A REVIEW: ENERGY, RENEWABLE ENERGY DEVELOPMENT AND TECHNOLOGIES, ROLE OF RENEWABLE ENERGY IN FUTURE SUSTAINABLE DEVELOPMENT

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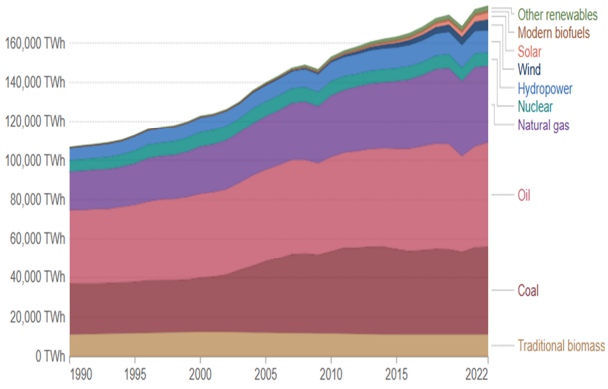
Abstract: Energy is essential for modern life and socioeconomic development. Developing countries have experienced significant economic growth in recent decades due to increased energy consumption. Global energy demand continues to rise rapidly as populations grow and seek to improve their welfare, health, and economic development. While the world is becoming increasingly interconnected and energy needs are expanding, the Earth's finite resources remain unchanged.[1] If improvements in energy efficiency fail to counter rising global demand, energy consumption will continue its year-on-year increase. Such sustained growth severely challenges the transition away from fossil fuels to low-carbon energy systems, potentially leading to a crisis. [4] Fossil fuels like coal, oil, and natural gas are unsustainable due to their finite and dwindling supplies. Furthermore, their daily combustion for energy releases harmful emissions with severe environmental consequences. [2] Since the world's finite fossil fuel reserves will eventually be exhausted, developing sustainable, eco-friendly alternatives has become an urgent priority.[3] Renewable resources are virtually inexhaustible over the long term, though their power output is limited at any given moment.[7] Renewable energy technologies are becoming essential as the world faces climate change and seeks to reduce reliance on finite, polluting fossil fuels. Their use is key to promoting sustainable development by meeting present needs

without harming future generations. [5] Renewable energy comes from naturally, constantly replenished sources and is often called clean energy because it produces little to no emissions. Examples include solar, wind, geothermal, biomass, hydroelectric, and marine energy. [6].

Keywords: Renewable energy sources; sustainability, clean energy, green energy, environmental sustainability, global warming, developing, economies, electricity, emerging, energy, low-carbon, sustainability development.

I. Introduction

As the population growth and economic development of the country increases, with which the global energy demand also continuously increasing every year [8]. From 1990 to 2022, due to an increasing world population by 47.67% resulting in increase in global energy consumption by 69.22% [8]. (Figure-1 and 2). After COVID-19, with the use of fossil fuels dominating energy sources, which account for 38% of petroleum, 23% of coal, and 20% of natural gas [9]. Global energy demand grew by 1.1% in 2022, but slower than the 5.5% growth in 2021, oil demand grew by 3.1, natural gas demand declined by 3% in 2022, coal demand grew by 0.6%, renewable energy continued to grow strongly, with solar and wind reaching a 7.5% of primary energy consumption [81].



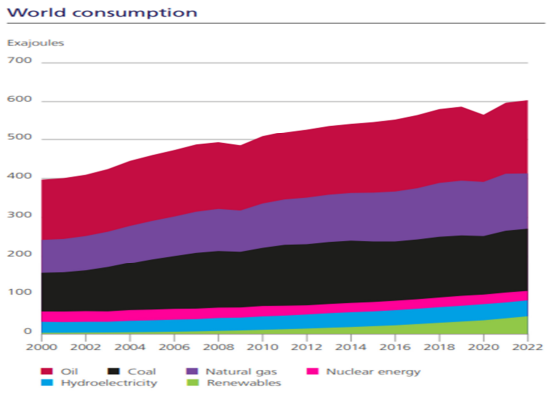


Figure – 1[8] **Figure – 2[28]**

Figure-1 and 2. Global Primary Energy Consumption by Source, Data source: [8] and [28]

Table 1. – Growth Rate of Global Primary Energy Consumption in 2021-2022[28]

	2021	2022	Growth Rate

Oil	184.86	190.69	3.1%
Natural gas	146.41	141.89	3%
Coal	160.43	161.47	0.6%
Nuclear Energy	25.33	24.13	2.3%
Hydro-electricity	40.4	40.68	
Renewables	39.97	45.18	7.5%
Total	597.41	604.04	1.1%

