Environment and Energy System Studies

Course Project on
"Solar energy in India: Challenges and policies"

Group 6. Renewable energy 1

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Abstract

India's electricity demand has doubled in the last ten years; however, its carbon power capacity has also doubled. This paper focuses on one of India's main problems: the use of coal, which is the cause of most of the carbon dioxide emissions. Throughout the paper we analyse both the challenges and future prospects for solar energy in India. We base our research on the analysis of solar energy policies in India, the demerits of solar energy, among others. We find that India's dependence on coal is due to the following factors: current policies regarding solar energy, housing infrastructure, economic inequality, etc. Within the paper we have also proposed a series of measures that India can adopt so that the existing energy demand is covered with solar energy.

Keywords: *India, coal, solar energy, power sector, energy, renewable energy, policies.*

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1. Introduction

The next report will cover the group project of the FMIF20 - Environmental Issues course. The aim of this paper is to study the situation that India is going through with the problem of dependence on coal and from there, propose solutions. It will be mainly studied how solar energy can help India to become energy independent in the coming decades.

The principal purpose of the Paris Agreement signed in 2015 is to reinforce the global response to the threat of climate change by keeping the global temperature increase in this century well below 2 degrees Celsius, that is why the generation of energy produced from coal, which is responsible for the majority of carbon dioxide emissions, must be gradually eliminated by 2050. (IPCC, 2019) Some studies predict that the world's carbon capacity will increase by around 25% in the coming years (Shearer et al., 2020).

In the last 10 years, two-thirds of the coal power plants in India were built and considering that India is one of the countries with the largest coal gas pipelines, most of these plants would be abandoned after 2030 if India apply the policies to comply with the Paris Agreement (Malik et al., 2020).

Notably, in recent years, the use of solar renewable energy has increased dramatically in India. This leads us to our first research question: Why India continues to use coal if the solar energy potential in India is steeply high? This work will answer this question. In addition, the time it will take for India to become self-sufficient in terms of energy generation will also be analysed, and we will focus above all on solar energy. This will lead us to our second research question which is what future barriers/measures do we need to overcome/implement to achieve carbon neutrality from the perspective of solar energy.

First of all, this report will place the reader on the current situation in India, both in the field of coal and in the field of solar energy. Following, a summary will be made of the highlighted policies regarding solar energy. Finally, a series of solutions will be proposed for India to become independent of carbon, in order to use renewable energy like solar energy in a way that reduces carbon dioxide emissions to the atmosphere and thus contribute to meeting the objectives set in the Paris Agreement of 2015.

2. Coal in India

India has a significant presence on the world scene. India is currently the second-most populated country in the world just after China, and looking at the present growth rate it is ascertaining that it will become the most populated country in the 2020s. India's economy in recent years has experienced largest growth rates in the world, becoming in nominal terms, the fifth largest. However, in turn, India's economy is low-income, with per capita income less than half of the world average. India's economy has great growth potential as half of its population is under 25 years of age.

Since 2000, India's energy demand has increased by more than 60%, although the differences between different parts of the country and socio-economic groups must be taken into account. In Figure 1 it can be seen how the demand for coal increased from 25% in 1990 to 60% in 2019, which is why carbon dioxide emissions also increased during this period.

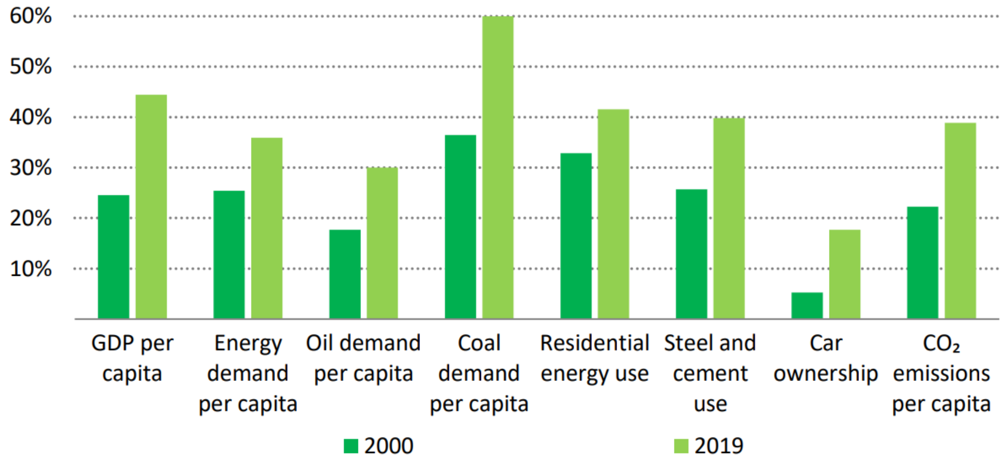

Figure 1. Key indicators in India as a percentage of global averages (IEA, 2021)

