Is Solar Power The Best Energy Option To Meet Our Future Demands?

Samyak Shami

Abstract: Currently, about 65% of global electricity generation now is fossil fuel-based – spewing 13 giga tonnes of CO_2 . With mass production and innovations in technology the prices of renewable energy sources have plummeted to such levels where have become a welcoming option even without the subsidies.China has installed nearly 100 gigawatts (GW) of wind power and plans to double it within the next five years , while Britain is also in offshore wind power in a big way. However, oil continues to be the most valued fuel source as almost all of it is consumed in internal combustion (IC) engines – mostly for transport and some for captive power plants. Biofuels and hydrogen fuel cells may be used as alternatives to petrol but biofuels, which include ethanol, hamper the performance of a vehicle.The production cost of solar power panels has come down so much that they are competing with the coal-based power even without the subsidy. The solar powered lanterns, made up of a few light-emitting diodes are bringing light and enhancing the quality of life in the world's poorest regions, which are also located in the equatorial region. The US Department of Energy's target is to produce 27% of America's electricity using solar power by 2050, up from less than 1% today. In Australia, solar power panels, most of them on rooftops, cater to almost 10% of the demand. About 25% households of South Australia have solar power followed by Queensland (22%) and Western Australia (18%).Modern innovations in solar cells show enormous capabilities for them to be used extensively on windows, buildings, even cell phones or any device that has a clear surface. Similar strides have been made in concentrated solar power. The Solar power however has limitations too. It can not generate power during night or when sky is overcast. Excessive power generated by solar panels has led to a crisis in Germany and elsewhere to the extent that generating companies in addition to selling, were also paying back the managers of the grid to take their electricity as the solar and wind generators produced 28.9 GW of power, taking the peak availability of power well beyond the grid could sustain. The 'grid-priority' meant that the conventional nuclear/coal/gas power plants had to go out of synchronization to save the grid, which they could not as they are not designed to get plugged off on short notice. The consequences of promoting renewable energy to the present extent have been disastrous for the existing conventional power plants, which are built keeping in mind 20-30 years perspective. The wholesale electricity prices though are going down as SPV cell production has been coming down at a fast pace, but the burden of subsidies has also been spiraling.However, the relatively low end of technology, abundant fallow land, relatively few skilled engineers and persons required to run a solar power plant and, short period required to install them provide a huge leveling of playing field as world's poor mostly live in the regions inundated with solar incidence who are bound to benefit most. For automobiles, fuel cells or nitrogen engines may provide the alternative to oil, where hydrogen and nitrogen gas is produced from the power generated through the solar cells.

Index Terms: Solar, Power, Energy, Perovskites, SPV, Renewable, fossil fuel, CO_2emission

1. INTRODUCTION

Scarcity of fuel and, concerns for the environment for meeting the energy demand have been topics of raging debate. Fossil fuel is not in unlimited supply.The most easily available and abundant fossil fuel is coal. It is also the dirtiest in terms of pollution. As estimated by the International Energy Agency (IEA), 17% of the overall energy is consumed in the form of electricity; 40 years ago, this figure was at 9%[1]. Currently, than 65% of global electricity generation now is fossil fuel-based – spewing 13 gigatonnes of CO2[2]. About 20% is produced by all renewable energy sources, including hydropower [3]. Solar power is catching up like no other source. The production cost has come down so much the solar panels are competing with coal-based power even without the subsidy. The CO2 emission data[4] is as shown in Fig. 1.

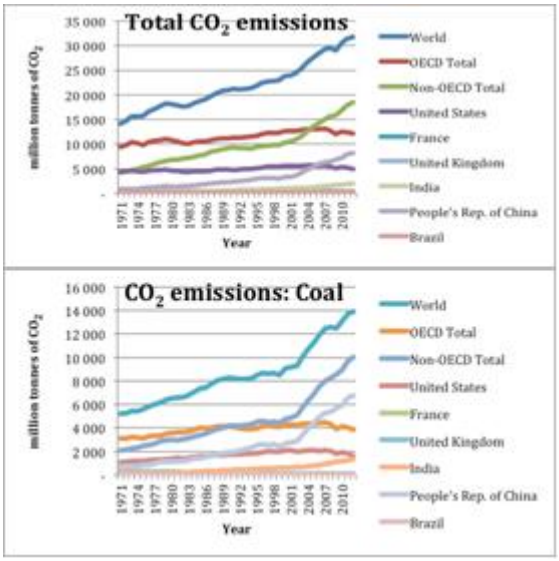

Fig. 1. *Carbon Dioxide emission.*

The share of fuels in meeting out energy demand in million tons of oil equivalent (Mtoe) is shown in Fig. 2 while in electricity generation it is shown in Fig. 3.[5]