Figure - 3

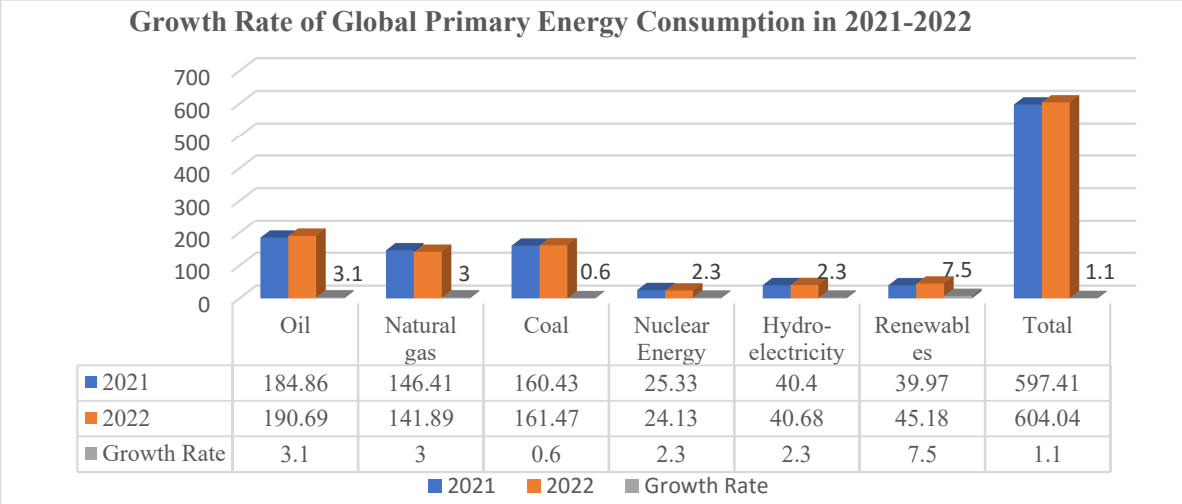


Table 2. - Global Primary Energy Consumption in 2012-2022 – per annum – per capita – [28]

Year	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2022**	**2012–22**
Growth Rate per Annum	527.96	537.19	542.87	547.39	553.98	565.6	581.05	587.39	566.49	597.41	604.04	1.1%	1.4%
Primary Consumption per Capita	73.7	74.1	74.0	73.7	73.7	74.4	75.6	75.6	72.2	75.5	75.7	0.3%	0.3%

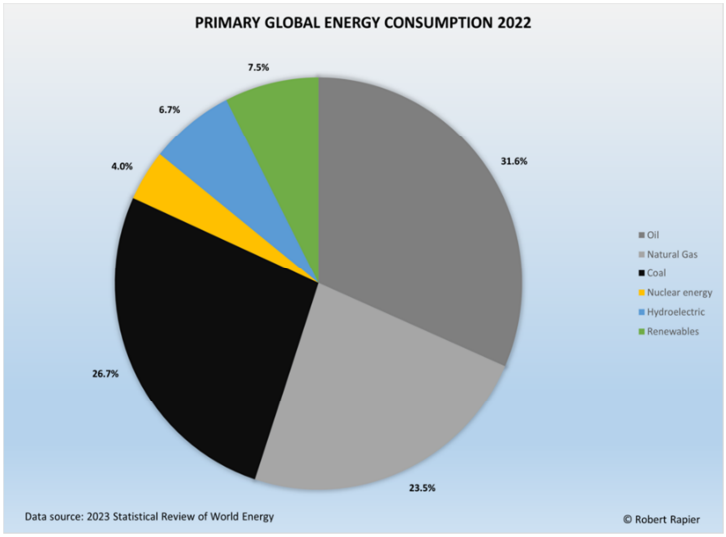


Figure – 4

1.1 - Projection of Global Primary Energy Consumption – (Table - 3) - A prediction of future power consumption is essential for the investigation of adequate environmental and economic policies [13] and also helps to determine future investments in renewable energy. Hence, international comparisons are helpful to identify past, present, and future power consumption. Table - 3 shows the primary energy consumption of the world (based on the BP Energy Outlook 2018 reports).

Table - 3 – Projected primary energy consumption of the world between 1990 and 2040 [28]

Region	**Consumption (million tons of equivalent) Mtoe**											**Change (percentage per annum)**	
	1990	**1995**	**2000**	**2005**	**2010**	**2016**	**2020**	**2025**	**2030**	**2035**	**2040**	**1990 - 2016**	**2016-2040**
United States	1996	2119	2310	2349	2284	2273	2334	2344	2341	2325	2299	0.60 %	0.00 %
Brazil	126	158	188	211	268	298	330	378	419	451	477	3.40 %	2.00 %
EU	167	166	173	181	175	164	166	162	157	151	146	-	-

	2	1	2	9	4	2	7	3	0	3	0	0.10 %	0.50 %
Russia	865	662	620	647	673	674	711	720	723	722	716	-1.00 %	0.30 %
Middle East	264	351	423	656	734	89	980	1085	1189	1287	1382	4.80 %	1.80 %
Africa	222	244	274	327	389	4440	509	603	710	840	1002	2.70 %	3.50 %
China	683	889	1008	1800	2491	3053	3387	3753	4017	4207	4319	5.90 %	1.50 %
India	195	251	316	394	537	724	880	1118	1365	1624	1921	5.20 %	4.20 %

