | 24 (SS) | 0.0088 | 0.9170 | LOW |
| **B23** | Lack of paying capacity of consumers | 0.023 | 18 (SS) | 0.0158 | 0.6827 | LOW |
| **B24** | Lack of private sector involvement | 0.013 | 23 (SS) | 0.0112 | 0.8756 | LOW |
| **B25** | Trade barriers | 0.029 | 15 (SS) | 0.0426 | 1.4482 | HIGH |
| **B26** | Lack of positive track records | 0.008 | 27 (NS) | 0.0025 | 0.3130 | LOW |
| **B31** | Need for backup or storage devices | 0.007 | 28 (NS) | 0.0052 | 0.7819 | LOW |
| **B32** | Inefficient and complex technology | 0.018 | 21 (SS) | 0.0224 | 1.2624 | HIGH |
| **B33** | Underinvestment in R&D | 0.037 | 12 (MS) | 0.0273 | 0.7419 | LOW |
| **B34** | Lack of trained people and training institutes | 0.021 | 19 (SS) | 0.0106 | 0.5098 | LOW |
| **B35** | Lack of infrastructure | 0.016 | 22 (SS) | 0.0136 | 0.8301 | LOW |
| **B36** | Lack of domestic manufacturing industries | 0.009 | 26 (NS) | 0.0055 | 0.6366 | LOW |

Table 4. 3. Normalized weights with their respective ranks and variance. (Cont.)

| Barrier code | Barrier | Weight | Rank | Standard Deviation | Coefficient of Variance (CV) | Variation Degree |
|---|---|---|---|---|---|---|
| **B41** | Faiths and Beliefs | 0.039 | 11 (MS) | 0.0421 | 1.0882 | HIGH |
| **B42** | Rehabilitation controversies | 0.049 | 6 (MS) | 0.0580 | 1.1899 | HIGH |
| **B43** | Criminal or terrorist activities | 0.067 | 3 (VS) | 0.0532 | 0.7980 | LOW |
| **B44** | Unavailability of topographic and/or geographical information | 0.020 | 20 (SS) | 0.0161 | 0.7887 | LOW |
| **B45** | Ecological issues | 0.045 | 7 (MS) | 0.0352 | 0.7744 | LOW |
| **B51** | Monopoly | 0.028 | 16 (SS) | 0.0344 | 1.2407 | HIGH |
| **B52** | Corruption | 0.032 | 14 (MS) | 0.0284 | 0.8826 | LOW |
| **B53** | Lack of standardization | 0.052 | 5 (VS) | 0.0341 | 0.6564 | LOW |
| **B54** | Lack of Political commitment and government policies | 0.040 | 10 (MS) | 0.0486 | 1.2220 | HIGH |
| **B55** | Rigidity in instructions and Centralized planning process | 0.044 | 8 (MS) | 0.0440 | 0.9988 | LOW |

*Figure 4.1* shows the Coefficient of variance (CV) for the five groups of barriers in graphical form. It is evident that the variation for the barrier groups is low. *Figure 4.2* shows the Coefficient of Variance (CV) for the individual barriers. It can be inferred from the graph that there are 7 barriers where the opinion of the experts was divided. These 7 barriers are, Lack of consumer awareness of Renewable Energy (B21), Trade Barriers (B25), Inefficient and Complex technology (B32), Faiths and Beliefs (B41), Rehabilitation controversies (B42), Monopoly (B51), and Lack of Political commitment and government policies (B54). The CV of the barrier "Rigidity in instructions and Centralized planning process (B55)" is very close to 1 but by definition of CV it will be considered as a low variation.

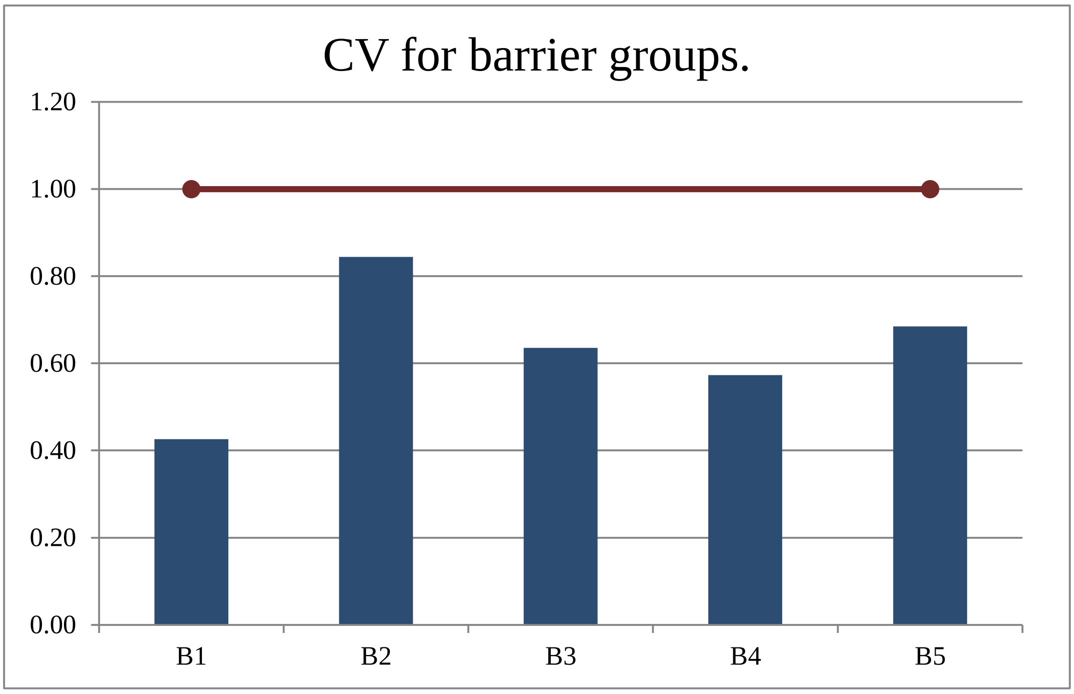


Figure 4. 1. CV for barrier groups.

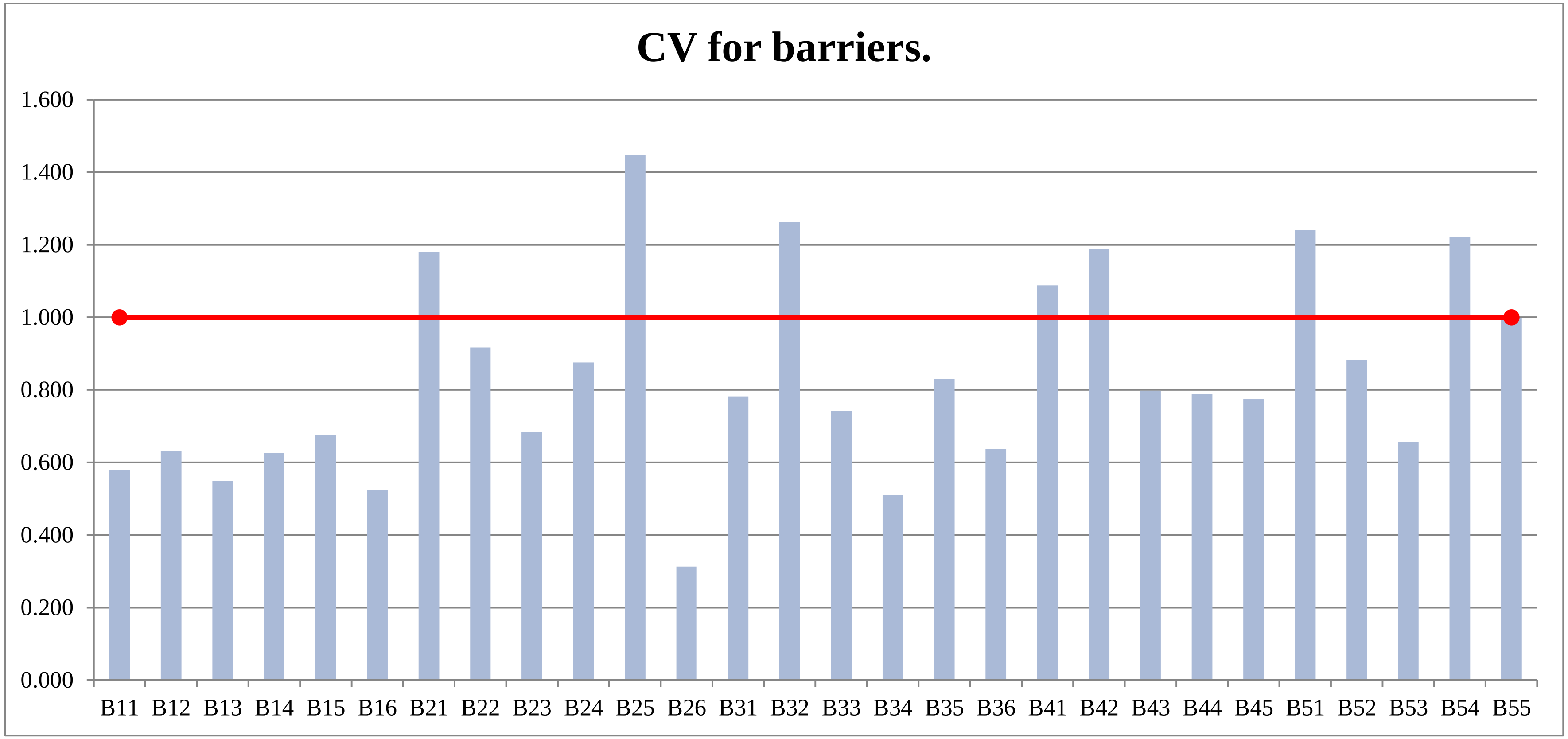


Figure 4. 2. CV for barriers

# 5. **DISCUSSION AND CONCLUSION**

## 5.1. Discussion

In the past few decades Renewable Energy has been a trendy topic. Since the oil crisis of 1973 and the realization of existential threats, like Climate Change and Global warming, there has been a lot of interest in Renewable Technology. There has been lot of research in this area. There has been very few research that have reviewed all the renewable sources of energy. All the major renewable sources have been reviewed in this research and important information is provided for each of them. Though there is a great potential and advantage of renewable sources many developing countries have been slow in implementing them. Most of the developing countries have high population growth and an exponential growth in the energy demand. Therefore, a need for research aroused in identifying what were the general barriers which hinder the implementation of renewable energy technology in these developing countries.

The weights for the barrier groups found in this research are as follows; Economical and Financial Barriers (0.386); Cultural, Social, and Environmental Barriers (0.220); Political and Government Barriers (0.196); Technical Barriers (0.107); Market Barriers (0.092).

When we look at similar research like that of Luthra *et al.* (2014), which focuses on India, the weights of the groups are as follows; Ecological and Geographical (0.303); Political and Government (0.267); Technical (0.152); Economic and Financial (0.127); Awareness and Information (0.080); Cultural and Behavioral (0.038); Market (0.033). To compare it with this research the weights of Ecological and Geographical are combined with Cultural and Behavioral (0.341).

It can be seen that Economic and financial barriers are ranked above Cultural, Social, and Environmental barriers this research whereas the research done by Luthra *et al.* (2014) ranks Cultural, Social, and Environmental barriers 3 ranks above Economic and Financial. It can be inferred from this that when the developing countries are looked at in general Economic and Financial barriers comes out to be more important than when only looked at India. Similarly, Political and Government barriers and Technical barriers are ranked above

Economic and Financial barriers in the research by Luthra *et al.* (2014) but are ranked below in this research. Market barriers in both the researches are ranked the lowest.