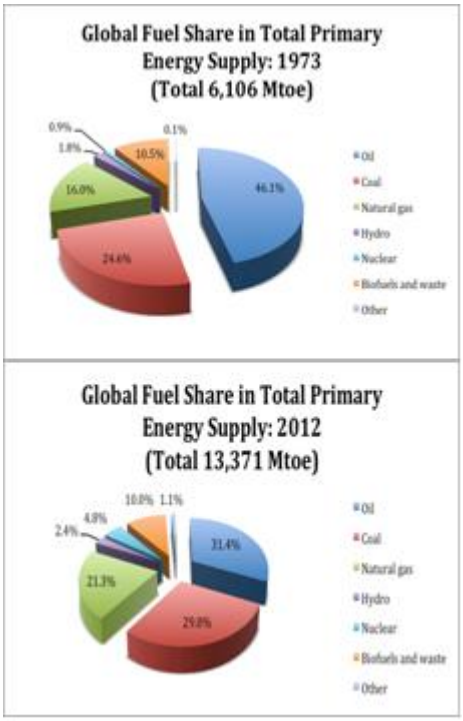

***Fig. 2**. Fuel share in primary energy. Oil and coal constitute more than half of the energy supply.*

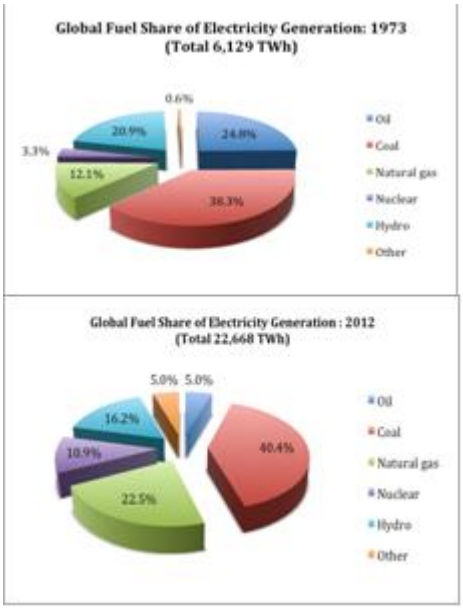

***Fig. 3.** Fuel share in electricity generation. Solar, biofuels and wind power share has grown to 5% from less than 1% in last four decades.*

2. NUCLEAR POWER

Nuclear power does not emit CO2 while producing electricity. Unlike other power sources, nuclear power reduces the dependence on foreign supplies and market price movement. In 2013, nearly 434 nuclear units were operating in 30 countries, with a total capacity of 371,737 MegaWatt electrical (MWe)[6]. However, nuclear fuel has increasingly been losing support particularly after Fukushima power station disaster in Japan in 2011. Japan has already closed 54 reactors of its, which were catering to almost 30% of its energy demand. Germany plans to close all its nuclear power generators by 2022. It is also planning to get 80% of its power from renewable sources by 2050[7]. In India there have been prolonged protests against newly commissioned plants at Kundankulam in the State of Tamil Nadu, and Chutka in the State of Madhya Pradesh with the generating power of 1000 MWe and 1400 MWe respectively. Apart from the resettlement and rehabilitation issues, safety evidently, is a dominant concern in operating the reactors and managing the radioactive waste. Another significant concern is the potential proliferation of nuclear weapons if the technology is allowed to be used freely.

3. RENEWABLE ENERGY

A sustainable alternative is sought from renewable energy - derived from natural processes (solar, geothermal, hydro, wind and biomass), sources of energy that replenish faster than they are consumed. The current European target is for renewables to make up 10% of the energy used in transport by 2020. In 2012, the world relied on renewable sources for around 13.2% of its total primary energy supply. In 2013 renewables accounted for almost 22% of electricity generated globally, a 5% increase from 2012[8]. As these options provide clean and green energy, governments give out liberal subsidies to promote renewable energy. With mass production and innovations in technology the prices of renewable energy sources have plummeted to such levels where have become a welcoming option even without the subsidies.