This leads us to the question of how India will meet this increased demand for energy. Except for solar, wind and coal, it could be said that India's resources are limited. In addition, it has several problems such as overpopulation, limitations in land use, high water stress, poverty and other socio-economic factors which make the availability of energy a major problem.

India's energy system is characterized by the coexistence of abundance and scarcity. India has the fifth largest coal reserve in the world, yet it is also one of the largest coal importers in the world. India is an important area to refine oil, however, it depends mainly on imported crude oil.

In terms of energy, there is a big difference in India determined by the choice of absolute or per capita values. On one hand, the absolute values are high and continue to grow, on the other hand, the values per capita are small. Although India is one of the countries that consumes the most energy, the energy consumption of Indians on average is much lower compared to citizens of advanced economies. In addition, India ranks third among the countries with the highest annual CO_2 emissions, yet according to per capita emissions India is among the top 100 countries.

India's energy demand is met primarily by three fuels: oil, coal, and biomass. Since 1990, these sources have collectively covered more than 80% of India's total energy needs (Deb et al., 2015). Coal has established itself as the leading energy source. Coal demand tripled between 2000 and 2019, accounting for half the growth in primary energy demand. Currently, 44% of India's primary energy needs are met by coal. Coal has been very important in the development of the Indian economy and, at the same time, it has caused pollution of the environment, air and greenhouse gas emissions.

Coal has become the cornerstone of the country's energy economy, accounting for 44% of the primary energy structure and ranking third among the Group of 20 (G20) countries. India's coal mines produce more than 700 million tonnes (Mt) of coal every year, mainly in the eastern states of Madhya Pradesh, Chhattisgarh, Jharkhand and Orissa. The coal is mainly produced in open-pit mines. Since the 1970s, the state-owned Coal India Limited (CIL) has been a leading producer of coal and is now the world's largest coal mining company, with more than 80% of the coal produced in the country (IEA, 2021).

India has the fifth largest coal reserve in the world (Ministry of Coal, 2020), yet domestic production has not been able to keep up with demand. This has led to an increase in imports in recent years, although since the mid-2010s, dependence on imports of thermal coal has slowed due to increased domestic production and lower demand growth. Part of the need for imports comes from the demand for coking coal from the steel industry since coking coal is not as abundant in the country as thermal coal. Additionally, approximately 18 GW of coal-fired power plants are located in coastal areas and are designed to use imported coal instead of low-quality domestic coal. Moreover, Indian coal has a high ash content and a low calorific value, thus increasing operating, transportation and maintenance costs. One of the government's goals is to eliminate coal imports by 2025, encouraging domestic coal production (IEA, 2020).

2.1. Current crisis 2021

Approximately half of India's CO_2 emissions come from coal-fired power plants, making it the third-largest emitter of CO_2 after China and USA. In the fiscal year 2018-19, coal generated 74.3% of India's electricity (MoP, 2019). This depicts the reliability of India on coal and shows how vulnerable the system will cease to be if the supply of coal is impacted. The irony here is that, despite being the world's second largest producer of coal, India is also the third largest importer of coal behind China and Japan. The (Annual report, 2019) gives the coal statistics in metric tonnes of coal produced and imported annually. Upon calculation of the percentage for the fiscal year 2019-20, we observed that India imported 34% of its annual requirement of coal.

Reports from India show that coal fired, thermal Power plants in India are currently [as of September 2021] facing a power crisis because coal stocks have fallen to unprecedented low levels and states are threatening blackouts. According to India's Central Electricity Authority, as of 12th October, nearly 80% of its coal-fired power plants are in the critical stage, which means their stocks could run out within five days. In Maharashtra, 13 thermal power plants were shut down and people were urged to conserve electricity. In Punjab, three power plants were halted, and scheduled power cuts lasting up to six hours were introduced. However, in contrast, despite a minor dip in production from 2019 to 2020 due to the pandemic, Indian coal production has continued to rise exponentially over the past two decades. The actual reason behind this is the global energy crisis and India's reliance on coal imports as stated previously, which has led to record highs in international prices and coal shortages.