Another similar research which focuses on Nepal, by Ghimire and Kim (2018), ranks the barrier categories as follows; Policy and Political Barriers (0.278); Economical Barriers (0.247); Geographic Barriers (0.153); Administrative Barriers (0.153); Social Barriers (0.099); Technical Barriers (0.089). To compare Policy and Political Barriers are combined with Administrative Barriers (0.431) and Social Barriers are combined with Geographic barriers (0.252). In this case, Policy and Political barriers are ranked 1st, two ranks above the Economic and Financial barriers after combination of barriers, whereas in this research it is the opposite. Combined weights of Geographical and Social Barriers is same as in this research. Technical Barriers are ranked last and since Market barriers are not considered in the research done by Ghimire and Kim (2018) it can be said both are ranked similarly in both the researches.

Another similar research which focuses on Pakistan, by Amer and Daim (2011), ranks the barrier categories as follows; Economical (0.35); Technical (0.26); Social (0.12); Environmental (0.15); Political (0.12). For comparison Social and Environmental categories are clubbed together (0.27). When compared with this research Economic and Social and Environment categories are ranked similarly. Technical category is ranked above Political category which is opposite in the case of this research. It can be inferred that in the case of Pakistan, Technical category could be more significant than Political category but when looked at the developing countries in general it could be different.

There is another similar research which focuses on Kazakhstan, by Karatayev *et al.* (2016), which ranks the barrier categories as follows; Economic and Financial (0.491); Technical (0.232); Institutional (0.153); Market Failure (0.083); Social and Cultural (0.039). Both this research and the research mentioned rank Economic and Financial as the most important barrier category. Political and Government category of this research can be said to be similar to the Institutional category of the research mentioned, and in both the researches they are ranked 3rd. Technical category is ranked 2nd in the research mentioned and 4th in this research that shows when it is looked at Nepal technical barriers may be more significant but when looked at in general developing countries it is not as significant. Similarly, the research in Nepal lists social and cultural barriers last but this research founds that it is a very significant category when looked at the developing countries in general. In both the research the category of Market comes out to be a not so significant category.

If the average of the research mentioned is taken, then Table 5.1 is obtained. The Awareness of Information category in the research by Luthra et. al (2014) is eliminated and its weight is divided amongst the other categories equally. When the ranks of the categories are looked at now they are much closer to this research. The only exception is Social, Cultural, and Environmental barriers that are ranked 2nd in this research and 4th in the average. The main reason for this difference is that the countries that have mostly been affected by Social, Culture, and Environmental barriers are the African countries, which still follow old traditions and tribal systems, and none of the studies mentioned have focused on them. The other categories come out to be similar to this research.

Table 5. 1. Average weights of categories from similar research.

| | **Luthra et. al (2014)** | **Ghimire and Kim (2018)** | **Amer and Daim (2011)** | **Karatayev *et al.* (2016)** | **Avg.** | **Rank** |
|---|---|---|---|---|---|---|
| **Economic and Financial Barriers** | 0.143 | 0.247 | 0.35 | 0.491 | 0.308 | 1 |
| **Cultural, Social, and Environmental Barriers** | 0.054 | 0.252 | 0.27 | 0.039 | 0.154 | 4 |
| **Political and Government Barriers** | 0.283 | 0.431 | 0.12 | 0.153 | 0.247 | 2 |
| **Technical Barriers** | 0.168 | 0.089 | 0.26 | 0.232 | 0.187 | 3 |
| **Market Barriers** | 0.049 | - | - | 0.083 | 0.066 | 5 |

The coefficient of variation was also calculated for the barrier categories of this research and is presented in the Results and Findings Section. It was found that there was no significant variation in the opinions of experts with regards to the weights of the barrier categories.

Luthra *et al.* (2015) identifies 27 barriers, Ghimire and Kim (2018) identifies 22 barriers, and Karatayev *et al.* (2016) identifies 17 barriers respectively. This information would be helpful in understanding the ranks and allotted category when doing the comparison amongst the barriers. The higher rank means that the barrier is more significant. So when this study allots a category to the barriers from the studies mentioned it will look at the total number of barriers these studied had identified.

There are five barriers that have been considered as very significant barriers by this research which are as follows; Lack of financial mechanism (0.128), High Investment Requirement (0.107), Criminal and terrorist activities (0.067), Exclusion of environment externalities in cost (0.053), and Lack of standardization (0.052).

Lack of Financial mechanisms and High Investment Requirement have been significant barriers to the adoption of Renewable Energy Technology in developing countries because most of the developing countries are also not financially rich countries when compared with the developed countries. However, there are a few exceptions like the oil rich Gulf states where there is no lack of financial resources for the government for investing in these technologies but there are other barriers there.

Criminal and terrorist activities has not been mentioned at all or in studies mentioned it is not mentioned as a very significant barrier. This barrier coming out to be so significant could be directed to increase in terrorist activities in many developing countries like India, Pakistan, Turkey, Middle East, Afghanistan etc. These terrorist activities cause huge damage to the infrastructure which also effects the Renewable sector. Even in developing countries where there is not so significant terrorism they have a significant amount of poor populace and this is one reason of theft. This barrier was considered by most of the experts as very significant.

Exclusion of environmental externalities is considered a big issue since power from Renewable Energy cannot compete with traditional power. The Governments of most developing countries even have subsidies on fossil fuels that makes it even worse. Therefore, to encourage investors to invest in Renewables including the cost of environmental damage would be a great asset.

The structural system of the developing countries is not well organized when compared to developed countries. The reasons for this are that most of the developing countries got their independence recently, have limited financial resources, and many have unstable governments. Therefore, the lack of standardization came out to be one of the significant barrier.

The research by Luthra et. al (2015) had ranked Lack of Financial Mechanism (0.0276) 10th and High initial capital cost (0.0276) which corresponds to High investment requirements as 8th. Therefore, when compared with this research they could be considered as moderately significant barriers with respect to their ranks when focusing on India. Criminal and terrorist activities, Exclusion of environment externalities in cost, and Lack of standardization are surprisingly not mentioned in the research by Luthra et. al (2014) though the experts, majority of which had experience in India, considered them to be significant barriers.

The research by Ghimire and Kim (2018) had ranked Lack of credit Access (0.053) which corresponds to Lack of financial mechanism as 9th, Lack of funds (0.056) as 7th and High capital cost (0.049) as 10th which together corresponds to High investment requirement. Lack of financial mechanism can be considered as moderately significant barriers with respective to their ranks when focusing on Nepal. This could be because Nepal is a very poor and unstable country, hence there are more significant problems than Lack of financial mechanisms. If we combine the weights of Lack of funds and High capital cost (0.105) the combined rank comes out to be 1st. This makes it a very significant barrier which is the case for this research also.

The research by Amer and Daim (2011) had ranked Capital cost (0.095) 1st, which corresponds to High investment requirement in this research. Both this research and the mentioned research have considered it as very significant barrier to the implementation of renewable energy technology.

The research by Karatayev *et al.* (2016), High capital investment ranked 11th and lack of financial resources ranked 12th, which when combined corresponds to High investment requirements in this research, Weak financial support, ranked 15th, which corresponds to Lack of financial mechanism, and Weak legal and regulatory framework, ranked 2nd, which corresponds to Lack of standardization are mentioned. It can be inferred from the ranks that the research by Karatayev et. al (2016) considers High investment requirements and Lack of financial mechanism as some-what significant barriers which is contrary to the results of this research, and Lack of standardization as a very significant barrier which is similar to the results of this research. The main reason for the difference is that Kazakhstan is an oil producing country and therefore has a lot of financial resources at its hand.

According to results of coefficient of variation, amongst the most significant barriers none of the barriers had a high variation that shows the experts had almost the same opinion about these very significant barriers. The barrier "Criminal and Terrorist activities" has not been mentioned in many studies but was inserted in the list with the insistence of the experts and collaboration with the academicians. The results show that it was a wise decision as it came out to be a very significant barrier.

After the very significant barriers next is the moderately significant barriers which are as follows; Rehabilitation controversies (0.049); Ecological issues (0.045); Rigidity in instructions and Centralized planning process (0.044); Policy of subsidies (0.040); Lack of Political commitment and government policies (0.040); Faiths and Beliefs (0.039); Underinvestment in R&D (0.037); High operation and maintenance cost (0.035); Corruption (0.032).

The research by Luthra *et al.* (2015) ranks Rehabilitation controversies (0.0205) as 17$^{th}$, Ecological issues (0.141) as 2$^{nd}$, Lack of subsidies (0.0192), which corresponds to Policy of subsidy in this research, is ranked 19$^{th}$, Lack of political commitment (0.141) which is ranked 1$^{st}$ and Lack of adequate government policies (0.09) which is ranked 4$^{th}$ combine corresponds to Lack of political commitment and government policies, Faiths and Beliefs (0.011) is ranked 22$^{nd}$, and Lack of R&D work, which corresponds to Underinvestment in R&D in this research, is ranked 15$^{th}$. Ecological issues and Lack of political commitment and government policies could be considered very significant barriers according to the research by Luthra *et al.* (2015) but in this research they came out to be moderately significant barriers. It can be inferred from this that Ecological issues and Lack of political commitment and government policies could be very significant in the case of India but when looking at the developing countries in general they come out to be moderately significant. This tells us that the barriers found in this study could have difference in their significance levels among the developing countries. But this study would also like to point out that the study by Luthra *et al.* (2015)

Lack of R&D work and Rehabilitation controversies could be considered as moderately significant, according to the ranking by Luthra *et al.* (2015), which is similar to ranking of the corresponding barriers in this research. Lack of Subsidies and Faiths and Beliefs could be considered as somewhat significant barriers, according to ranking by Luthra *et al.* (2015), but in this research they came out to be moderately significant. This is because the research by Luthra (2014) is focused on India and the barriers Faiths and Beliefs has more significance in the African countries and in the case of subsidies the Indian government have given many subsidies to renewable energy technologies hence it would not be very significant when focusing of India.

The research by Ghimire and Kim (2018) ranks Lack of transparency in decision process (0.056), which corresponds to Rigidity in instruction and centralized planning process, as 8$^{th}$, Political instability (0.089) ranked 1$^{st}$ and Lack of coherent RE policy (0.074) ranked 3$^{rd}$ combine to correspond to the Lack of political commitment and government policies, Lack of social acceptance (0.018) that corresponds to Faiths and Beliefs barrier of this research is ranked 21$^{st}$, Lack of R&D facility (0.027) which corresponds to Underinvestment in R&D is ranked 17$^{th}$, and Corruption and Nepotism (0.059), which corresponds to Corruption in this research, is ranked 5$^{th}$.

Political instability, Lack of coherent RE policy, and Corruption could be considered as very significant barrier in the case of Nepal but is moderately significant according to this research when looked at developing countries in general. Lack of transparency in decision process can be considered as a moderately significant barrier in the case of Nepal and this is similar to the results of this research. Underinvestment in R&D could be considered as somewhat significant barrier and Faiths and Beliefs as not so significant barrier, when grouping them according to this research, in the case of Nepal but in this study the results show them as moderately significant. The reason behind this could be that Nepal is a very small country and has faced many political crises in the near past. Therefore, the political barriers are more significant in the country and the barriers like Underinvestment in R&D and Faiths and Beliefs are not so important right now. This situation could change in the future. Therefore, it can be inferred from this that the barriers could also have change in the significance level according to the political scenario of a country.