4. GEOTHERMAL POWER

Amongst renewable energy resources, geothermal power is confined to mainly those geographical areas that lie on the 'ring of fire'. These regions are also amongst the more prosperous regions, flushed with power.

5. HYDROPOWER

Hydropower has had a significant share in electricity generation with China making quantum leaps in enhancing its capabilities. Hydroelectric projects create the cheapest power, but are not free from resettlement and rehabilitation issues, or from ecological concerns.

6. WIND, SOLAR AND TIDAL POWER

Wind, solar and tidal power plants have carved a niche in renewable energy sources. Tidal power can only be used in countries with coastline. China has installed nearly 100 gigawatts (GW) of wind power and plans to double it within the next five years[9], while Britain is also in offshore wind power in a big way. Wind and solar power share is likely to grow as technological innovations are likely to bring down the cost of power production. Solar power's share has been continuously increasing. Australia has crossed 3GW of solar power mainly through rooftop panels[10]. Spain and the US have already established world's largest concentrated solar power plants. India is soon to establish world's largest solar photovoltaic power plant of 700 Megawatts (MW). The cost of solar power panels has come down so much that they are now competing with the coal based thermal power even without subsidy. Japan set one of the world's highest tariffs for buying renewable energy in 2012, as part of a bid to live without atomic power following the Fukushima disaster. Japan

is planning to increase renewables' share of electricity output to 20% by 2030, almost double its pre-Fukushima share[11]. Renewables, excluding large hydropower schemes, now account for nearly a tenth of global power generation. On current trends they will make up a fifth by 2030.[12]

7. ALTERNATIVES TO OIL

When first discovered, oil was mostly used for lighting the lamps. Natural gas is favoured for electricity generation, though not available readily everywhere. It has to be imported through very large vessels or pipelines. The latter tend to run into political imbroglio if the pipeline runs through different countries. The availability of oil increased with the newly evolved 'fracking' process for getting oil out of shale by fracturing them. This mostly benefitted North America and offshore drilling in Europe. Fracking also jacks up the cost of production. At low market price the fracking becomes an expensive proposition. Gulf countries are refusing to cut on their production driving the frackers out of business. Lots of well thus dug up through fracking are lying plugged waiting for the oil prices to go up. The oil market price therefore, will remain uncertain and, at the mercy of geopolitical vagaries. Transport accounts for 27% of the global energy demand[13]. Oil is the most valued fuel source as almost all of it is consumed in internal combustion (IC) engines – mostly for transport and some for captive power plants. The cartelisation among its producers result in geopolitical tensions and consequent shocks in global oil prices. The CO2 emission level in 2012 from burning of oil was 11.2 gigatonnes (Fig.4).[14]

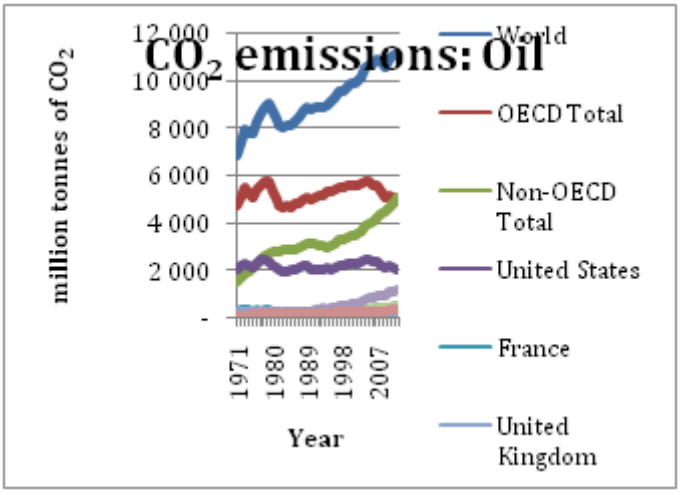

Fig. 4. *Carbon Dioxide emission: Oil. The CO_2 emission is much higher in developed countries primarily because of greater use of motorized transport.*