This phenomenon may seem scary, but world has seen a fair share of market fluctuations in the prices of oil and coal before. From India's perspective, the only way to circumvent such aforementioned scenarios is to either be self-sufficient with the coal production or to switch to renewable means of generating energy. The first method is infeasible as India's annual coal production is nowhere near to being self-sufficient. Also, being finite, the coal reserves will only deplete further with time and coal prices will soar. This crisis is an indicator to boost India's renewable energy production in order to be self-sustainable in the near future. This switch will also help us to realize the net zero goal set by India for itself. The goal of the first part of our research is to analyse the time duration needed to phase out India's reliability and be entire self-sufficient by not importing coal and balancing the power generation workload through other means.

3. Time Analysis

This section is an effort to realise how long will it take for India to realize its set energy goals or the time it will take India to be able to produce all of its energy requirements by itself. India has done a commendable job in expanding the total installed capacity for renewable energy sources. The graphs shown below give a breakdown statistic of the renewable energy consumption in India. Wind energy currently holds the largest share for total generation annually (Elavarasan et al., 2020). However, the notable exponential increase in the generation of solar energy is also of interest here. The contribution of renewable energy to India's total energy generation from all sources increased from 5.56 % in 2014 to 11 % in 2021 (Annual report, 2019). This is a significant rate of increase and we can give significant credit to India's focus on renewable energy policies.

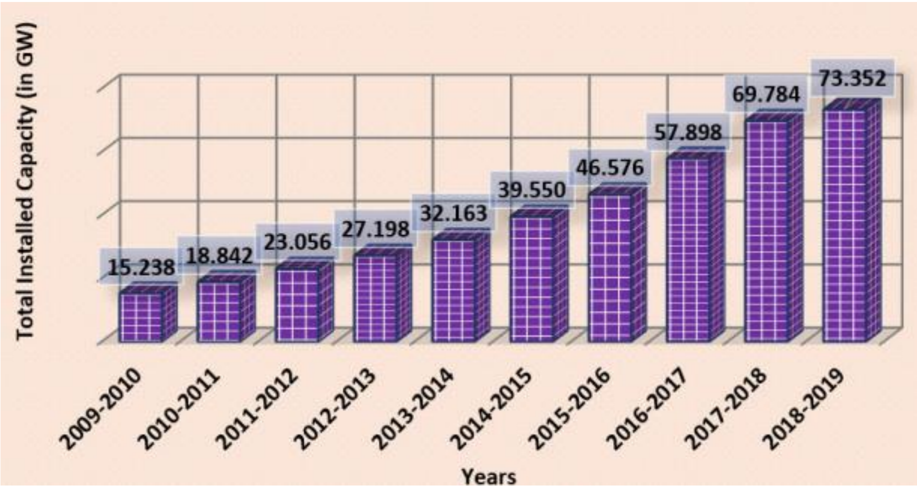

Figure 2. Renewable energy growth in the last decade (Elavarasan et al., 2020: p.74433).

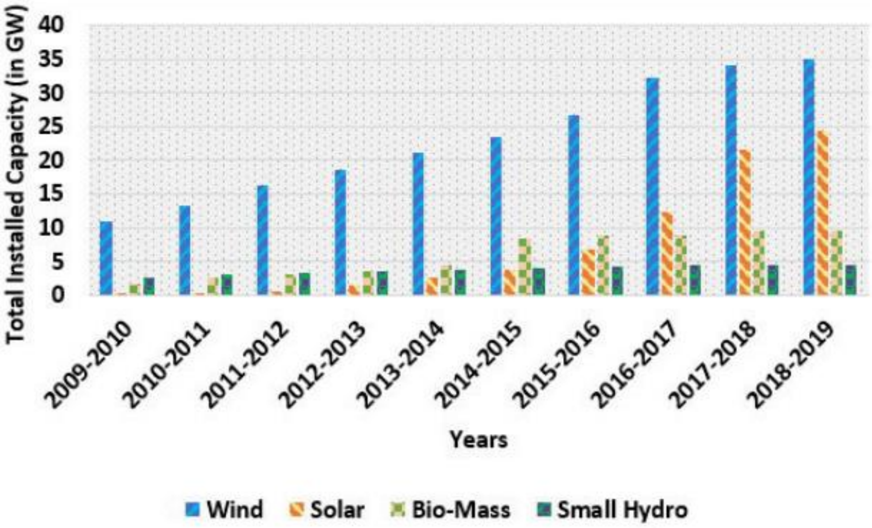

Figure 3. Breakdown of renewable energy sources for the last decade, (Elavarasan et al., 2020: p.74433).