The research by Karatayev *et al.* (2016) ranks Complicated bureaucratic procedures, which corresponds to Rigidity in instructions and Centralized planning process, as 16$^{th}$, Fossil fuel subsidies that corresponds to Policy of subsidies ranks 10$^{th}$, Lack of social acceptance that corresponds to Faiths and Beliefs ranks 13$^{th}$, and Lack of R&D that corresponds to Underinvestment in R&D ranks 14$^{th}$. According to the criteria established in this research if these barriers are grouped under the significance categories, except for Fossil fuel subsidies all the other mentioned would be categorized as either somewhat significant or not so significant whereas in this study all of the mentioned barriers fall under moderately significant barriers. The reason for this is that Kazakhstan government has been actively working on the renewable energy sector and even have set prices for the power being generated by them. This is in compliance with the goal of the country in being a green economy by 2050.

According to the results of coefficient of variance there are three barriers from the list of moderately significant barriers where the variation in the opinions of the experts was significant. These three barriers with their CV are as follows; Rehabilitation controversies (1.19); Lack of Political commitment and government policies (1.22); Faiths and Beliefs (1.09). For these three barriers, amongst the moderately significant barriers, the difference in weighting them amongst the experts was significant.

After moderately significant barriers the group of somewhat significant (SS) barriers is analyzed. There are ten barriers which are grouped under somewhat significant barriers that are as follows; Trade barriers (0.029); Monopoly (0.028); Transaction cost (0.023); Lack of paying capacity of consumers (0.023); Lack of trained people and training institutes (0.021); Unavailability of topographic and/or geographical information (0.020); Inefficient and complex technology (0.018); Lack of infrastructure (0.016); Lack of private sector involvement (0.013); Lack of sufficient market base (0.010).

Luthra *et al.* (2015) ranks Transmission and Distribution losses (0.0202) that corresponds to Transaction cost barrier of this study as 18$^{th}$, Lack of paying capacity (0.0066) ranked 24$^{th}$, Lack of trained people and training institutes (0.0158) ranked 21$^{st}$, Unavailability of solar radiation data (0.033) that corresponds to Unavailability of topographic and./or geographical information of this study is ranked 9$^{th}$, Less efficiency (0.0275) ranked 15$^{th}$, Inefficient technology (0.0237) ranked 14$^{th}$ and Technological complexity (0.0366) ranked 7$^{th}$ together correspond to Inefficient and complex technology barrier of this study, Lack of local infrastructure (0.0185) ranked 20$^{th}$ and lack of national infrastructure (0.0249) ranked 13$^{th}$ together corresponds to the Lack of infrastructure barrier of this study, and Lack of sufficient market base (0.0109) is ranked 23$^{rd}$. Going by the criteria of this study, Transmission and Distribution losses, Lack of trained people and training institutes, lack of paying capacity, and lack of sufficient market base will fall under the category of somewhat significant barriers similar to this study. Unavailability of solar radiation data, less efficiency, inefficient technology and technological complexity together, and lack of local infrastructure and lack of national infrastructure together would fall under either moderately significant or highly significant contrary to this research.

The research by Ghimire and Kim (2018) ranks Lack of consumer paying capacity (0.048) as 11th; Lack of skilled manpower (0.023) that corresponds to Lack of trained people and training institutes barrier is ranked 19th; Unreliable supply (0.017) that corresponds to Inefficient and complex technology barrier of this research is ranked 22nd; Lack of Grid connection mechanism (0.026) that corresponds to the barrier Lack of infrastructure of this research is ranked 18th; Lack of Sufficient size of market (0.032) that corresponds to Lack of sufficient market base is ranked 16th. Lack of skilled manpower, lack of sufficient market base, and Lack of Grid connection mechanism would fall under somewhat significant barriers according to the criteria of this study. This is similar to this research. Lack of consumer paying capacity would fall under moderately significant barriers and Unreliable Supply would fall under not-so significant barriers, which is contrary to this research. Nepal as mentioned before is a very poor country and hence the paying capacity of the population is a more significant barrier in the case of Nepal.

The research by Karatayev *et al.* (2016) ranks Lack of competition that corresponds to Monopoly barrier of this study as 17th; Social Poverty is ranked 6th and corresponds to "Lack of paying capacity of consumers" barrier of this study; Lack of skilled training facilities corresponds to Lack of trained people and training institutes and is ranked 16th; Inefficient technologies is ranked 4th and corresponds to Inefficient and complex technologies barrier of this study. Lack of competition and Lack of skilled training facilities would fall under the not so significant barriers. Social Poverty and Inefficient technologies would either fall under moderately significant or very significant barrier category.

According to the results of coefficient of variance there are three barriers from the list of somewhat significant barriers where the variation in the opinions of the experts was significant. These three barriers with their CV are as follows; Trade barriers (1.45), Monopoly (1.24), and Inefficient and complex technology (1.26). For these three barriers, amongst the somewhat significant barriers, the difference in weighting them by the experts was significant.

The last category of the barriers left is the not so significant barriers. This study identified four barriers, which would fall under this category, that are as follows; Lack of consumer awareness of Renewable energy (0.009); Lack of domestic manufacturing industries (0.009); Lack of positive track records (0.008); Need for backup or storage devices (0.007).

The research by Luthra *et al.* (2015) ranks Lack of consumer awareness of technology (0.0109), which corresponds to Lack of consumer awareness of Renewable Energy in this study, as 23rd; Need for backup or storage device (0.0208) is ranked 16th. According to the criteria both of the mentioned barriers would fall under the category of somewhat significant which is contrary to the results of this research. The research by Ghimire and Kim (2018) ranks Lack of public awareness (0.033) that corresponds to Lack of consumer awareness of Renewable energy as 14th; Risk and uncertainty (0.019) that corresponds to Lack of positive track records is ranked 20th. Lack of public awareness would fall into the category of some-what significant and Lack of positive track records under not-so significant barriers. The research by Karatayev *et al.* (2016) ranks Low consumer awareness, which corresponds to Lack of consumer awareness of Renewable energy, as 9th. This is contrary to the result of this study as the barrier would fall under moderately significant whereas in this research it was found to be not so significant.

The coefficient of variance for the not so significant barriers had one barrier with high variation which is Lack of consumer awareness of Renewable energy. There was a significant difference of opinion which ranking this barrier among the experts. This is to be understood since there is a big gap in the literacy rate of different developing countries.

For further evaluation first the opinion of experts from India is analyzed. This analysis was required to understand the difference of opinion amongst the experts from India regarding the barriers to the adoption of renewable energy to know about which barriers difference of opinion exist amongst the experts from the same region. Table 5.2 shows the variance level among the Indian experts.

Table 5. 2. Indian Experts opinion about the barriers.

| **Barrier code** | **E1** | **E3** | **E4** | **E6** | **E9** | **E10** | **AVG.** | **Standard Deviation** | **CV** | **Variance Level** |
|---|---|---|---|---|---|---|---|---|---|---|
| **B1** | 0.50 | 0.21 | 0.50 | 0.10 | 0.46 | 0.46 | 0.37 | 0.17 | 0.46 | LOW |
| **B2** | 0.24 | 0.04 | 0.07 | 0.04 | 0.09 | 0.06 | 0.09 | 0.08 | 0.87 | LOW |
| **B3** | 0.06 | 0.09 | 0.26 | 0.16 | 0.05 | 0.15 | 0.13 | 0.08 | 0.62 | LOW |
| **B4** | 0.10 | 0.40 | 0.06 | 0.43 | 0.26 | 0.26 | 0.25 | 0.15 | 0.59 | LOW |
| **B5** | 0.10 | 0.26 | 0.11 | 0.27 | 0.14 | 0.08 | 0.16 | 0.08 | 0.52 | LOW |
| **B12** | 0.23 | 0.03 | 0.14 | 0.01 | 0.20 | 0.19 | 0.13 | 0.09 | 0.70 | LOW |
| **B11** | 0.12 | 0.06 | 0.15 | 0.02 | 0.12 | 0.11 | 0.10 | 0.05 | 0.51 | LOW |
| **B43** | 0.05 | 0.02 | 0.00 | 0.03 | 0.15 | 0.15 | 0.07 | 0.06 | 0.95 | LOW |
| **B15** | 0.03 | 0.01 | 0.11 | 0.03 | 0.06 | 0.08 | 0.06 | 0.04 | 0.68 | LOW |
| **B53** | 0.04 | 0.01 | 0.05 | 0.02 | 0.06 | 0.03 | 0.04 | 0.02 | 0.52 | LOW |
| **B42** | 0.01 | 0.14 | 0.03 | 0.17 | 0.02 | 0.02 | 0.07 | 0.07 | 1.04 | HIGH |
| **B45** | 0.02 | 0.08 | 0.02 | 0.10 | 0.05 | 0.05 | 0.05 | 0.03 | 0.61 | LOW |
| **B55** | 0.02 | 0.05 | 0.03 | 0.03 | 0.04 | 0.02 | 0.03 | 0.01 | 0.41 | LOW |
| **B13** | 0.07 | 0.02 | 0.02 | 0.00 | 0.03 | 0.04 | 0.03 | 0.02 | 0.77 | LOW |
| **B54** | 0.02 | 0.09 | 0.02 | 0.03 | 0.01 | 0.01 | 0.03 | 0.03 | 0.98 | LOW |
| **B41** | 0.01 | 0.12 | 0.01 | 0.11 | 0.02 | 0.02 | 0.05 | 0.05 | 1.10 | HIGH |
| **B33** | 0.02 | 0.03 | 0.10 | 0.05 | 0.02 | 0.06 | 0.05 | 0.03 | 0.63 | LOW |
| **B14** | 0.03 | 0.07 | 0.03 | 0.03 | 0.02 | 0.02 | 0.03 | 0.02 | 0.63 | LOW |

Table 5. 2. Indian Experts opinion about the barriers (Cont.)

| **Barrier code** | **E1** | **E3** | **E4** | **E6** | **E9** | **E10** | **AVG.** | **Standard Deviation** | **CV** | **Variance Level** |
|---|---|---|---|---|---|---|---|---|---|---|
| **B52** | 0.02 | 0.03 | 0.01 | 0.10 | 0.02 | 0.01 | 0.03 | 0.03 | 1.05 | HIGH |
| **B25** | 0.12 | 0.00 | 0.00 | 0.00 | 0.03 | 0.02 | 0.03 | 0.05 | 1.62 | HIGH |
| **B51** | 0.00 | 0.08 | 0.01 | 0.09 | 0.01 | 0.00 | 0.03 | 0.04 | 1.30 | HIGH |
| **B16** | 0.02 | 0.01 | 0.05 | 0.02 | 0.04 | 0.02 | 0.02 | 0.01 | 0.56 | LOW |
| **B23** | 0.05 | 0.01 | 0.02 | 0.01 | 0.03 | 0.02 | 0.02 | 0.01 | 0.69 | LOW |
| **B34** | 0.02 | 0.02 | 0.03 | 0.03 | 0.01 | 0.03 | 0.02 | 0.01 | 0.41 | LOW |
| **B44** | 0.00 | 0.04 | 0.00 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.82 | LOW |
| **B32** | 0.00 | 0.01 | 0.08 | 0.02 | 0.01 | 0.03 | 0.02 | 0.03 | 1.18 | HIGH |
| **B35** | 0.01 | 0.02 | 0.03 | 0.05 | 0.00 | 0.01 | 0.02 | 0.02 | 0.79 | LOW |
| **B24** | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.38 | LOW |
| **B22** | 0.02 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.94 | LOW |
| **B21** | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 1.49 | HIGH |
| **B36** | 0.01 | 0.01 | 0.01 | 0.02 | 0.00 | 0.01 | 0.01 | 0.00 | 0.46 | LOW |
| **B26** | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.17 | LOW |
| **B31** | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.00 | 0.65 | LOW |

From Table 5.2 it is evident that there was not much difference in the opinion of the experts from India about the weights of the barrier groups. However, there was a difference in opinion regarding some of the barriers. The barriers which had a high variance are as follows: Rehabilitation controversies; Faiths and Beliefs; Corruption; Trade barriers; Monopoly; Inefficient and complex technology; Lack of consumer awareness of Renewable energy.