The alternative fuel for transport has been subject to intensive research and innovations. Biofuels are ethanol produced from crops like maize and jatropha. Ethanol can be mixed with oil to and still be able to run the automobile without significant changes in the IC engines' performance. Biofuels however, have their challenges too. Arable land cannot be diverted to meet the energy needs alone as that would affect food security. Increasing the yield through genetically modified (GM) crops is not a welcome idea as consequences of GM crops themselves are being fiercely debated. In the US, maize growers have been demanding to increase the ethanol in petrol from 10% at present to 15%. This is being resisted on the ground that this would lead to the damage in the engines and consequent litigations[15]. Ethanol also increases the smog formation as it burns to create ground level ozone. Further, the chemical energy of ethanol is less than that of petrol, which brings down the mileage of a vehicle. The biofuels thus turn out to be more expensive than they appear. Hydrogen fuel cell is essentially a Proton-Exchange-Membrane (PEM) - a polymer membrane coated with expensive platinum-palladium catalyst, which deprives hydrogen of its electron as it passes to the air filled cathode compartment to make water. The removed electrons thus produce power through an external circuit. The electricity generated can make a car run over 300 miles on a full tank of hydrogen. The refueling is far quicker than recharging the batteries of an electric car.[16] A further research is going on in making automobiles run on liquid nitrogen. Liquid nitrogen rapidly expands on mixing with water and a few chemicals. This can drive piston in an IC chamber. As nitrogen boils at -195˚C, engines made of even plastic can deliver the power. Furthermore, liquid nitrogen is a by-product of the industrial process for making liquid oxygen and produces four times the oxygen. Liquid nitrogen, therefore, is cheap and abundant. Use of nitrogen engines would cut the cost of fuel, the engine and the consequent weight of the vehicles.

8. ELECTRICITY AND LESS DEVELOPED COUNTRY

Globally, an additional 7200 GW would be needed to keep pace with the increasing demand and replacing the old plants retiring by 2040. About 620 million people in sub-Saharan Africa do not have access to the electricity. This is approximately 13% of the global population sharing only 4% of global energy consumption.[17] India alone needs 40% of world's current power generation to attain 5000 kWh per capita electricity consumption. In poor countries the energy needs are mostly fulfilled with biomass. This has led to vast deforestation in countries like Nigerian. The forest cover loss has been more than 40% since 1990 @ 3.3% per year. In 2010, more than 15 million households lacked electricity. To cover them total capital required was $25 billion, which was equal to the government budget[18]. Solar insolation is 1300 Watts per metre square (W/m2) at the top of the atmosphere.[19] The solar incident graph as Annexed at the end shows that solar power can obliterate the power apartheid in the poorest regions of Africa. The solar powered lanterns, made up of a few light-emitting diodes (LEDs) are bringing light and enhancing the quality of life in the world's poorest regions, which are also located in the equatorial region. Selling them to such a large market has become a good business proposition. Financially clever ways have been devised to enable the people to buy and maintain the solar lanterns. Kenya based M-KOPA's customers can pay as little as 50 cents a day to keep their solar-powered devices (solar panel, three lights and a cellphone charger) running. Within an entire year, entire cost of the system worth $200 is recovered. Solar lanterns are improving education attainments and quality of life in the less developed economies. Even health standards have improved as kerosene usage has reduced lighting purposes. Fire hazard and pulmonary diseases due to inhalation of kerosene fumes are thus avoided to a great extent. The amount spent on

kerosene varies from 10-25% of the family income. Similar approach is found in SociaLite scheme of Ghana where a centralised, large solar panel in a village that charges a car battery. Smaller LED lanterns can then be charges by it. A family pays $4-5 for the lamp and membership of the scheme followed by $1-2 a month for recharging. Faulty lamps are replaced while being under repair. The whole payment is usually made within 18 months.[20] Solar Power As Major Renewable Energy Resource There are two main kinds of solar energy: Solar photovoltaic (SPV) that directly converts solar energy into electricity using a SPV cell made of a semiconductor material. Concentrating solar power (CSP) devices that concentrate energy from the sun's rays to heat a receiver to high temperatures. This heat is transformed first into mechanical energy (by turbines or other engines) and then into electricity – solar thermal electricity (STE). The world increased its CSP capacity from 11MW in 2007 to 1950 MW by 2013[21]. At present, US and Spain are the only countries with significant CSP capacity[22]. The Ivanpah solar-thermal plant in California, US delivers around 377 megawatts (MW). The US Department of Energy's target is to produce 27% of America's electricity using solar power by 2050, up from less than 1% today. Solar power in the form of SPV and STE does not involve carbon emission during power production, nor is there a requirement for fuel. In 2012, the contribution of photovoltaics grew by 17 GW in European Union alone[23]. India and China are making big strides in SPV power.