Renewable energy prices have dramatically decreased in India, and many of the current Renewable energy projects in India are cheaper than coal fired thermal power plants (Creutzig et al., 2017). On a parallel note, in accordance to the Paris Agreement, carbon emitting coal-fired power must be phased out by 2050 from India, if we are to stay well below 2°C (IPCC, 2019; Luderer et al., 2018). These trend of increasing renewable energy share and India's commitments look promising. This is also positive to avoid future struggles from a coal crisis arising in the future.

To predict the pathway for the India's future energy scenario, we review similar work in this domain. The first example is from (de la Rue du Can et al., 2019) wherein they forecast India's projected capacity for the next few decades.

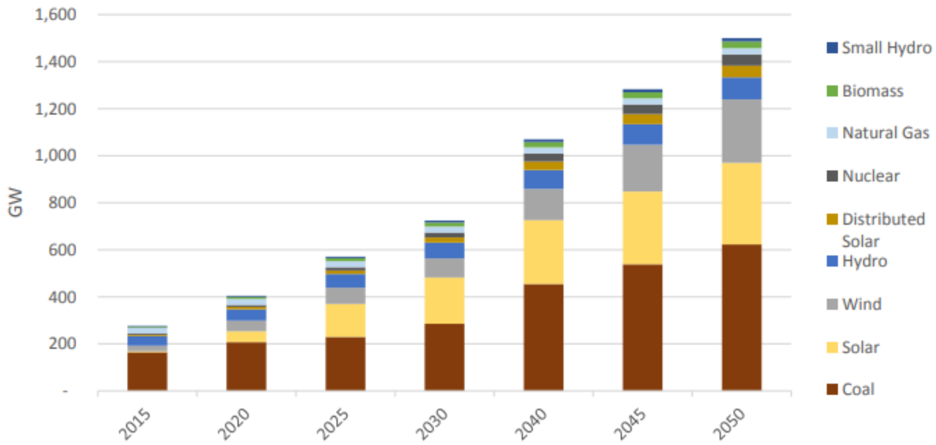

Figure 4. Projected future capacity in India from 2015 to 2050 (de la Rue du Can et al., 2019)

The model takes into account India's renewable and climate goals, future demand scenarios along with certain buffers for retrospective trends for demand fluctuations. The model accounts the data from 2015 as the baseline. We exclude Natural gas and Nuclear energy from our calculations and we observe that the share of renewable energy sources will produce more than 50 % of India's energy in between 2045 and 2050. From the perspective of coal, the report predicts that power generated from coal will decline to below 50 % before 2030. Also, as India imports 30 % of its coal currently, we can also say that with the increase in renewable energy sources, India will be able to fulfil all of its energy requirements by itself in between the span of 2025 and 2030.

We get further insight into this prediction when we refer the data from the Central Electricity Authority of India report of 2019 (MoP, 2019). The report estimates coal to be the largest source of electricity generation till 2050. Despite a constantly increasing share of renewable energy, coal is projected to remain the largest source of electricity until 2050. According to the National Electricity Plan for 2018 coal's share in power generation will decline from 72% in 2019 to 48% in 2030 (Montrone, Ohlendorf and Chandra, 2021).

This acts as validation to the model developed by (de la Rue du Can et al., 2019) and both these policies state the expansion in the solar and wind energy sector as the most influential actors for the role of future self-sufficiency for India. However, the models are guided by the ambitious renewable policies and goals set by India. Another important aspect shows up when we observe the notable expansion of the share of solar energy in the future years. The share of wind energy sector is somewhat stagnant even if it generates the largest amount in renewables currently.

In the next section, we will focus on the current state of solar energy in India and witness steps and policies implemented by India in this sector. These past and current policies along what future steps should be taken to increase solar energy share will be discussed in the next section. We will also investigate potential future solutions and current shortcomings for India to become energy independent in the next few decades.