The experts from India had one on one interview and hence it is easier for this study to know about the difference of opinion amongst these experts. These difference of opinion arises due to multi culturalism and federal system of India. Corruption, Rehabilitation Controversies, and Monopoly are problems which have different effects in different states since different laws are enacted in different states. Similarly Lack of consumer awareness of Renewable energy and Inefficient and complex technology are very much related to the literacy rate of the region and the literacy rate is significantly different if the north region of India is compared with the South. With regards to the Trade barriers some of the experts considered it necessary to promote domestic manufacturers and others had a different opinion.

This study further compares the average weights given by the experts from India with two objectives, first to understand the difference of opinion and second to understand whether the high frequency of Indian experts had any impact on the overall result of this study.

First, this study compares the average weights given by Indian Experts with Expert 2 who has experience in USA and Turkey. Table 5.3 shows the result of the comparison.

Table 5. 3. Difference of opinion between the Indian Experts and E2.

| **Barrier code** | **AVG. WEIGHTS GIVEN BY INDIAN EXPERTS** | **AVG. WEIGHT GIVEN BY E2 (USA, TURKEY)** | **AVG.** | **ST. DEV.** | **CV** | **Variance Level** |
|---|---|---|---|---|---|---|
| **B1** | 0.37 | 0.15 | 0.26 | 0.16 | 0.60 | LOW |
| **B2** | 0.09 | 0.04 | 0.06 | 0.03 | 0.53 | LOW |
| **B3** | 0.13 | 0.06 | 0.09 | 0.05 | 0.56 | LOW |
| **B4** | 0.25 | 0.25 | 0.25 | 0.00 | 0.02 | LOW |

Table 5.3. Difference of opinion between the Indian Experts and E2 (Cont.).

| Barrier code | AVG. WEIGHTS GIVEN BY INDIAN EXPERTS | AVG. WEIGHT GIVEN BY E2 (USA, TURKEY) | AVG. | ST. DEV. | CV | Variance Level |
|---|---|---|---|---|---|---|
| **B5** | 0.16 | 0.51 | 0.33 | 0.25 | 0.74 | LOW |
| **B12** | 0.13 | 0.03 | 0.08 | 0.07 | 0.93 | LOW |
| **B11** | 0.10 | 0.01 | 0.05 | 0.06 | 1.13 | HIGH |
| **B43** | 0.07 | 0.02 | 0.05 | 0.03 | 0.72 | LOW |
| **B15** | 0.06 | 0.02 | 0.04 | 0.03 | 0.80 | LOW |
| **B53** | 0.04 | 0.09 | 0.06 | 0.04 | 0.64 | LOW |
| **B42** | 0.07 | 0.06 | 0.06 | 0.01 | 0.12 | LOW |
| **B45** | 0.05 | 0.10 | 0.07 | 0.03 | 0.41 | LOW |
| **B55** | 0.03 | 0.16 | 0.10 | 0.09 | 0.96 | LOW |
| **B13** | 0.03 | 0.06 | 0.05 | 0.02 | 0.47 | LOW |
| **B54** | 0.03 | 0.16 | 0.10 | 0.09 | 0.97 | LOW |
| **B41** | 0.05 | 0.02 | 0.03 | 0.02 | 0.56 | LOW |
| **B33** | 0.05 | 0.02 | 0.03 | 0.02 | 0.69 | LOW |
| **B14** | 0.03 | 0.03 | 0.03 | 0.00 | 0.11 | LOW |
| **B52** | 0.03 | 0.03 | 0.03 | 0.00 | 0.06 | LOW |
| **B25** | 0.03 | 0.01 | 0.02 | 0.01 | 0.77 | LOW |
| **B51** | 0.03 | 0.06 | 0.04 | 0.02 | 0.38 | LOW |
| **B16** | 0.02 | 0.01 | 0.02 | 0.01 | 0.63 | LOW |
| **B23** | 0.02 | 0.01 | 0.01 | 0.01 | 0.74 | LOW |
| **B34** | 0.02 | 0.01 | 0.01 | 0.01 | 0.80 | LOW |
| **B44** | 0.02 | 0.05 | 0.03 | 0.02 | 0.71 | LOW |
| **B32** | 0.02 | 0.00 | 0.01 | 0.01 | 1.01 | HIGH |
| **B35** | 0.02 | 0.01 | 0.01 | 0.01 | 0.46 | LOW |
| **B24** | 0.01 | 0.01 | 0.01 | 0.00 | 0.10 | LOW |
| **B22** | 0.01 | 0.00 | 0.01 | 0.01 | 0.99 | LOW |
| **B21** | 0.01 | 0.01 | 0.01 | 0.00 | 0.38 | LOW |
| **B36** | 0.01 | 0.00 | 0.01 | 0.00 | 0.79 | LOW |
| **B26** | 0.01 | 0.01 | 0.01 | 0.00 | 0.07 | LOW |
| **B31** | 0.01 | 0.02 | 0.01 | 0.01 | 0.71 | LOW |

From Table 5.3 it can be concluded that in general there was not much difference of opinion with regards to weighting the barrier groups and barriers amongst the experts from India and Expert 2. However, they had a difference of opinion regarding two of the barriers that are “High investment requirements” and “Inefficient and complex technology”. This difference of opinion regarding High Investment requirements can be understood when looked in the perspective economic conditions in Turkey and India. Turkey is a middle income country and hence it can much better afford investment in Renewable technologies rather than India. The barrier “Inefficient and complex technology” is very much related to the literacy rate and hence it is not surprising that the expert from Turkey had a difference of opinion since literacy rate in Turkey is far better than that of India.

Next the study compares the average weights given by Indian Experts to the weights given by Expert 5 who has experience in Nigeria and Kenya. Table 5.4 shows the result of the comparison.

Table 5. 4. Difference of opinion between the Indian Experts and E5.

| Barrier code | AVG. WEIGHTS GIVEN BY INDIAN EXPERTS | AVG. WEIGHT GIVEN BY E5 (Nigeria, Kenya) | AVG. | Standard Deviation | CV | Variance Level |
|---|---|---|---|---|---|---|
| **B1** | 0.37 | 0.45 | 0.41 | 0.06 | 0.14 | LOW |
| **B2** | 0.09 | 0.07 | 0.08 | 0.02 | 0.21 | LOW |
| **B3** | 0.13 | 0.06 | 0.09 | 0.05 | 0.55 | LOW |
| **B4** | 0.25 | 0.20 | 0.23 | 0.03 | 0.15 | LOW |
| **B5** | 0.16 | 0.22 | 0.19 | 0.04 | 0.22 | LOW |
| **B12** | 0.13 | 0.13 | 0.13 | 0.00 | 0.01 | LOW |
| **B11** | 0.10 | 0.14 | 0.12 | 0.03 | 0.27 | LOW |
| **B43** | 0.07 | 0.10 | 0.08 | 0.02 | 0.27 | LOW |
| **B15** | 0.06 | 0.02 | 0.04 | 0.03 | 0.73 | LOW |
| **B53** | 0.04 | 0.10 | 0.07 | 0.05 | 0.70 | LOW |
| **B42** | 0.07 | 0.01 | 0.04 | 0.04 | 0.95 | LOW |
| **B45** | 0.05 | 0.01 | 0.03 | 0.03 | 0.99 | LOW |
| **B55** | 0.03 | 0.02 | 0.03 | 0.01 | 0.32 | LOW |
| **B13** | 0.03 | 0.05 | 0.04 | 0.01 | 0.33 | LOW |

Table 5. 4. Difference of opinion between the Indian Experts and E5 (Cont.).

| **Barrier code** | **AVG. WEIGHTS GIVEN BY INDIAN EXPERTS** | **AVG. WEIGHT GIVEN BY E5 (Nigeria, Kenya)** | **AVG.** | **Standard Deviation** | **CV** | **Variance Level** |
|---|---|---|---|---|---|---|
| **B54** | 0.03 | 0.03 | 0.03 | 0.00 | 0.01 | LOW |
| **B41** | 0.05 | 0.05 | 0.05 | 0.00 | 0.07 | LOW |
| **B33** | 0.05 | 0.00 | 0.03 | 0.03 | 1.19 | HIGH |
| **B14** | 0.03 | 0.08 | 0.05 | 0.03 | 0.59 | LOW |
| **B52** | 0.03 | 0.06 | 0.04 | 0.02 | 0.39 | LOW |
| **B25** | 0.03 | 0.00 | 0.02 | 0.02 | 1.06 | HIGH |
| **B51** | 0.03 | 0.01 | 0.02 | 0.02 | 0.76 | LOW |
| **B16** | 0.02 | 0.03 | 0.03 | 0.01 | 0.22 | LOW |
| **B23** | 0.02 | 0.03 | 0.03 | 0.01 | 0.20 | LOW |
| **B34** | 0.02 | 0.01 | 0.02 | 0.01 | 0.35 | LOW |
| **B44** | 0.02 | 0.03 | 0.02 | 0.01 | 0.35 | LOW |
| **B32** | 0.02 | 0.01 | 0.02 | 0.01 | 0.75 | LOW |
| **B35** | 0.02 | 0.03 | 0.02 | 0.00 | 0.17 | LOW |
| **B24** | 0.01 | 0.00 | 0.01 | 0.01 | 0.83 | LOW |
| **B22** | 0.01 | 0.01 | 0.01 | 0.00 | 0.21 | LOW |
| **B21** | 0.01 | 0.02 | 0.01 | 0.00 | 0.37 | LOW |
| **B36** | 0.01 | 0.00 | 0.01 | 0.00 | 0.55 | LOW |
| **B26** | 0.01 | 0.00 | 0.01 | 0.00 | 0.77 | LOW |
| **B31** | 0.01 | 0.00 | 0.00 | 0.00 | 0.67 | LOW |

Similarly, there was not much a difference in opinion regarding the weighting of barrier groups and barriers between the Indian experts and Expert 5. The barriers where there was a difference of opinion were “Underinvestment in R&D” and “Trade barriers”. Since Nigeria and Kenya are poorer countries than India it is understood that Investment in R&D would not be priority barrier for them. Next the opinion of Indian experts was compared with that of Expert 7 who has experience in Australia, Middle East, Sudan, and UK. Table 5.5 shows the results of the comparison.