9. HOW SPV CELLS WORK

A solar photovoltaic cell converts light energy into electrical energy by photoelectric effect in semiconductors, which absorb photons of light. The absorbed photons displace electrons from the atoms. Photoelectric cells have multiple electric fields, which result in forces acting on the displaced electrons. These forces guide electrons generating current. Two metal contacts are placed on the top and bottom of the cell to extract this current. The cells produce direct-current electricity. Multiple cells make up a module and several modules make up an array. The amount of electricity produced depends on the area of a module or of the array[24]. Swanson's law suggests that the cost of the photovoltaic cells needed to generate solar power falls by 20% with each doubling of global manufacturing capacity. With nearly $80/Watt in 1970s, the cost has come to less than 80 Cents/Watt. Power-station construction costs can add $4 to that which is rapidly coming down as efficient construction techniques are being employed. There is no fuel cost and very little maintenance required after that. Coal-fired plants cost about $3 a watt to build in the United States, and natural-gas plants cost $1.[25] Recurring fuel costs as well as the maintenance cost are to be added to them. In sunny regions SPV power is competitive even without subsidy. The conventional power plants can be kept to meet the intermittency. Over the period 2000 - 11, solar PV was the fastest growing renewable power technology worldwide. Cumulative installed capacity of solar PV reached roughly 65 GW at the end of 2011, up from only 1.5 GW in 2000. In 2011, Germany and Italy accounted for over half the global cumulative capacity, followed by Japan, Spain, the United States and China[26]. Australia installed 3GW of solar power panels. Most of them on rooftops catering to almost 10% of the demand. 25% dwellings of South Australia have solar power followed by Queensland (22%) and Western Australia (18%)[27].

10. RECENT ADVANCES IN HARNESSING SOLAR ENERGY

The efficiency of the best silicon solar cells is roughly 25%. The extensive production has brought the cost of solar panels to under 80 Cents/Watt. John Rogers from the University of Illinois, Urbana Champaign has created more efficient cells that convert 42.5% of sunlight. Even with panels these cells convert 35% of sunlight. The efficiency in future could rise to 50%. This cell is more efficient because four layers sit on top of each other. Each layer is made of a different semiconductor absorbing different bands of wavelength spectrum - from longer to the shorter. With increased efficiency these cells would be able to produce cheaper electricity than that produced by coal. A team of researchers led by Richard Lunt at Michigan State University, US has developed a new type of solar concentrator which is transparent. It is called a transparent luminescent solar concentrator (LSC). Even though its current efficiency is about 1% against the coloured LSCs' about 7%, it has enormous capabilities to be used extensively as it can be used on windows, buildings, even cell phones or any device that has a clear surface. Boudoire and Artur Braun of the Swiss Federal Laboratories for Materials Science and Technology are trying to turn solar energy into fuel, using photoelectrochemical (PEC) cells. Using iron oxide and tungsten oxide spheres a few hundred nanometres across to capture light by total internal reflection, the nanospheres can capture upto 35% of incident sunlight. This converts the light into electricity and thus creates a circuit that runs through the water additionally producing hydrogen and oxygen gases. Gases can be sold or used at night to generate electricity. Methylammonium lead iodide and materials like it are collectively known as perovskites. These are cheap to turn into cells as instead of slicing 200 micron thick wafers. Perovskite cell can be made by pouring it with some chemicals onto a suitable backing. Entire buildings can be coated with perskovites making them power surplus buildings.[28] Their efficiency is 3.8% compared to 20-25% of silicon cells. Henry Snaith of Oxford University, and his colleagues blended perovskite at room temperature. Laboratory versions of cells made from it cost about 40 cents per watt, which is at half the present SPV cell cost and far more attractive than the conventional coal/gas fired power plants.[29] STE uses steam produced by solar energy, to drive turbines to produce electricity. Dr Gang Chen and his colleagues at the Massachusetts Institute of Technology (MIT) have come up with an approach to heat up the surface and produce steam using a double-layered black disc floating on the surface of water. The disc's top layer consists of graphite flakes forming a 5mm-thick porous matrix that absorbs and concentrates the heat from sunshine. The lower 10mm-thick porous carbon foam layer floats on the water and prevents the heat on the top layer from being lost to the water below. This a pressure gradient that slowly and continuously draws water up through the disc, where the popcorned graphite easily turns the thin layer into steam, increasing the efficiency to 85%.[30]