Figure-5

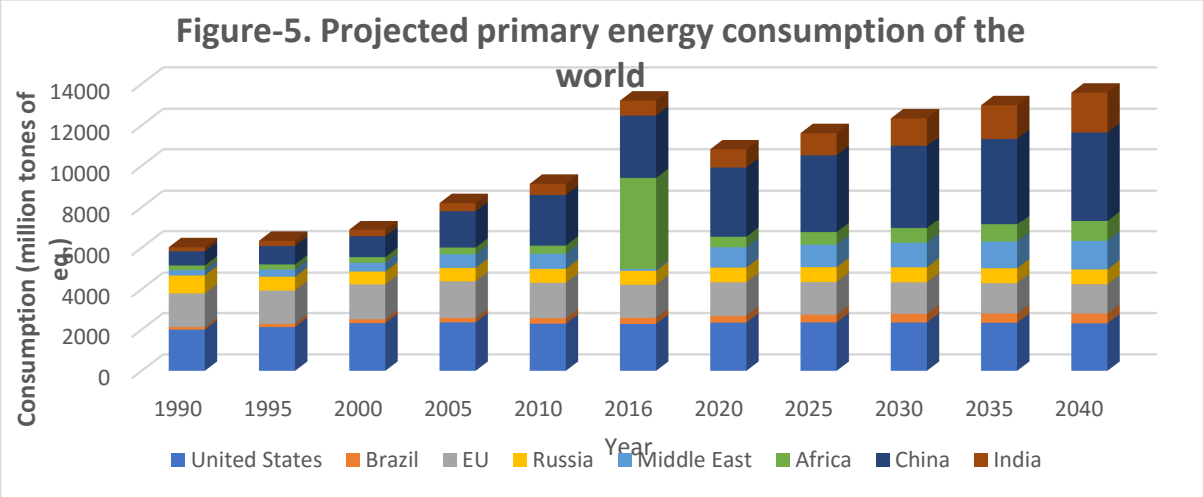
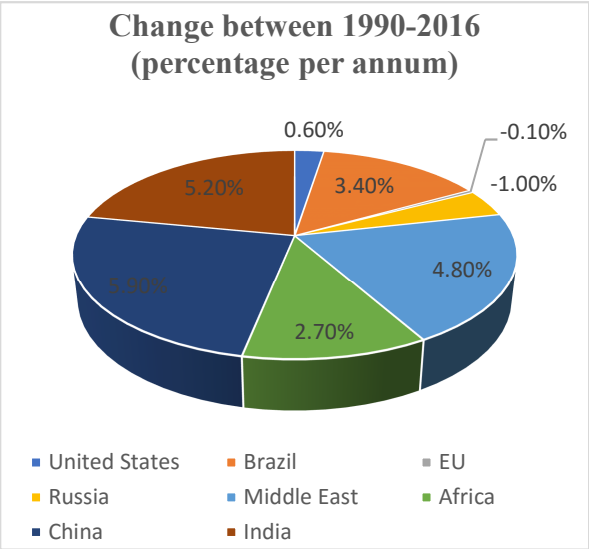


Figure-6

Figure-7



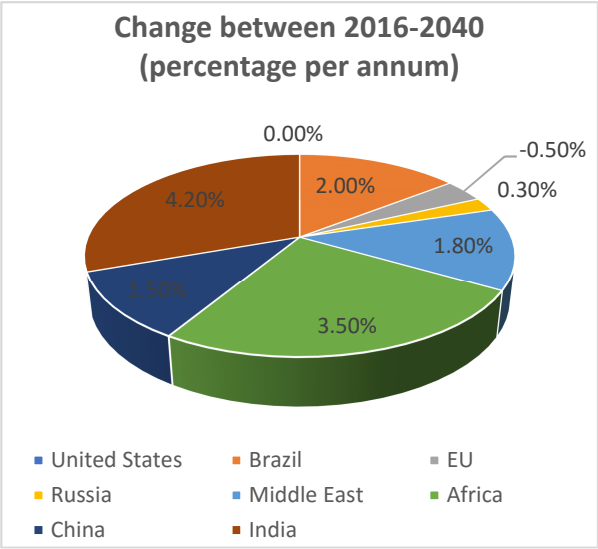
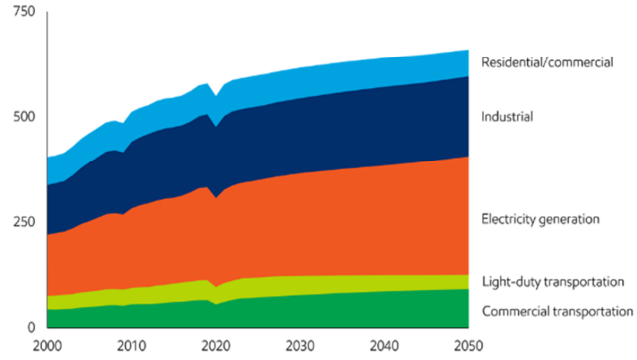
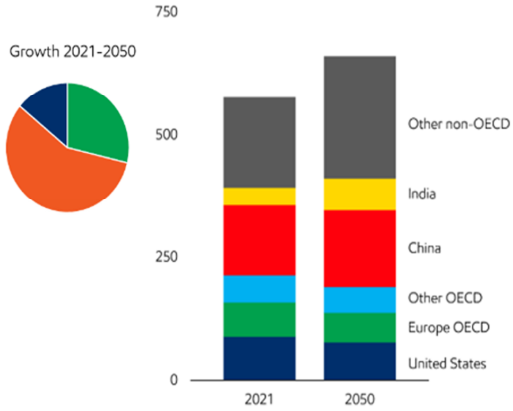