Table 5. 5. Difference of opinion between the Indian Experts and E7.

| Barrier code | AVG. WEIGHTS GIVEN BY INDIAN EXPERTS | AVG. WEIGHT GIVEN BY E7 (Australia, Middle East, Sudan, UK) | AVG. | Standard Deviation | CV | Variance Level |
|---|---|---|---|---|---|---|
| **B1** | 0.37 | 0.50 | 0.44 | 0.09 | 0.21 | LOW |
| **B2** | 0.09 | 0.05 | 0.07 | 0.03 | 0.42 | LOW |
| **B3** | 0.13 | 0.07 | 0.10 | 0.04 | 0.46 | LOW |
| **B4** | 0.25 | 0.16 | 0.21 | 0.06 | 0.31 | LOW |
| **B5** | 0.16 | 0.22 | 0.19 | 0.04 | 0.23 | LOW |
| **B12** | 0.13 | 0.01 | 0.07 | 0.09 | 1.22 | HIGH |
| **B11** | 0.10 | 0.00 | 0.05 | 0.07 | 1.41 | HIGH |
| **B43** | 0.07 | 0.03 | 0.05 | 0.02 | 0.48 | LOW |
| **B15** | 0.06 | 0.02 | 0.04 | 0.03 | 0.74 | LOW |
| **B53** | 0.04 | 0.00 | 0.02 | 0.02 | 1.41 | HIGH |
| **B42** | 0.07 | 0.01 | 0.04 | 0.04 | 0.97 | LOW |
| **B45** | 0.05 | 0.06 | 0.06 | 0.00 | 0.07 | LOW |
| **B55** | 0.03 | 0.00 | 0.02 | 0.02 | 1.41 | HIGH |
| **B13** | 0.03 | 0.00 | 0.02 | 0.02 | 1.16 | HIGH |
| **B54** | 0.03 | 0.00 | 0.01 | 0.02 | 1.41 | HIGH |
| **B41** | 0.05 | 0.02 | 0.03 | 0.02 | 0.58 | LOW |
| **B33** | 0.05 | 0.09 | 0.07 | 0.03 | 0.45 | HIGH |
| **B14** | 0.03 | 0.01 | 0.02 | 0.01 | 0.64 | LOW |
| **B52** | 0.03 | 0.00 | 0.02 | 0.02 | 1.41 | HIGH |
| **B25** | 0.03 | 0.02 | 0.02 | 0.01 | 0.24 | LOW |
| **B51** | 0.03 | 0.00 | 0.02 | 0.02 | 1.41 | HIGH |
| **B16** | 0.02 | 0.02 | 0.02 | 0.01 | 0.33 | LOW |
| **B23** | 0.02 | 0.01 | 0.02 | 0.01 | 0.35 | LOW |
| **B34** | 0.02 | 0.04 | 0.03 | 0.01 | 0.31 | LOW |
| **B44** | 0.02 | 0.06 | 0.04 | 0.03 | 0.76 | LOW |
| **B32** | 0.02 | 0.03 | 0.03 | 0.01 | 0.23 | LOW |
| **B35** | 0.02 | 0.08 | 0.05 | 0.05 | 0.88 | LOW |
| **B24** | 0.01 | 0.05 | 0.03 | 0.03 | 0.93 | LOW |
| **B22** | 0.01 | 0.05 | 0.03 | 0.03 | 1.00 | HIGH |

Table 5. 5. Difference of opinion between the Indian Experts and E7 (Cont.).

| Barrier code | AVG. WEIGHTS GIVEN BY INDIAN EXPERTS | AVG. WEIGHT GIVEN BY E7 (Australia, Middle East, Sudan, UK) | AVG. | Standard Deviation | CV | Variance Level |
|---|---|---|---|---|---|---|
| **B21** | 0.01 | 0.00 | 0.00 | 0.01 | 1.41 | HIGH |
| **B36** | 0.01 | 0.15 | 0.08 | 0.10 | 1.25 | HIGH |
| **B26** | 0.01 | 0.03 | 0.02 | 0.02 | 0.78 | LOW |
| **B31** | 0.01 | 0.00 | 0.00 | 0.00 | 1.41 | HIGH |

There was not much variance between the weights given by Indian experts and that given by Expert 7 when looking at the barrier groups. But there were a lot of barriers where the variance was high. The barriers where the experts differed were as follows: Lack of financial mechanism; High investment requirements; Lack of standardization; Rigidity in instructions and Centralized planning process; Policy of subsidies; Lack of Political commitment and government policies; Underinvestment in R&D; Corruption; Monopoly; Lack of sufficient market base; Lack of consumer awareness of Renewable energy; Lack of domestic manufacturing industries; Need for backup or storage devices.

Amongst these 13 barriers where there was significant difference of opinion between Indian Experts and Expert 7, there were 10 barriers where the average of weights given by Indian Experts was greater than the weights by Expert 7 and 3 barriers where the situation was opposite.

The 10 barriers where the average of weights given by Indian Experts was greater than weights given by Expert 7 are as follows: Lack of financial mechanism; High investment requirements; Lack of standardization; Rigidity in instructions and Centralized planning process; Policy of subsidies; Lack of Political commitment and government policies; Corruption; Monopoly; Lack of consumer awareness of Renewable energy; Need for backup or storage devices. “Lack of financial mechanism” and “High Investment Requirements” are barriers which are related to the financial capacity of a country and

Middle East is an oil rich nation hence it is obvious why Expert 7 didn't consider them to be as significant as the Indian experts.

In recent years many Middle Eastern countries have introduced many policies regarding Renewable Energy technology and therefore "Lack of standardization", "Rigidity in instructions and Centralized planning process", "Lack of Political commitment and government policies" and "Policy of subsidies" is not a big issue when compared with India. The literacy rate of majority of Middle Eastern Countries is much better than that of India hence the reason why Expert 7 weighted "Lack of consumer awareness of Renewable energy" lower when compared with the average weight given by Indian experts. This study could not understand the difference in opinion for the following barriers: Corruption; Monopoly.

In the end the opinion of Indian experts would be compared with Expert 8 who has experience in Syria, Turkey, France, and Tunisia. Table 5.6 shows the results of the comparison.

Table 5. 6. Difference of opinion between the Indian Experts and E8.

| **Barrier code** | **AVG. WEIGHTS GIVEN BY INDIAN EXPERTS** | **AVG. WEIGHT GIVEN BY E8 ( Syria, Turkey, France, Tunisia )** | **AVG.** | **Standard Deviation** | **CV** | **Variance Level** |
|---|---|---|---|---|---|---|
| **B1** | 0.37 | 0.52 | 0.45 | 0.11 | 0.24 | LOW |
| **B2** | 0.09 | 0.23 | 0.16 | 0.10 | 0.62 | LOW |
| **B3** | 0.13 | 0.12 | 0.12 | 0.01 | 0.05 | LOW |
| **B4** | 0.25 | 0.08 | 0.16 | 0.12 | 0.76 | LOW |
| **B5** | 0.16 | 0.05 | 0.11 | 0.08 | 0.73 | LOW |
| **B12** | 0.13 | 0.01 | 0.07 | 0.09 | 1.22 | HIGH |
| **B11** | 0.10 | 0.00 | 0.05 | 0.07 | 1.41 | HIGH |
| **B43** | 0.07 | 0.03 | 0.05 | 0.02 | 0.48 | LOW |
| **B15** | 0.06 | 0.02 | 0.04 | 0.03 | 0.74 | LOW |
| **B53** | 0.04 | 0.00 | 0.02 | 0.02 | 1.41 | HIGH |

Table 5. 6. Difference of opinion between the Indian Experts and E8 (Cont.).

| Barrier code | AVG. WEIGHTS GIVEN BY INDIAN EXPERTS | AVG. WEIGHT GIVEN BY E8 ( Syria, Turkey, France, Tunisia ) | AVG. | Standard Deviation | CV | Variance Level |
|---|---|---|---|---|---|---|
| **B42** | 0.07 | 0.01 | 0.04 | 0.04 | 0.97 | LOW |
| **B45** | 0.05 | 0.06 | 0.06 | 0.00 | 0.07 | LOW |
| **B55** | 0.03 | 0.00 | 0.02 | 0.02 | 1.41 | HIGH |
| **B13** | 0.03 | 0.00 | 0.02 | 0.02 | 1.16 | HIGH |
| **B54** | 0.03 | 0.00 | 0.01 | 0.02 | 1.41 | HIGH |
| **B41** | 0.05 | 0.02 | 0.03 | 0.02 | 0.58 | LOW |
| **B33** | 0.05 | 0.09 | 0.07 | 0.03 | 0.45 | LOW |
| **B14** | 0.03 | 0.01 | 0.02 | 0.01 | 0.64 | LOW |
| **B52** | 0.03 | 0.00 | 0.02 | 0.02 | 1.41 | HIGH |
| **B25** | 0.03 | 0.02 | 0.02 | 0.01 | 0.24 | LOW |
| **B51** | 0.03 | 0.00 | 0.02 | 0.02 | 1.41 | HIGH |
| **B16** | 0.02 | 0.02 | 0.02 | 0.01 | 0.33 | LOW |
| **B23** | 0.02 | 0.01 | 0.02 | 0.01 | 0.35 | LOW |
| **B34** | 0.02 | 0.04 | 0.03 | 0.01 | 0.31 | LOW |
| **B44** | 0.02 | 0.06 | 0.04 | 0.03 | 0.76 | LOW |
| **B32** | 0.02 | 0.03 | 0.03 | 0.01 | 0.23 | LOW |
| **B35** | 0.02 | 0.08 | 0.05 | 0.05 | 0.88 | LOW |
| **B24** | 0.01 | 0.05 | 0.03 | 0.03 | 0.93 | LOW |
| **B22** | 0.01 | 0.05 | 0.03 | 0.03 | 1.00 | LOW |
| **B21** | 0.01 | 0.00 | 0.00 | 0.01 | 1.41 | HIGH |
| **B36** | 0.01 | 0.15 | 0.08 | 0.10 | 1.25 | HIGH |
| **B26** | 0.01 | 0.03 | 0.02 | 0.02 | 0.78 | LOW |
| **B31** | 0.01 | 0.00 | 0.00 | 0.00 | 1.41 | HIGH |

There was not much variance when weighting the barrier groups between the Indian Experts and Expert 8. But there was difference of opinion regarding the weights of barriers. The barriers with high variance are as follows; Lack of financial mechanism; High investment requirements; Lack of standardization; Rigidity in instructions and Centralized planning process; Policy of subsidies; Lack of Political commitment and government policies; Corruption; Monopoly; Lack of consumer awareness of Renewable energy; Lack of domestic manufacturing industries; Need for backup or storage devices. Expert 8 also had one on one interview and therefore his comments regarding the barriers were recorded which would help in analyzing this difference of opinion.

Amongst these 11 barriers where there was significant difference of opinion between Indian Experts and Expert 8, there were 10 barriers where the average of weights given by Indian Experts was greater than the weights by Expert 8 and only one barrier where the situation was opposite. These barriers are as follows: Lack of financial mechanism; High investment requirements; Lack of standardization; Rigidity in instructions and Centralized planning process; Policy of subsidies; Lack of Political commitment and government policies; Corruption; Monopoly; Lack of consumer awareness of Renewable energy; Need for backup or storage devices.

Expert 8 was of the opinion that the significance of barriers mentioned has significantly reduced in recent years. The cost of the technology has reduced, the banks are more open to giving credits for ventures in Renewable energy, and the governments have introduced and adopted many policies to encourage the implementation of renewable energy. The people in the countries where he worked have a much better literacy rate than India which shows the difference of opinion regarding the barrier “Lack of consumer awareness of technology”.

The one barrier where the weight given by Expert 8 was more than the average weight given by the Indian experts was “Lack of domestic manufacturing industry”. The expert was of the opinion that even with the significant reduction in the investment requirements there is a lack of domestic production.