11. FUTURE IMPACT

One perspective is that harnessing solar energy is a very difficult and expensive affair. Huge amounts of land are to be acquired. Arable land will remain unaffected by such acquisitions cannot be determined. Even in deserts there are issues of resettlement and rehabilitation and, disturbing wild life. The large solar power projects like Ivanpah, California, US are not without negative aspects. Even though the site occupies 3,500 acres of public desert, the animal life in the area was affected. Nearly 130 tortoises had to be evacuated from the area even after spending $22m on their evacuation[31]. The subsidies continue to drive investment in renewable energy. Through a 'net-metering' system, consumers with small solar installations (primarily on rooftops) can sell surplus power to the grid at the same price as they pay for power flowing in. Similar arrangement exists in Australia. However, only the rich would be in a position to install solar panels of their own. Those living in rented apartments or who cannot afford solar panels of their own do not reap any benefit of the subsidies, which are also levied on them. The affluent therefore, not only get their bills reduced, but also get paid back for the electricity fed into the grid. Excessive renewable energy and policies giving preference to it can play havoc as is evident from the experience of Germany. Angela Merkel herself said that a rise in green energy projects would harm Germany's competitive advantage in the global economy. In Germany on 16 Jun 2013, the wholesale price of electricity fell to minus €100 per megawatt hour (MWh). That is, generating companies in addition to selling, were also paying back the managers of the grid to take their electricity as the solar and wind generators produced 28.9 GW of power, taking the peak availability of power well beyond the grid could sustain. The 'grid-priority' meant that the conventional nuclear/coal/gas power plants had to go out of synchronization to save the grid, which they could not as they are not designed to get plugged off on short notice. The result was prices went negative. The gas-fired and hard-coal power plants consequently reduced their output to about 10% of their capacity.[32] Even though this may sound as the desired result of promoting renewable energy, this would eventually discourage the running of conventional power plants. The consequences of promoting renewable energy to the present extent have been disastrous for the existing conventional power plants, which are built keeping in mind 20-30 years perspective. Germany plans to close all its nuclear power generation by 2022 and to get 80% of its power from renewable sources by 2050[33]. The southward push of electricity prices is evident in Germany due to the renewable energy sources. From more than €60 per MWh in 2008 to under €38 per MWh. The wholesale electricity prices though are going down as SPV cell production has been coming down at a fast pace, but the burden of subsidies has also been spiraling. The net result would be not only be money-losing. Utilities would go out of business. Also the intermittency required for renewable energy would get severely affected. Unstable grid may lead to blackouts or brownouts. The power utilities business cannot be run where pricing has to be determined when it turns negative. The time tested energy sources are being replaced with less reliable and expensive utilities[34]. As indicated by SMA Solar Technology AG's (Niestetal, Germany) web based performance tool, Germany set a new record on sunny days in June 2013 for solar photovoltaic (PV) electricity production well exceeding 20 GW. This was about 40% of the country's electricity demand during those hours. It must be noted however, that for quite a few weeks in December and January, close to no electricity was produced by these 1.1 million solar panels. To avoid blackouts, the grid operators had to import energy from neighbouring countries including the Czech Republic and France. Things got so miserable that an old oil-fired power plant in Austria was put to use. Spain by 2012 doubled its solar power capacity of 690 MW in 2007. However, at the same time the burden of subsidies also rose from €190m in 2007 to €3.5 billion in 2012. It is also argued that even though photovoltaic panels have halved in price since 2008, [35] the cost of power production is competing with that of coal or gas fired power plants. If other levelised costs are taken into account, they do not show solar power in poor light. [36] For instance the cost of intermittency should also be taken into account when the days are not sunny or during night. Similarly for wind power on calm days when conventional power must keep running. Their operational as well as capital costs, including those incurred in waste management, have to be taken into account. The net cost for solar energy in fact turns out to be negative[37]. With subsidies, wind and solar power are pushing the conventional coal/gas based power plants to the corner. In recent years, nearly half of the power augmentation is through renewable energy sources.. Environmentalists and the governments have been justifying the promotion of renewable energy sources as being clean and green. The legal 'grid-priority' given to the renewable energy sources means the power must first be drawn from the renewable sources if there is excess power in the grid.