Figure – 8 - Global Primary Energy Demand by Sector [18]

Figure- 9 - Developing Countries Lead Primary Energy Demand [18]





From graphical presentation 8 and 9, it is to be predicted that,

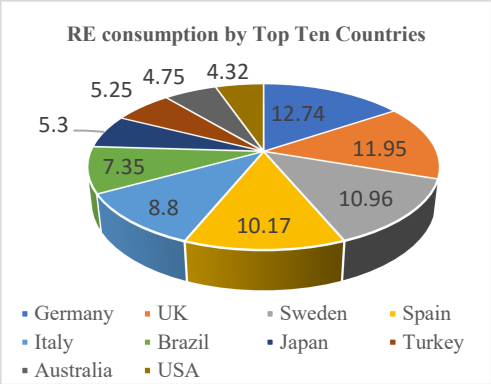
- In 2050, the global demand will reach up to 660 quadrillion Btu, reflecting a growing population and rising prosperity.
- Residential and commercial primary energy demand declines by approximately 15% to 2050 [18].

However, after the COVID-19 pandemic, due to the economic recovery between 2020 and 2021, it was found that the overall world energy consumption rebounded by 5% [8]. A study of nations around the world found that these countries uses the highest amount of renewable energy all making up the top ten [10]. **Table-4 [4]**

Table-4

Sr.	Country	Energy	Figure - 10

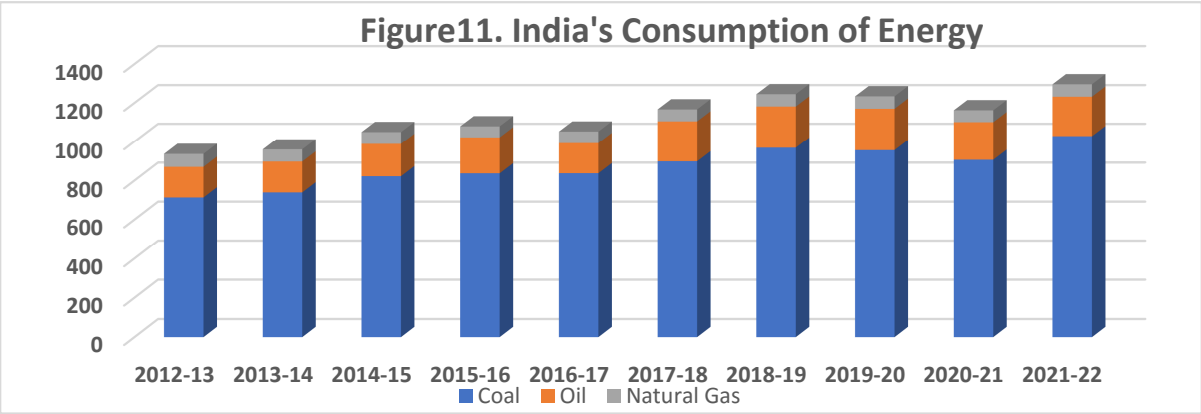
No.		Consumption
1	Germany	12.74%.
2	UK	11.95%
3	Sweden	10.96%
4	Spain	10.17%
5	Italy	8.8%
6	Brazil	7.35%
7	Japan	5.3%
8	Turkey	5.25%
9	Australia	4.75%
10	USA	4.32%



1.2 - Mapping of India's Energy System –

Since 1990, coal, oil and biomass largely satisfy India's energy needs and these sources, in aggregate, consistently met over 80% of India's total energy demand. As the dominant energy source, coal has strengthened its role and also maintaining its strong position not only in power generation but also being as fuel of choice for many industries. Thus, in India's economic development, coal played a significant role, however, contributing to tremendous environmental air pollution and growing GHG emissions. [19].