From these comparisons it can be understood that though in general the variance was low amongst the opinion of experts but some of the barriers had different level of significance according to these experts. The difference in opinion amongst the experts from

India was certainly due to the federal system of governance and difference in the literacy rate amongst the states. The barriers listed by this study can be said to be general barriers but the significance some of these barriers could change according to the regions. Even if a country is considered there could be a difference of opinion regarding some of the barriers as seen in the case of India.

## 5.2. Conclusion

Renewable energy has been a very trendy topic in recent decades. After the oil crisis and realization of threat of Global warming and Climate change a lot of interest has been generated in this topic. This research seeks to confirm the following objectives; (1) To review the major sources of renewable energy; (2) to evaluate the barriers that hinder the adoption of renewable energy technology in developing countries; (3) to rank and analyze the barriers; (4) compare the results with existing studies that are similar to this study.

The first objective was accomplished to an extent by reviewing the literature for all the major renewable sources of energy. The information like their definition, history, current situation, and benefits and limitations was provided to get an idea about these major sources of renewable energy. This study has a limitation for this objective. This study has considered only the five major types of the renewable sources of energy: Solar, Wind, Hydropower, Geothermal and Biomass. These five types of renewable resources have been mentioned in many studies whereas Tidal Power is somewhat new compared to these five types. Hence, this study did not consider Tidal Power as renewable source of energy for this research though it acknowledged as a renewable energy resource. Tidal energy though not significant now but could play a major role in the future and hence it can be considered as a limitation for not including it.

The second objective was accomplished by evaluating 15 studies from different parts of the world and finding the barriers which hinder the adoption of renewable energy technology in developing countries. The barriers which were too specific to a region or too specific to a renewable source were not considered. This study focused on general barriers that were responsible for hindering the adoption of renewable technology in developing countries. From 116 barriers found in the literature the list was reduced to 28 barriers by combining similar barriers, forming new barriers, and by eliminating the region or renewable source specific barriers. These 28 barriers were also divided into 5 categories.

The third objective was accomplished by getting the interviews from the experts and analyzing them by the help of AHP decision making tool. The weights were calculated for each barrier by the data provided by ten experts from the industry. Average was calculated of the weights of each barrier and then normalized. After this they were ranked and hence this marked the accomplishment of the third objective.

In the discussion section the results were compared with studies that were similar to this study and thus accomplished the fourth objective. It could be concluded from the comparison that the barriers found in this study are general to developing countries and their significance could differ when looked at specific countries. Some of the barriers like Exclusion of Environmental externalities in cost, Criminal or terrorist activities, High operation and maintenance cost, lack of private sector involvement, Lack of domestic manufacturing industries, and Need for backup or storage devices were not mentioned in the three studies which are used to compare the barriers with.

Exclusion of Environmental externalities in cost and Criminal or terrorist activities were found to be very significant barriers and it can be concluded for these two barriers that future studies should study about these barriers more to get their significance in today’s world.

The barriers found in this study could apply to developing countries in general and this study could be used by the developing countries to get the general barriers that hinder the adoption of renewable technology in their respective countries though the level of significance for each barrier could change according to the country being considered. More data and opinion of experts is required for getting more precise result or in other words near ideal results that could give a more general view of the barriers in developing countries.

. The Experts are essential part of this study. This study used many experts with experience in different renewable energy source and different countries. This was necessary since this study aimed to find the general barriers that could be applied generally to majority of the developing countries and renewable energy sources. It can also be seen there was difference of opinion between the experts from different regions regarding the weights of barriers but this difference of opinion also persists amongst the experts of the same region like seen in this study in the case of India. Therefore, it can be concluded that this study gives a big picture regarding the barriers to renewable energy in developing countries and acknowledges that the significance could be different in different regions. No expert from geothermal sector could be found for this study and 6 of the 10 experts were from the solar energy sector which could have affected the results.

The method used in this study have some limitations. The AHP technique utilized in this study considers that there is no interrelationship between the risk factors of different groups. The possibility of having an interrelationship between some barriers can be considered. In the case of developing countries, there are very few studies available in the literature in this area that have used AHP as a decision making tool. There is a need to find the barriers for a developing country from different continents to compare the results of this study. There is especially very less data for Africa and the estimated potential of renewable energy is very high in the continent. The studies that are used to compare this study all belong to Asia.

The contribution of this study to the literature is to provide a comprehensive review of Renewable Energy and its major categories but the main contribution is to provide the general barriers to the adoption of renewable energy technology in developing countries. Moreover, very limited studies have been conducted that have considered to analyze developing countries as a group and find the barriers affecting them. Most of the studies in the literature have either been country specific or renewable energy specific or both. Few researches have clubbed countries according to their geographical positions but fewer researches have clubbed and analyzed them according to their development status. This study is a step forward for the researchers to analyze the countries by clubbing them according to their development status.

# REFERENCES


A brief History of hydropower. *International hydropower association*. https://www.hydropower.org/a-brief-history-of-hydropower, accessed in May 2019.

A. Gurbuz. 2006. The role of Hydropower in Sustainable development. *European Water 13/14:63-70, 2006, European water publications.*

A. Jagadeesh. 2000. Wind Energy development in Tamil Nadu and Andhra Pradesh, India Institutional dynamics and barriers- A case study. *Energy policy 28 (2000) 157-168.*

A. John Armstrong, Esq. and Dr. Jan Hamrin. The Renewable Energy Policy Manual. *U.S. Export Council for Renewable Energy*.

A. Manzella. 2017. Geothermal energy. Institute of Geosciences and Earth Resources - Pisa, Italy. *EPJ Web of Conferences 148, 00012 (2017).*

Abbas Mardani, Ahmad Jusoh, Edmundas Kazimieras Zavadskas, Fausto Cavallaro, and Zainab Khalifah. 2015. Sustainable and Renewable Energy: An Overview of the Application of Multiple Criteria Decision Making Techniques and Approaches. *Sustainability 2015, 7, 13947-13984.*

Adams and Charlotte A. 2015. Geothermal energy – The global opportunity. Proceedings of the Institution of Mechanical Engineers. *Part A: Journal of Power and Energy 229.7 Nov 2015: 747-754.*

Aleksandar R. Radivojevi, Tomislav M. Pavlovi, Dragana D. Milosavljevi, Amelija V. Djordjevi, Mila A. Pavlovi, Ivan M. Filipovi, Lana S. Panti, and Milan R. Puniši. 2015. Influence of Climate and Air Pollution on Solar Energy Development in Serbia. *Thermal Science: Year 2015, Vol. 19, Suppl. 2, pp. S311-S322*

Alina Bradford and Stephanie Pappas. 2017. Effects of Global Warming, Article, Live Science. https://www.livescience.com/37057-global-warming-effects.html, accessed in May 2019.

Amr Faruk. 2017. Critical Infrastructure Protection in Developing Countries. *Handbook of Research on Economic, Financial, and Industrial Impacts on Infrastructure Development, section: Key terms.*

Anna Pegels. 2010. Renewable Energy in South Africa: Potentials, barriers and options for support. *Energy Policy 38 (2010) 4945-4954.*

Askari Mohammad Bagher, Mirzaei Vahid, and Mirhabibi Mohsen. 2014. Geothermal Energy. *Journal of Engineering and Technology research, Vol 6(8), p.p. 146-150, December 2014.*

Baumol WJ, Panzar JC, Willig TD. 1982. Contestable markets and theory of industry structure. *New York, NY, USA: Harcourt Brace Jovanovich; 1982.*

Blachndra Ravindranath NH. 2009. Sustainable bio energy for India: technical, economic and policy analysis. *Renew Energy 2009; 34:1003–13*

Brown MA. 2001. Market failures and barriers as a basis for clean energy policies. *Energy Policy 2001; 29:1197 (-07).*

C.W. Lewis. 1981. Biomass through the ages. *Biomass Volume 1, Issue 1, September 1981, Pages 5-15.*

Cataldi, R., Hodgson, S.F., Lund, J.W. 1999. Stories from a Heated Earth –Our Geothermal Heritage. *Geothermal Resources Council, Davis, California, 580 pp.*

César R. Chamorro, María E. Mondéjar, Roberto Ramos, José J. Segovia, María C. Martín, Miguel A. Villamañán. 2012. World geothermal power production status: Energy, environmental and economic study of high enthalpy technologies. *Energy Volume 42, Issue 1, June 2012, Pages 10-18.*

Chris Frewin, Topic: Renewable Energy, *Student Energy website*. https://www.studentenergy.org/topics/renewable-energy, accessed in May 2019.

Çiçek Bezir Nalan, Öztürk Murat, and Özek Nuri. 2009. Renewable energy market conditions and barriers in Turkey. *Renewable and Sustainable Energy Reviews 13 (2009) 1428-1436.*

Climate Change. 2015. *Paris Agreement, UN*. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement, accessed in May 2019.

Comparison of Lifecycle Greenhouse Gas Emissions of Various Electricity Generation Sources. 2011. *WNA.*

Cherni JA, Kentish J. 2007. Renewable energy policy and electricity market reforms in China. *Energy Policy 2007;35(7):3616–29*

Christopher J. Rees & Beverley D. Metcalfe. 2008. Organizational change and development in transition economies: critical perspectives from Eastern Europe, 11:2, 113-118.

Dan Kasper. USEPA, 2018. Renewable Energy and Non Renewable Energy. *Instructor, John A. Dutton e-Education Institute, College of Earth and Mineral Sciences, The Pennsylvania State University.*

Daniel Duedney. 1981. Hydropower. *Environment Volume 23. No: 7.*

Daniela Thrän, Thilo Seidenberger, Jürgen Zeddies, and Ruth Offermann. 2010. Global biomass potentials — Resources, drivers and scenario results. *Energy for Sustainable Development 14(3):200 – 205.*

Dennis Y.C. Leung and Yuan Yang. 2012. Wind Energy Development and its environmental impact: A review. *Renewable and Sustainable Energy Reviews 16 (2012) 1031–1039.*

Dickson, M.H., Fanelli, M. 2003. Geothermal background, Geothermal Energy: Utilization and Technology. *UNESCO Renewable Energy Series, Earthscan Publications Ltd., London, UK, pp. 1–28.*

Doner J. Barriers to adoption of renewable energy technology. 2007. Institute for Regulatory Policy Studies Working Paper. *Institute for Regulatory Policy Studies, Illinois State University; 2007; 1–31.*

Durmus Kaya. 2006. Renewable Energy policies in Turkey. *Renewable and Sustainable Energy Reviews 10 (2006) 152-163.*

Economic Benefits, Pages, Hydro flows here, Bonneville Power Administration. https://www.bpa.gov/Hydroflowshere/Pages/Economic-Benefits.aspx, accessed in May 2019.

Ehsanul Kabir, Pawan Kumar, Sandeep Kumar, Adedeji A. Adelodun and Ki-Hyun Kim. 2017. Solar energy: Potential and future prospects. *Renewable and Sustainable Energy Reviews 82 (2018) 894–900.*

Elizabeth Lokey. 2009. Barriers to clean development mechanism renewable energy projects in Mexico. *Renewable Energy 34 (2009) 504-508.*

Enrico Barbier. 2002. Geothermal energy technology and current status: an overview. *Renewable and Sustainable Re- view, Vol. 6, No. 1-2, 2002, pp. 3-65.*

Frans H. Koch. 2002. Hydropower—the politics of water and energy: Introduction and overview. *Energy Policy Volume 30, Issue 14, November 2002, Pages 1207-1213.*

Fridleifsson I. 2001. Geothermal energy for the benefit of the people. *Renewable and Sustainable Energy Reviews, 2001, vol. 5, issue 3, 299-312.*

Fridleifsson, I.B., Bertani, R., Huenges, E., Lund, J.W., Ragnarsson, A. and Ryback, L. 2008. The possible role and contribution of geothermal energy to the mitigation of climate change. *IPCC Scoping Meeting on Renewable Energy Sources, Luebeck, Gewrmany 21-25th January 2008.*

Gary W. Frey and Debora M. Linke. 2002. Hydropower as a renewable and sustainable energy resource meeting global energy challenges in a reasonable way. *Energy Policy Volume 30, Issue 14, November 2002, Pages 1261-1265*.