12. INDIAN SCENARIO

The largest SPV plant in India - Diken Solar Power Plant (DSPP), is built on 500 acres of land and is spread out symmetrically in all four directions. The overall cost of the project was roughly $ 1.5 billion (100 billion Indian rupees). The government provided land on lease. It took roughly 18 months to establish this facility. The maximum daily output of the plant is 104 mega watts. If the output continues to be the same, 215350 Megawatt hour would be produced annually[38]. Power is generated from 6:30 AM to 6:30 PM and the peak hours start at 11:00 AM and end at 2:30 PM. DSP has 442,000 solar panels, each with an area of 1.9 sqmetre. The plant uses fixed solar panels to contain maintenance and operating costs. Currently, the plant has 5 engineers, 15 technicians and roughly 30 labourers. The cost of the maintaining the plant is less than 0.1% of the cost of the plant. The plant has signed a 25 year power buying agreement with the state government. During its construction, a majority of the 1000 people employed to work were locals. After its establishment, the area nearby has also seen an improvement in its infrastructure. India hopes to soon open the world's largest solar park. The plant will be situated at Rewa in the state of Madhya Pradesh. The project will have a total installed capacity of 750MW. The park shall be spread over a vast area of 1500 acres. The Solar Energy Corporation of India (SECI), a government enterprise, is heading the project. The investment required for this plant is a massive $ 6.2 billion (400 billion Indian rupees)[39].

13. CONCLUSION

European Union targets to generate 30% of its electricity from renewable sources by 2020, up from about 13% now. In Britain opposition to wind power is mounting due to the ugliness the gigantic wind turbines give to the landscape, about 85% of Britons back new solar projects - less intrusive on sunny hillsides. It is hoped that big arrays may even encourage some kinds of wildlife, for example by sheltering ground-nesting birds.[40] Fossil-fuel-powered electricity will not be pushed aside quickly. Fracking, a technological breakthrough which enables natural gas to be extracted cheaply from shale, means that gas-fired power stations, which already produce a fifth of the world's electricity, will keep the pressure on wind and solar to get better still. Nuclear power is not a realistic alternative. It is too unpopular and the capital costs are huge. And coal's days seem numbered. In America, the share of electricity generated from coal has fallen from almost 80% in the mid-1980s to less than a third in April 2012, and coal-fired power stations are closing in droves. Hydroelectric power plants are safe, yet they have the problem of being geographically immobile and can provide energy to areas in the nearby vicinity only. Biofuels and hydrogen fuel cells may be used as alternatives to petrol but biofuels, which include ethanol, hamper the performance of a vehicle.Vehicles with hydrogen fuel cells still haven't been produced on a reasonably large scale. It is true, one day we shall run out of fossil fuels and its several by products. Hopefully, when that day comes we shall be prepared to substitute it with other alternatives. If we take a look at solar power, it does seem to be a viable option. Sunlight falls on the planet everywhere. While there are certain patches of land where the proposition of solar power may not work due to geographical reasons, a majority of land does enjoy the benefits the sunlight. The cost of solar power panels is rapidly coming down with their efficiency going up. Solar energy can satisfy a substantial amount of our energy demands. This would be a huge leveling of playingfield as world's poor mostly live in the regions inundated with solar incidence who are bound to benefit most. At the same time lessons are to be learnt from Germany. Solar power can help us in the absence of oil too. Already on 9th March 2015 André Borschberg, a Swiss pilot, took off from Abu Dhabi on a solar-powered aircraft - Solar Impulse 2, on a journey around the world. For automobiles, fuel cells or nitrogen engines may provide the alternative to oil, where hydrogen and nitrogen gas is produced from the power generated through the solar cells. One thing looks certain that in future solar energy is going to significantly power our homes and, perhaps our automobiles and aeroplanes too.

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