	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
Coal	713.39	739.34	822.13	836.73	837.22	898.49	968.36	955.92	906.33	1,028.12
Oil	157	158	166	185	155	206	213	214	194	204
Natural Gas	66	62.1	61.2	57.3	59.8	62.2	63.8	64.2	61.7	64.1



1.3 - Projected Primary Energy Consumption in India -

The demand for energy generally based on the size and growth of a country's population. It is found that, India's overall energy consumption in 2016 was 724 million tons of oil equivalent (Mtoe) and is expected to rise to 1920 Mtoe by 2040 with an average growth rate of 4.2% per annum. In 2019, India ranked second with 1.368 billion citizens [31]. The projected estimation of global energy consumption demonstrates that energy consumption in India is continuously rising and retains its position even in 2035/2040 [15]. Compared with the world's population, the yearly growth rate is found to be 1.18% and will be assumed that India's energy consumption will be the fastest among all significant economies by 2040. The increase in India's energy consumption will push the country's share of global energy demand from 5% in 2016 to 11% in 2040 [28]. However, it is to be predicated, that the demand for renewables in India will meet a tremendous growth in renewables in 2040 (256 Mtoe) from 17 Mtoe in 2016, with an annual increase of 12%, as shown in Table-1 [28].

Table-5 – [28]

Projected primary energy consumption of India (including renewable energy) from 2016 to 2040.													
Source	**Level (Mtoe)**												
	2010	**2015**	**2000**	**2005**	**2010**	**2016**	**2020**	**2025**	**2030**	**2035**	**2040**	**0-2016**	**6-2040**
Oil	58	75	106	122	155	212	251	308	359	419	485	5.10%	3.50%
Gas	11	17	24	32	54	45	57	72	89	106	128	5.60%	4.50%
Coal	110	140	164	211	290	412	485	593	710	824	955	5.20%	3.60%

Nuclear	1	2	4	4	5	9	11	16	27	35	44	7.10%	7.00%
Hydro	15	17	17	22	25	29	36	43	47	50	52	2.60%	2.50%
Renewables	0	0	1	2	7	17	41	86	133	191	256	35.10 %	12.00 %
Total	195	251	316	393	536	724	881	1118	1365	1625	1920	5.20%	4.20%