Geothermal Energy throughout the ages, Electricity & Alternative Energy, *Government of Alberta website*. http://www.history.alberta.ca/energyheritage/energy/alternative-energy/geothermal-energy/geothermal-energy-throughout-the-ages.aspx, accessed in May 2019.

Golic, Z. (2019). Problem of Financing Women Entrepreneurs: Experience of Women Entrepreneurs in Post-Conflict Bosnia and Herzegovina. *F. Tomos, N. Kumar, N. Clifton, & D. Hyams-Ssekasi (Eds.), Women Entrepreneurs and Strategic Decision Making in the Global Economy (pp. 278-304). Hershey, PA: IGI Global.*

Green MA, Emery K, Hishikawa Y, Warta W, Dunlop ED. 2016. Solar cell efficiency tables (version 47). *Prog Photovoltaic 2016; 24:3–11*.

Guozhu Mao, Hongyang Zou, Guanyi Chen, Huibin Du, and Jian Zuo. 2015. Past, current and future of biomass energy research: A bibliometric analysis. *Renewable and Sustainable Energy Reviews 52 (2015) 1823–1833*

Helene Ahlborg and Linus Hammar. 2014. Drivers and barriers to rural electrification in Tanzania and Mozambique-Grid-extension, off-grid, and renewable energy technologies. *Renewable Energy 61 (2014) 117-124.*

History of Hydropower, Water Technology Office, Office of Energy Efficiency and Renewable Energy. *U.S. Department of Energy*. https://www.energy.gov/eere/water/history-hydropower, accessed in May 2019.

Hoskisson, R.E., L. Eden, C.M. Lau, and M. Wright. 2000. Strategy in emerging economies. *Academy of Management Journal 43, no. 3: 249–67.*

Hydropower. *Cambridge English Dictionary*. https://dictionary.cambridge.org/dictionary/english/hydropower, accessed in May 2019.

Hydropower. Glossary of hydropower terms, Office of Energy Efficiency and Renewable Energy. *US Department of Energy*. https://www.energy.gov/eere/water/glossary-hydropower-terms, accessed in May 2019.

Hydropower. Glossary. *OECD website*. https://stats.oecd.org/glossary/detail.asp?ID=1271, accessed in May 2019.

Hydropower. Oct, 2009. Global Warming. *National Geographic website*. https://www.nationalgeographic.com/environment/global-warming/hydropower/, accessed in May 2019.

Hydropower. Types of hydropower, IHA. *Hydropower website.* https://www.hydropower.org/types-of-hydropower, accessed in May 2019.

I. Stober and K. Bucher. 2013. History of Geothermal Energy Use. *Geothermal Energy, Berlin, Heidelberg, 2013, 15-24.*

Ibrahim Yüksel. 2010. Hydropower for sustainable water and energy development. *Renewable and Sustainable Energy Reviews Volume 14, Issue 1, January 2010, Pages 462-469.*

Ifijeh, G., Iwu-James, J., Izuagbe, R., & Nwaogu, H. 2019. Faculty Using E-Journals in Developing Countries: Issues and Challenges. *Y. Inoue-Smith (Ed.), Faculty Roles and Changing Expectations in the New Age (pp. 156-175). Hershey, PA: IGI Global.*

Iordanis M. Eleftheriadis and Evgenia G. Anagnostopoulou. 2015. Identifying barriers in the diffusion of renewable energy sources. *Energy Policy 80 (2015) 153-164.*

J.P. Painuly. 2001. Barriers to renewable energy penetration; a framework for analysis. *Renewable Energy 24 (2001) 73-89.*

John W. Lund, Derek H. Freeston, and Tonya L. Boyd. 2011. Direct utilization of geothermal energy 2010 worldwide review. Geothermics Volume 40, Issue 3, September 2011, Pages 159-180.

Jon Limbergera, Thijs Boxemb, Maarten Pluymaekers, David Bruhn, Adele Manzella, Philippe Calcagno, Fred Beekmana, Sierd Cloetingh, Jan-Diederik van Wees. 2018. Geothermal energy in deep aquifers: A global assessment of the resource base for direct heat utilization. *Renewable and Sustainable Energy Reviews 82 (2018) 961–975.*

Kannan N and Vakeesan D. 2016. Solar energy for future world: – A review. *Renewable and Sustainable Energy Reviews 62 (2016) 1092–1105*.

Konstantinos D. Patlitzianas, Haris Doukasm and John Psarras. 2006. Enhancing renewable energy in Arab states of the Gulf: Constraints and efforts. *Energy policy 34 (2006) 3719-3726*

Kumar A, Kumar K, Kaushik N, Sharma S, Mishra S. 2010. Renewable energy in India: current status and future potentials. *Renew Sustain Energy Rev 2010;14 (8):2434–42.*

Laxman Prasad Ghimire and Yeonbae Kim. 2018. An analysis on barriers to renewable energy development in the context of Nepal using AHP. *Renewable Energy 129 (2018) 446-456.*

Lee S, Kim K, and Choi W. 2011.Annoyance caused by amplitude modulation of wind turbine noise. *Control Engineering Journal 2011; 59(1):38-46*

Lora Shinn. 2018. Renewable Energy: The Clean Facts. *NRDC*. https://www.nrdc.org/stories/renewable-energy-clean-facts, accessed in May 2019.

Luke Richardson. 2018. News Article "History of Solar Energy". *Energy sage*. https://news.energysage.com/the-history-and-invention-of-solar-panel-technology/, accessed in May 2019.

Machol R. Economic value of U.S. fossil fuel electricity health impacts. *Environ Int 2013; 52:75–80.*

Marat Karatayev Stephen Hall, Yelena Kalyuzhnova, and Michèle L.Clark. 2016. Renewable energy technology uptake in Kazakhstan: Policy drivers and barriers in a transitional economy. *Renewable and Sustainable Energy Reviews 66 (2016) 120-136.*

Mark Z. Jacobson. 2009. Review of solutions to global warming, air pollution, and energy security. (Review Article) *Energy Environ. Sci.*, 2009, **2**, 148-173.

Martin Pasqualetti, Robert Righter, and Paul Gipe. 2004. History of Wind Energy. *Encyclopedia of Energy, Publisher: Academic Press, Editors: Cutler Cleveland, pp.419-433*.

Masayuki Kaimoto, Biomass Energy: Curbing Global Warming by increasing the Economic Value of Forests. *Environment and Energy.*

Mathew Mason, Article titled "Renewable Energy: All you need to know". https://www.environmentalscience.org/renewable-energy, accessed in May 2019.

Mathias Aarre Maehlum. 2018. Wind Energy Pros and Cons. *Article, Energy Informative website*. http://energyinformative.org/wind-energy-pros-and-cons/, accessed in May 2019.

Miguel-Angel Perea-Moreno, Esther Samerón-Manzano and Alberto-Jesus Perea-Moreno. 2019. Biomass as Renewable Energy: Worldwide Research Trends. *Sustainability2019,11, 863.*

Monique Hoogwijk, Andre´ Faaij, Bas Eickhout, Bert de Vries, and Wim Turkenburg. 2005. Potential of biomass energy out to 2100, for four IPCC SRES land-use scenarios. Biomass and Bioenergy 29 (2005) 225–257

Muhammad Amer and Tugrul U. Daim. 2011. Selection of renewable energy technologies for a developing county: A case of Pakistan. *Energy for Sustainable Development 15 (2011) 420–435.*

Naomi Oreskes. 2004. The Scientific Consensus on Climate Change. *Science, New Series, Vol. 306, No. 5702, Opportunity at Meridiani Planum (Dec. 3, 2004),* p. 1686.

Nguyen NT, Duong MH, Tran TC, Shresth RM, Nadaud F. 2010. Barriers to the adoption of renewable and energy-efficient technologies in the Vietnamese power sector. *Halshs-00444826, version 1–7; January 2010*

Nisha Sriram and Mohammad Shahidehpour. 2005. Renewable Biomass Energy. *Electric Power and Power Electronics Center, Illinois Institute of Technology.*

Olayinka S. Ohunakin, Muyiwa S. Andaramola, Olanrewaju. M. Oyewola, and Richard O. Fagbenle. 2014. Solar Energy applications and development in Nigeria: Drivers and barriers. *Renewable and Sustainable Energy Reviews 32 (2014) 294-301.*

Omar Ellabban, Haitum Abu-Rub, and Frede Blaabjerg. 2014. Renewable Energy Resources: Current Status, future prospects, and their enabling technology. *Renewable and Sustainable Energy Reviews 39 (2014)* 748-764.

Ossadnik, W., Schinke, S. & Kaspar, R. H. 2016. Group aggregation techniques for analytic hierarchy process and analytic network process: A comparative analysis. *Group Decision and Negotiation, 25, 421-457.*

Paul L. Younger. 2015. Geothermal Energy: Delivering on the Global Potential. *Energies 2015, 8, 11737-11754.*

Phebe Asantewaa Owusu and Samuel Asumadu-Sarkodie. 2016. A review of renewable energy sources, sustainability issues and climate change mitigation. *Cogent Engineering (2016), Volume 3.*

Pradhnye Tajne. 2015. Wind Energy Timeline – From Persian Windmills Crushing Grains to Vesta's Wind Turbines Churning out 8 MW of Output. *Article, Alternate energy magazine April (2015)*. https://www.altenergymag.com/article/2015/04/wind-energy-timeline-%E2%80%93-from-persian-windmills-crushing-grains-to-vesta%E2%80%99s-wind-turbines-churning-out-8-mw-of-output/19496, accessed in May 2019.

Priyantha D.C. Wijayatunga, Kanchana Siriwardena, W.J.L.S. Fernando, Ram M. Shrestha, and Rahula A. Attalage. 2006. Strategies to overcome barriers for cleaner generation technologies in small developing power systems: Sri Lanka case study. *Energy Conversion and Management 47 (2006) 1179–1191.*

Ralph E.H. Sims. 2008. Hydropower, Geothermal, and Ocean Energy. *Massey University, New Zealand, and International Energy Agency, France.*

Rand S, David B, Brunori G, Dockès AC, Fischler M, Guillaumin A, *et al.* 2008. WP 4: Environmental Technologies Synthesis Report; April 2008

Reddy S, Painuly JP. 2004. Diffusion of renewable energy technologies-barriers and stakeholders' perspectives. *Renew Energy 2004:29 (9); 1431-47.*

Reed, G. F., Lynn, F. & Meade, B. D. 2002. Use of coefficient of variation in assessing variability of quantitative assays. Clinical and diagnostic laboratory immunology, 9, 1235-1239.

Renewable Energy, Definition, *Business Dictionary*. http://www.businessdictionary.com/definition/renewable-energy.html, accessed in May 2019.

Renewable Energy: R&D Priorities – Insights from IEA Technology Programs. 2006. *IEA/ OECD, Paris, 2006*. www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1592, accessed in May 2019.