4. Present scenario of Solar power in India

4.1. Solar power policies timeline in India

The energy sector relies largely on coal as a fuel source. According to the International Energy Agency (IEA), India will contribute the second-largest amount of energy to global demand by 2035. Among India's priorities are awareness, grid parity, cost competitiveness, and cost-effectiveness. According to research, renewable energy still costs 50% more than conventional methods of generating energy. Therefore, sound and steady policies are needed to facilitate these goals (Anon, 2020). Subsidizing renewable energy production is a step in that direction, but research indicates that subsidized renewable energy production is still 50% more expensive than conventional means of generation (Raina & Sinha, 2019).

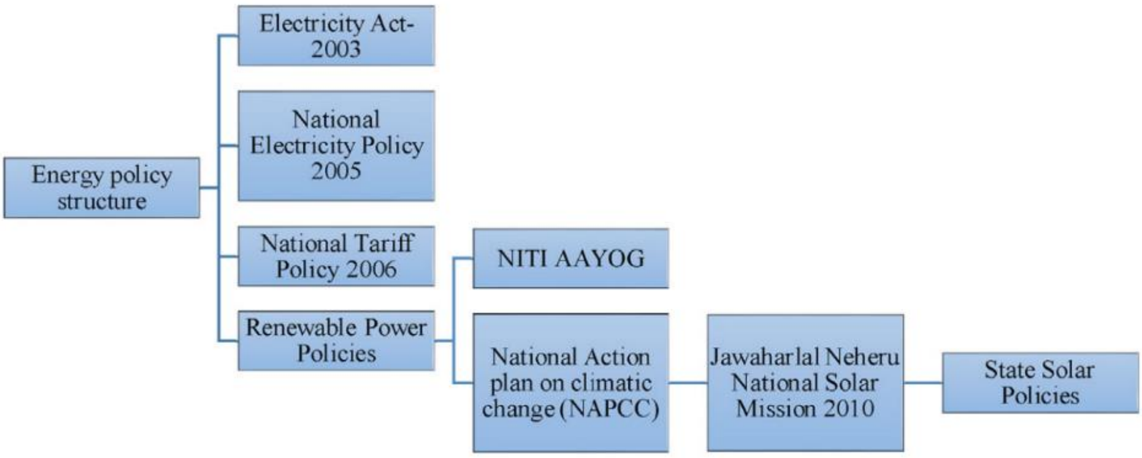

Figure 5. Energy Policy structure for solar energy India.

<u>Indian Electricity Act of 2003</u>

The Electricity Law was promulgated in 2003 to integrate laws related to energy production, transmission, and distribution across the nation. With the promulgation, the power industry will be promoted, power will be distributed to all regions, including rural areas, and electricity prices will be rationalized. According to the bill, the central government may negotiate with state governments regarding power generation policies. The electricity price policy was created with the implementation of the "Electricity Law." Additionally, the Electricity Law aims to privatize the power generation, distribution, and transmission sectors. In this bill, tariff subsidies (FIT) and renewable energy purchase obligations (RPO) were introduced (Raina & Sinha, 2019).

<u>National Electricity Policy of 2005</u>

The national power policy was revised in 2005 to provide all families in India with high-quality and reliable power that meets required standards at lower prices and with higher efficiency. The goal of this policy is to encourage private participation in the power sector through the implementation of a national-level open access transmission system. To improve the efficiency of the distribution network, the policy ensures that supervisory control and data acquisition (SCADA) and data management systems are used. This policy is expected to undergo a revision in 2005 with the aim of providing every Indian family with reliable, high-quality electricity that meets the required standards at lower prices with higher efficiency (Tarai and Kale, 2018).

National Tariff Policy of 2006

The Indian government launched the National Electricity Price Policy in 2006 to increase the financial viability of the electric power industry by attracting potential investors (Rathore, 2018). The goal of this policy is to increase competition by providing electricity to all consumers at a reasonable and reasonable unit price, Efficiency, and operational quality. According to the plan, tariffs will be implemented nationwide for many years, and availability-based tariffs have been introduced at the state level. The allocation of renewable energy procurement licenses is carried out through competitive bidding. The policy requires the National Electricity Regulatory Commission to determine the minimum percentage of energy purchased from renewable sources, considering the availability of such resources in the region and its impact on retail electricity prices (Anon, 2020).