Figure-12

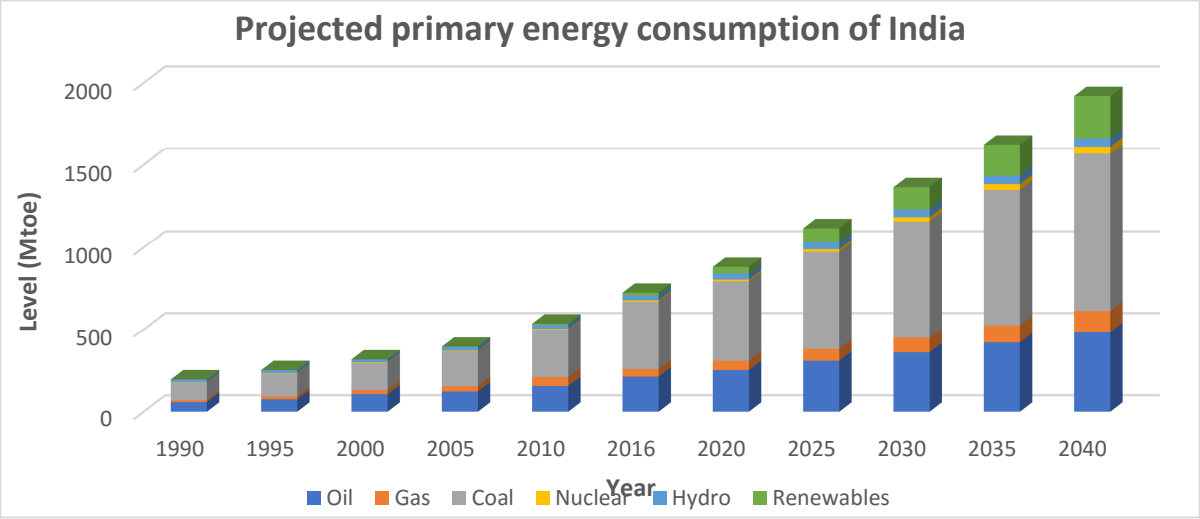


Figure - 13

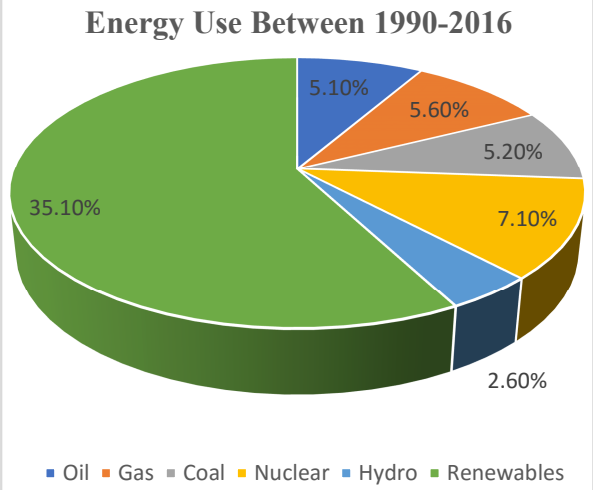
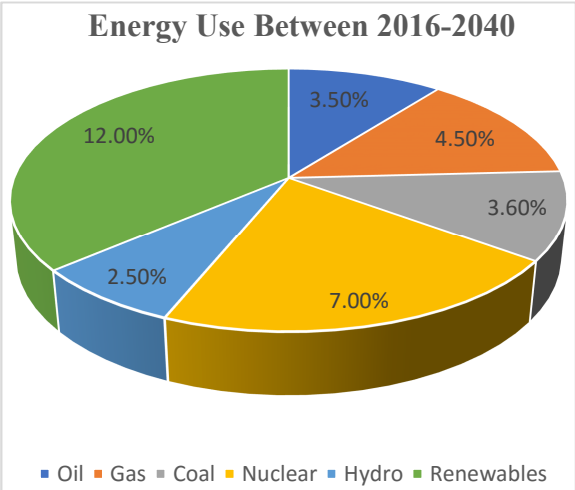


Figure -14



II. The Development of Renewable Energy

From the above discussion, human beings are increasingly depending on the use of fossil fuels (coal and natural gas). The

widespread use of these sources have harmful impact on the environment and planet such as global warming, extreme weather changes and loss of natural habitats as a result.

Thus, the renewable energy is key a solution for the future power needs. We have been harnessing the natural power of nature for centuries e.g. windmills and water wheels, the sun to create fire for heat and light. However, recent advances in capture and storage has created an expansion in renewable and green energy production towards Net Zero. These advances range from small-scale production (roof top) to large-scale facilities like offshore wind farms [22].

2.1 What is renewable energy?

Renewable energy sources are natural and persistent flow of energy happening in our immediate environment. Renewable energy, often referred to as clean energy since, these are derived from natural sources or processes that are constantly being replenished at a higher rate than they are consumed. For example, sunlight and wind keep shining and blowing, even if their availability depends on time and weather [20]. Renewable energy sources, all around us are plentiful [21]. Generating renewable energy creates far lower emissions than burning fossil fuels and are cheaper and generate three times more jobs than fossil fuels [21].

2.2. Why is it Important? - Renewable energy is important as it provides energy using natural resources at a lower environmental risk, with reliable supplies and fuel diversification, thus, could meet our future power needs for years to come [22].

2.3. How Effective is it? - The effectiveness of renewable energy depends on the sources from which they are obtained and used. Some are readily available and more effective than others, while some (such as geothermal) are of great use in some locations only due to their accessibility [22].

2.4. What is the Best Type of Renewable Energy? - Each type of renewable energy has its own benefits and drawbacks; however, its use widely depends on location and resource in together.[22]

2.5. Will Renewable Energy Run Out? - Renewable energy sources will never run out for many millions of years. They provide a variable alternative to non-renewable resources [22].

2.6. Can Renewable Energy Replace Fossil Fuels? – We known that there is a

finite amount of coal and oil on the earth, means these will eventually run out and we need renewables for the future. That means renewable energy will one day replace fossil fuels. However, to fully replace fossil fuels and to have a totally renewable possible future, there is a need to continue innovating renewable energy solutions and much work to be done to reach net zero. [22]. In addition, the environmental benefits of renewable energy in the future as a clean and green source are becoming increasingly important.

III. Renewable energy Technologies

Renewable energy technologies for energy production used include: bioenergy, direct solar energy, geothermal energy, hydropower, wind and ocean energy (tide and wave).

a. Hydropower - Hydropower is a globally used, most important and largest renewable energy source for electricity. Most hydroelectric power projects are located on dams (reservoirs). Energy is harnessed from water which is forced through tunnels in the dam and moving from higher to lower elevation levels, which turns huge turbines and generates electricity. Hydropower reservoirs in addition to power production have multiple uses such as providing drinking water, water for irrigation, flood and drought control, navigation services etc. India's hydropower is the sixth biggest hydropower producer in the globe as well the major contributors to our nation's hydroelectric power [21,31,32,33,63].

b. Bioenergy – Bioenergy, a renewable energy source derived from a variety of organic materials, called biomass, such as wood, charcoal, dung and other biological sources. Biomass is any organic material that comes from plants or microorganisms. Bioenergy is an important source of energy, mainly heat and power, which can also be used for transport using biodiesel, electricity generation, cooking and heating. We get energy from biomass by burning it or can be converted into biofuel. Biomass is mostly used in rural areas by poorer populations in developing countries generally for cooking, lighting and space heating etc. Since, biofuels releases less harmful pollutants, these often described as a clean and a greener alternative to coal and other fossil fuels. However, bioenergy should only be used in limited applications, given potential negative

environmental impacts and resulting in deforestation and land-use change [33,34,35].