Renewables. 2018. *Renewables Global Status Report*.

Ronald DiPippo. 2015. Geothermal power plants: evolution and performance assessments. *Geothermics Volume 53, January 2015, Pages 291-307.*

Ruth Shortall, Brynhildur Davidsdottir, and Guðni Axelsson. 2015. Geothermal energy for sustainable development: A review of sustainability impacts and assessment frameworks. *Renewable and Sustainable Energy ReviewsVolume 44, April 2015, Pages 391-406.*

Salsabila Ahmad, Mohd Zainal Abidin Ab Kadir, and Suhaidi Shafie. 2011. Current Perspective of the renewable energy development in Malaysia. *Renewable and Sustainable Energy Reviews 15 (2011) 897-904.*

Sara Gollessi and Giulia Valerio. Hydropower and Environment. *Brochure, SHERPA Project.*

Sawin JL. Charting a new energy future in State of the world 2003. In: Starke Linda, editor. New York: W.W. Norton & Company; 2003. p. 85–109.

Sebastian Farquhar, John Halstead, Owen Cotton-Barrat, Stefan Schubert, Haydn Belfield and Andrew Snyder-Beatti.2017. *Existential Risk Diplomacy & Governance*. Global Properties Project.

Solar Energy, Encyclopedia, National Geographic Society, *National geographic.* https://www.nationalgeographic.org/encyclopedia/solar-energy/, accessed in May 2019.

Sonal Sindhu, Vijay Nehra, and Sunil Luthra. 2017. Solar energy deployment for sustainable future of India: Hybrid SWOCAHP analysis. *Renewable and Sustainable Energy Reviews 72 (2017) 1138–1151*

Sørensen, J. B. 2002. The use and misuse of the coefficient of variation in organizational demography research. Sociological methods & research, 30, 475-491.

Souvik Sen and Sourav Ganguly. 2017. Opportunities, barriers and issues with renewable energy development-A discussion. *Renewable and Sustainable Energy Reviews 69 (2017) 1170-1181.*

Srivastava S, Sharma R. The future of energy in India. 2013. *J. Petrotech 2013; VIII(8): 78–85*

Stacy Muise. Topic: Hydropower. https://www.studentenergy.org/topics/hydro-power, accessed in May 2019.

Sunil Luthra, Sanjay Kumar, Dixit Garg, and Abid Haleem. 2015. Barriers to renewable/sustainable energy technologies adoption: Indian Perspective. *Renewable and Sustainable Energy Reviews 41 (2015) 762-776*.

Suzuki M, Okazaki B, Jain K. 2010. Identifying Barriers for the implementation and the operation of biogas power generation projects in Southeast Asia: an analysis of clean development projects in Thailand. *Economics and Management Series Working Paper. International University of Japan; 2010; 20.*

T Marland, G., T.A. Boden, and R.J. Andres. 2017. Global, Regional, and National Fossil Fuel $CO_2$ Emissions. *U.S. Department of Energy.* https://cdiac.ess-dive.lbl.gov/trends/emis/overview.html, accessed in May 2019.

Tania Urmee, David Harries, and August Schlapfer. 2009. Issues related to rural electrification using renewable energy in developing countries of Asia and Pacific. *Renewable Energy 34 (2009) 354-357*

The history of Solar, Energy Efficiency and Renewable Energy, *U.S. Department of Energy*. https://www1.eere.energy.gov/solar/pdfs/solar_timeline.pdf, accessed in May 2019.

Thomas L. Saaty. 1977. A Scaling Method for Priorities in Hierarchical Structures. *Journal of mathematical psychology, 15, 234-281.*

Thomas L. Saaty. 1988. What is the Analytic Hierarchy Process? *Mathematical models for decision support, NATO ASI series, Vol. F48.*

Thomas L. Saaty. 2001. The Seven Pillars of the Analytic Hierarchy Process. *Multiple Criteria Decision Making in the New Millennium.*

Toufic Mezher, Gihan Dawelbait, and Zeina Abbas. 2012. Renewable Energy policy options for Abu Dhabi: Drivers and barriers. *Energy policy 42 (2012) 315-328.*

Tsoutsos T, Frantzeskaki N, Gekas V. 2005. Environmental impacts from the solar energy technologies. *Energy Policy 2005;33(3):289–96.*

Tyler Moss and Caitlin Morton. 2018. 14 places most affected by Climate Change, *article, Cntraveler*. https://www.cntraveler.com/gallery/10-places-to-visit-before-theyre-lost-to-climate-change, accessed in May 2019.

Country classification. 2014. UN. https://www.un.org/en/development/desa/policy/wesp/wesp_current/2014wesp_country_classification.pdf, accessed in May 2019.

What is Hydropower? https://www.originenergy.com.au/blog/about-energy/what-is-hydropower.html, accessed in May 2019.

Willie Scott, Article: What is Hydropower Electricity? Definition Energy, Power Plant, Turbines. https://www.brighthubengineering.com/hydraulics-civil-engineering/64901-water-power-is-renewable-energy/, accessed in May 2019.

World Energy Outlook. 2012. International Energy Agency. http://www.worldenergyoutlook.org/weo2012/, accessed in May 2019.

# APPENDIX-A

# (INTERVIEW FORMAT)

<table>
<tr><td colspan="2">Information about Expert</td><td rowspan="8"></td></tr>
<tr><td>Expert's Name/ Surname</td><td></td></tr>
<tr><td>Job Title*</td><td></td></tr>
<tr><td>Work Experience(years)*</td><td></td></tr>
<tr><td>Countries in which experience gained*</td><td></td></tr>
<tr><td>The types of Projects Completed by the Expert( Solar Power Plant, Wind Power, Hydropower, Geothermal power, Bio power plant)*</td><td></td></tr>
<tr><td colspan="2">* Compulsory to fill</td></tr>
<tr><td colspan="2">Disclaimer<br>Thank you for your contribution to the Master thesis done under the guidance of Asst. Prof. Dr. Semra Comu YAPICI at Bogazici University, Istanbul. All the information given would only be used for academic purposes. Any information would not be shared without the consent of the interviewee.</td></tr>
<tr><td colspan="3">Example Code Selection for Criteria</td></tr>
</table>

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Criteria 2 is Very strongly preferred than Criteria 1 | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| Criteria 1 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Criteria 2 |
| | | | | | | | | | | | | | | |
| Criteria 3 is Strongly to very strongly preferred than Criteria 4 | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| Criteria 3 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Criteria 4 |
| | | | | | | | | | | | | | | |
| **Pairwise comparison of main categories of Barriers to Renewable Energy.** | | | | | | | | | | | | | | |
| Economic and Financial | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Market |
| Economic and Financial | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Technical Barriers |
| Economic and Financial | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Cultural, Social and Environmental Barriers |
| Economic and Financial | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Political and Government Barriers |
| Market | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Technical Barriers |
| Market | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Cultural, Social and Environmental Barriers |
| Market | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Political and Government Barriers |
| Technical Barriers | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Cultural, Social and Environmental Barriers |
| Technical Barriers | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Political and Government Barriers |
| Cultural, Social and Environmental Barriers | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Political and Government Barriers |
| **Pairwise comparison of sub- category (Economicand Financial Barriers)** | | | | | | | | | | | | | | |
| High investment requirements | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of financial mechanism |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High investment requirements | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Policy of subsidies |
| High investment requirements | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | High operation and maintenance cost |
| High investment requirements | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Exclusion of environment externalities in cost |
| High investment requirements | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Transaction cost |
| Lack of financial mechanism | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Policy of subsidies |
| Lack of financial mechanism | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | High operation and maintenance cost |
| Lack of financial mechanism | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Exclusion of environment externalities in cost |
| Lack of financial mechanism | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Transaction cost |
| Policy of subsidies | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | High operation and maintenance cost |
| Policy of subsidies | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Exclusion of environment externalities in cost |
| Policy of subsidies | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Transaction cost |
| High operation and maintenance cost | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Exclusion of environment externalities in cost |
| High operation and maintenance cost | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Transaction cost |
| Exclusion of environment externalities in cost | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Transaction cost |
| **Pairwise comparison of sub- category (Market Barriers)** | | | | | | | | | | | | | | |
| Lack of consumer awareness of Renewable energy | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of sufficient market base |
| Lack of consumer awareness of Renewable energy | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of paying capacity of consumers |
| Lack of consumer awareness of Renewable energy | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of private sector involvement |
| Lack of consumer awareness of Renewable energy | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Trade barriers |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lack of consumer awareness of Renewable energy | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of positive track records |
| Lack of sufficient market base | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of paying capacity of consumers |
| Lack of sufficient market base | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of private sector involvement |
| Lack of sufficient market base | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Trade barriers |
| Lack of sufficient market base | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of positive track records |
| Lack of paying capacity of consumers | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of private sector involvement |
| Lack of paying capacity of consumers | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Trade barriers |
| Lack of paying capacity of consumers | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of positive track records |
| Lack of private sector involvement | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Trade barriers |
| Lack of private sector involvement | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of positive track records |
| Trade barriers | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of positive track records |
| **Pairwise comparison of sub- category (Technical barriers)** | | | | | | | | | | | | | | |
| Need for backup or storage devices | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Inefficient and complex technology |
| Need for backup or storage devices | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Underinvestment in R&D |
| Need for backup or storage devices | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of trained people and training institutes |
| Need for backup or storage devices | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of infrastructure |
| Need for backup or storage devices | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of domestic manufacturing industries |
| Inefficient and complex technology | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Underinvestment in R&D |
| Inefficient and complex technology | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of trained people and training institutes |
| Inefficient and complex technology | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of infrastructure |
| Inefficient and complex technology | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of domestic manufacturing industries |
| Underinvestment in R&D | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of trained people and training institutes |
| Underinvestment in R&D | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of infrastructure |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Underinvestment in R&D | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of domestic manufacturing industries |
| Lack of trained people and training institutes | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of infrastructure |
| Lack of trained people and training institutes | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of domestic manufacturing industries |
| Lack of infrastructure | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of domestic manufacturing industries |
| **Pairwise comparison of sub- category (Cultural, Social and Environmental Barriers)** | | | | | | | | | | | | | | |
| Faiths and Beliefs | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Rehabilitation controversies |
| Faiths and Beliefs | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Criminal or terrorist activities |
| Faiths and Beliefs | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Unavailability of topographic and/or geographical information |
| Faiths and Beliefs | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Ecological issues |
| Rehabilitation controversies | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Criminal or terrorist activities |
| Rehabilitation controversies | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Unavailability of topographic and/or geographical information |
| Rehabilitation controversies | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Ecological issues |
| Criminal or terrorist activities | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Unavailability of topographic and/or geographical information |
| Criminal or terrorist activities | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Ecological issues |
| Unavailability of topographic and/or geographical information | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Ecological issues |
| **Pairwise comparison of sub- category (Political and Government Barriers)** | | | | | | | | | | | | | | |
| Monopoly | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Corruption |
| Monopoly | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of standardization |
| Monopoly | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of Political commitment and government policies |
| Monopoly | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Rigidity in instructions and Centralized planning process |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Corruption | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of standardization |
| Corruption | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of Political commitment and government policies |
| Corruption | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Rigidity in instructions and Centralized planning process |
| Lack of standardization | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Lack of Political commitment and government policies |
| Lack of standardization | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Rigidity in instructions and Centralized planning process |
| Lack of Political commitment and government policies | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Rigidity in instructions and Centralized planning process |