Integrated Energy Policy of 2006

Despite offering overall policy guidelines for action, this integrated policy document recommended a particular focus on renewable energy development and identified specific targets for capacity expansion. National Action Plan for Climate Change (NAPCC) 2008 The government of India developed a mission model action plan for sustainable growth under NAPCC to address climate change. Its first task is to strengthen solar energy development. It also recommends setting the RPO at 5% of the total grid purchases and increasing it by 1% every year for 10 years (Anon, 2020).

Jawaharlal Nehru National Solar Mission (JNNSM) from 2010

The Indian government announced the Jawaharlal Nehru National Solar Energy Mission (JNNSM) in 2010 to encourage the economic growth of solar energy in response to India's energy challenges. For example, electricity, clean energy, sustainable growth, human resource development, research and development of key raw materials, parts, and products, and domestic production are all insufficient. The initial goal of the mission was to install 20 GW of solar energy in three phases by 2020, which was later modified by NITI Aayog. The goal of the first and first phase of JNNSM is to increase the installed capacity to 1GW by March 2013 and complete it in 2012. The second phase is expected to last until March 2017, with a target capacity of 10 GW, and the final target capacity is 20 GW by March 2022, or before the final stage. Another basic goal of JNNSM is to make India a global leader in the solar field by enhancing confidence in power developers, promoting manufacturing in the solar industry, and deploying large-scale goals with appropriate policy frameworks (Rathore, 2018).

The efforts put in by India to improve the solar potential are visible on the energy charts. Owing to the periodic policies implemented by India, solar energy production has shown a noticeable increase over the last decade. However, we need to continue these efforts if we are to realize the ambitious future goals set for India's energy independence. To do so, we first take a look at the drawbacks of solar energy and the current limitations and hurdles to India's ambitious solar energy goals. Realizing these hurdles and drawbacks and drafting future policies to subdue or overcome them is the way to go forward for India to eliminate its reliance on imports for its own energy requirements.

4.2. Demerits of Solar Power

The electric power from the sun is harvested based on the Einstein's photoelectric effect principle, the electrons for the Photovoltaic (PV) cells emitted when the sun light strikes on the cell. There is no direct emission of harmful gases or dust particles during electricity generation from the PV cells. However, there can be some emissions during other stages like manufacturing, transportation, installation, maintenance, decommissioning and dismantlement which can be related with solar power. According to the IPCC report (Arvizu *et al.*, 2012) on Concentrated Solar Power (CSP) the life cycle emission of such plant was found to be 0.08 to 0.2 pounds of carbon dioxide equivalent per kilowatt-hour. This number is very low in comparison to coal or natural gas, yet the amount of emission can be in considerable amount when we look globally.

The other demerit of solar power is the during the extraction of silicon. There is risk of silica particles to be released in open air during the mining and refining stage, these silica particles can cause lung diseases if inhaled. Similarly, the production phase of semiconductor requires use of hazardous chemicals like hydrochloric acid, nitric acid, hydrogen fluoride, acetone, etc. So, the safety of miners and production workers is an important aspect to be considered in panel manufacturing. Likewise, heavy metals like gallium, arsenide, cadmium, lead, chromium mercury, nickel etc. are used for the manufacturing of the panels. The study (Fthenakis, Kim and Alsema, 2008) mentions that solar power emits 0.004 g/GWh of Cadmium directly. Cadmium is harmful when inhaled in high amount can cause cadmium toxicity. The manufacturing process for PV cells should be properly regulated to mitigate the different risks from the PV panels.

Additionally, land use is one of the major issues associated with solar panels. Unlike wind power plants, the land of solar power plants cannot be properly used for agriculture or other purposes. Based on different estimates it is found that utility scale solar plants require 3.5-10 acres and Concentrating Solar thermal Plants (CSP) require 4 to 16.5 acres of land per megawatt (Environmental Impacts of Solar Power | Union of Concerned Scientists, 2013). Hence, this impact of solar power can be reduced by using low quality locations, commercial building and even roof top of houses.

With the increasing production capacity of solar power all over the world, panel waste and batteries wastes are a growing issue. Currently only 50% of the batteries in the world is recycled (Melin, 2018) as recycling batteries is expensive technology and requires proper policy intervention to make it cost effective. As mentioned above the manufacturing of panels require heavy metals. Decomposing of panels in landfills creates high risk of such metals leeching into the soil and causing health hazards. It is also harmful for the quality of soil.