c. Solar energy – Solar energy is the most abundant of all renewable energy resources that can even be harnessed in cloudy weather. According to the National Renewable Energy Laboratory (NREL), "more energy from the sun falls on the earth in one hour than is used by everyone in the world in one year." [33]. Solar energy technology is obtained from solar irradiance that convert IR radiations from sunlight into electrical energy through photovoltaic panels (PV) or through concentrating solar power (CSP), to produce thermal energy [64]. Solar technologies can deliver heat, cooling, natural lighting, electricity, and fuels for a most of applications [36,38]. Solar energy can be captured "actively" (e.g. power lights, heating systems, computers, and televisions or "passively" (e.g. green roofs, cool roofs, and radiant barriers) [21].

d. Geothermal energy - Geothermal energy is obtained naturally from the earth's interior deep beneath the surface i.e. Earth's core as heat energy source which is constantly moving toward the Earth surface. At the surface, the fluids of various temperatures can be used to generate electricity. The underground geothermal heat energy can access in different ways - one way of using geothermal energy is with "geothermal heat pumps" in which a pipe of water loops between a building and holes dug deep underground. Then water can be injected underground beneath and is warmed by the geothermal energy underground and then brings the warmth aboveground. When the steam comes to the surface, it is used to turn a generator and create electricity [21,38].

e. Wind Energy - Wind exists everywhere in the world, in some places with considerable energy density. Wind energy is generally harnessed from kinetic energy by moving air. People have been using this wind's energy for a long time. This kinetic energy of wind can be converted to electrical energy using large wind turbines located on land (onshore) or in sea- or freshwater (offshore) [21,33,39,40,41].

f. Ocean energy (tide and wave) - The ocean stores enough energy in the form of waves, tide, currents and heat to meet the total worldwide demand for power. Ocean energy derives from technologies that use the kinetic and thermal energy of seawater waves or currents to produce electricity or heat. There are presently four ways of obtaining energy from sea areas, viz Wind, Tides, Waves and Thermal differences between deep and shallow sea water. When wind passes over water (ocean), surface waves are created. The following factors are affecting - wind speed, longer the wind is sustained, greater distance the wind travels, greater the wave height. [21,42,43].

IV. Sustainable Development: A Brief Look -

Sustainable development as a concept emerged in 1980s and was defined as the development that is able to meet the needs of the present without compromising the ability of the future generations to do the same [44]. In other words, sustainable energy development is defined as the development of the energy sector in terms of energy generation, distribution and its utilisation facts that are based on sustainability rules [51]. Sustainable development takes into account the different factors such as social, environmental, and economic that ensure the optimal balance while pursuing an enhanced quality of life and a better future for all. The idea is to access the resources available to everyone they need to live a adequate life, without harming the planet. Sustainable development includes the various methods and strategies that can be effectively influenced to achieve the goal

of sustainability [44]. Now, the sustainable development has become the centre of recent national policies, strategies and development plans of many countries in communicating with climate change, renewable energy, food, health and water provision. It needs to require a coordinated global monitoring and modelling of many factors which are socially, economically and environmentally oriented [46,47]. It also examines the activities to be required to meet shared long-term climate benefits, clean air and energy access targets. In addition, sustainable development includes utilizing renewable-energy applications, smart grid technologies, energy security, and energy pricing and having a sound energy policy [52].

V. Sustainable Energy

The energy which can be depleted, remain forever and does not need to be replenished is known as sustainable energy. It meets the demand of human life with minimal risk, doesn't harm the environment, doesn't running out, that's why it is sustainable. Examples of sustainable energy sources include wind, solar and water (hydropower), geothermal etc. All of which can be considered inexhaustible and widely available to almost everyone [55]. Tester (2005) defines sustainable energy as, "a dynamic harmony between the equitable availability of energy-intensive goods and services to all people and preservation of the earth for future generations" [57]. The main renewable energy forms and their uses are presented in Table 6.

Table - 6 [1]

Sr. No.	Energy Sources	Energy Conversion and Uses
1	Hydropower	Power generation
2	Biomass	Heat and power generation
3	Geothermal	Power generation, hydrothermal
4	Solar	Solar home systems, solar dryers, solar cooker, solar heaters etc.
5	Wind	power generation, water pump
6	Ocean	power generation

5.1. Role of Renewable Energy Technologies in Sustainable Development -

There is a direct relationship of renewable energy and sustainable development. Renewable energy sources provide opportunities in energy security, social and

economic development, energy access, climate change and environmental and health impacts [58]. To ensure a sustainable future for all and also for the economic, social and environmental benefits for the present as well as future generations, there is a need of accommodation of clean and green renewable source of energy. Individuals and also employees from government, private sectors must work together to accelerate the transition towards a more sustainable energy future. This will help to all reduce the negative impacts of climate change and on environment [56].

Figure 17 - shows the opportunities of renewable energy sources towards sustainable development.

Figure – 15,16 - Renewable energy and opportunities, Source – [1]

There is a broad range of benefits to transitioning to sustainable energy. Below we'll list the top ways sustainable energy can positively impact our communities and planet:

a. Improves Public Health -

When fossil fuels are burned for energy, they release emissions like air and water that negatively have an impact on the surrounding communities and environments. The burning of fossil fuels (coal and natural gas) creates many serious public health issues, such as neurological damage, cancer, heart attacks, breathing problems and premature death. Sustainable energy sources are typically clean and green and emits net zero, hence, switching to sustainable energy, all these associated risks can be reduced [55].

b. Creating Job Prospects -

Sustainable renewable energy technologies can also help fuel your local communities in creating the jobs and in stimulating the economic growth of the country, particularly in the manufacturing and installation of renewable energy systems. Since, most facilities and sustainable energy infrastructure are commonly built locally or in the same county. That means, instead of spending more money in importing energy from fossil fuel companies, is better to spent on materials and workmanship to maintain sustainable energy facilities [55,56].

c. Decreases Your Carbon Footprint (Reducing emissions of greenhouse gases) -

It is clear that, renewable energy such as wind and solar, creates zero carbon emissions that can harm the atmosphere in contributing climate change and global warming. Simply switching to sustainable energy sources, and eliminating the dependence on fossil fuels, greenhouse gas emissions can be reduced and the effects of climate change can be mitigated. This sustainable development will help country's financial sector experience exceptional growth [55,56].

d. Long-term Cost is More Affordable -

Sustainable energy are easily available for little or even no cost and are more reliable. They are much more cost-effective than traditional energy resources, such as. Thus, it can make a huge long-term difference to the electricity and energy costs of our homes and businesses. Considering the long-term investment, sustainable energy costs decrease each and every year and will pays off in just a few years. Ultimately, you could end up saving exponentially just by making the switch to a sustainable energy system like solar panels [55,56].

e. Energy Security -

Sustainable energy, by definition, the most reliable sources of energy, are evenly

distributed around the globe as compared to fossils and in general less traded on the market. These will never deplete and reduces the likelihood of nation's reliance on imported fossil fuels and become more self-sufficient. By relying locally readily available sustainable energy resources like solar and wind also helps in conserving our planet's natural resources and also reduce the pollution associated with commercial energy sources and increase their energy independence [55,56,59,60]. Thus, the introduction of renewable energy contributes in increasing the reliability of energy services and represent opportunities to enhance energy security across the globe.

f. Providing energy access -

Access to energy is essential for many aspects of daily life, such as lighting, cooking, and heating etc and raise living standards, especially in poor countries where previously powerless groups can now use renewable energy sources. The sustainable development goal seeks to ensure that energy is clean, affordable, available and accessible to all and this can be achieved with renewable energy source, since they are generally evenly distributed across the globe. The renewable energy technologies, thus can provide ease of access to energy to communities particularly in developing countries [56,60].

g. Promoting the growth of rural areas -

It is realised that the energy sector is the most important key in the economic development with a strong correlation between economic growth and expansion of energy consumption. Globally, per capita incomes are positively correlated with per capita energy use and economic growth. Renewable energy technologies can support the development by providing access to energy to all communities, which can help to improve quality of life also. Thus, by providing rural people to access with renewable energy technologies can support the development of rural areas by enhancing agricultural output, driving economic growth, and enhancing the quality of life [56,60].

VI. Conclusion

Energy is an everyday requirement of human life as a way of improving human development leading to economic growth and productivity. The term "renewable" is commonly used to that energy resources

and technologies which are being inexhaustible and refillable. Renewable resources include solar energy, wind, falling water, geothermal energy, biomass, waves, ocean currents, temperature differences, ocean energy, and tides. Using renewables and replacing the harmful fossil fuels with can help in minimising the problems regarding environment, also the excessive use of water and land, loss of habitat, climate change, global warming etc. However, the cost, price, political environment and market conditions may cause the barriers in developing, least developed as well as developed countries to fully utilize its potentials. Yet, the knowledge regarding the interrelations between renewable energy and sustainable development is still limited. That means, harnessing the renewable energy has many challenges to us and by overcome these challenges will help to meet energy demand of future generations. Clearly, much work to be needed to be done to increase these usages in order to achieve a completely renewable future. The government should facilitate and create opportunities in this sector and should allow more funds to support research and innovation activities. Adequate services, maintenance and proper facilities with better reliability in technology will help some renewable energy technologies. Further, awareness of renewable energy among communities should be properly done and a significant focus on their socio-cultural practices should be considered. Governments should support such technologies and invest largely in the expansion of renewable energy to speed up.

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