5. Current challenges and outlook for India

The International Energy Agency's analysis shows that tariff policies, national-level policies, and greater private sector participation in 2006 played a key role in the overall growth of India's installed renewable energy capacity. However, as India is advancing to achieve the goal of 175 GW of renewable energy and 100 GW of solar installed capacity by 2022, the 40 GW RTPV target is facing new challenges at different stages of installation and use. Several policy analyses have been carried out. Although the Climate Group recommends that the performance of the commercial and industrial sectors will play a greater role in achieving the goals, it strongly recommends that the private sector strengthen cooperation to double existing capabilities. Net metering and a package of incentive measures for public utilities are the necessary foundation. Methods to cover investor risk and increase consumer awareness can be fundamental components (Khanna, Ashish, 2010).

Policy and Regulatory Barriers

Many developers agree that policy and regulation are the most critical obstacles, while half of developers agree with infrastructure obstacles. Some developers believe that solar radiation is also an important obstacle. Few developers believe that technology and funding are not the main issues for India's adoption of solar energy. Solar energy is one of the most prominent and useful energy sources supporting the development of developing countries in the new era. When dust particles accumulate on the photovoltaic panel, the performance of solar photovoltaic technology is reduced by 85% (Nandal, Kumar & Singh, 2019).

Amongst the policy and regulatory barriers, the key issues raised by the developers are the need to build consumer awareness about the technology, its economics and right usage, the complexity of the subsidy structure and the involvement of too many agencies like MNRE, IREDA, electricity board and electricity regulatory commission, which make the development of solar PV projects difficult, The Power Purchase Agreement (PPA) signing is a long procedure under the Generation Based Incentive scheme, and there is a need for better financing infrastructure, models, and arrangements to stimulate the PV industry and consumption of PV products (Nandal, Kumar & Singh, 2019).

Infrastructure Barriers

To increase the share of solar energy in the Indian power sector, local facilities and infrastructure play an important role and are considered a key obstacle. The development of solar power projects requires additional infrastructure, such as solar panel support structures, land, connecting roads, power evacuation transmission lines, etc. This presents a challenge to society in terms of adopting solar energy (Nandal, Kumar, & Singh, 2019). Land acquisition has become a major factor in solar energy adoption. Developers of large-scale solar projects. In addition to this tax system, project developers also need a large amount of investment to develop infrastructure; the lack of clearance from the project approval system and single window makes infrastructure an obstacle. Of all the obstacles related to infrastructure, land is the most critical (Khanna, Ashish, 2010).

Financing Barriers

Due to the nature of the technologies involved, solar energy is generally classified as highly capital-intensive and low-cost. A reliable, efficient, and low-cost photovoltaic integrated storage device requires a lot of funds to develop and install. This means that it requires long-term finance. The most challenging issue identified by industrialists, enterprises, banks, and governments who are interested in solar projects is the high investment risk that is involved, as well as the high interest rate, because of which financial institutions typically do not finance such projects. It is now possible to mobilize funds for the development of renewable technologies, storage technologies, and new manufacturing facilities, as well as for institutions of research and training, using a new innovative financial instrument (Nandal, Kumar, & Singh, 2019). Thus, adequate funding schemes at the government level are critical for the deployment of sustainable, clean, and green energy technologies in societies. In order to overcome this cost-related issue, some of the points should be taken to address the high initial investment cost of PV technologies (Raina & Sinha, 2019). Also, small and medium-sized enterprises and homeowners should be able to get loans for PV installations from banks with more flexibility. Net metering benefits can be obtained by limiting the number of stages of approvals required. The government should introduce a credit guarantee scheme, which would provide a means of mitigating credit risk to lenders, which will protect the lender from default risks and ensure that the borrower can repay the loan in case of default. It should also eliminate import duties on solar panels in order to reduce the high capital costs of PV plants.

Power storage for grid flexibility

As discussed earlier, India largely depends on coal for energy. As per Paris agreement, India promised to generate 40% of installed power capacity from non-fossil sources. Recently, in the COP26 Indian prime minister Mr. Narendra Modi made an announcement to reach net zero emissions by 2070. He also declared a decrease in dependency of non-renewable sources and get 50% of total energy from renewable by 2030. Solar energy shall have huge contribution to realize these targets.

Solar power is considered as a clean source of energy, its carbon footprint over lifetime is very low in compared to coal and other non-renewable power plants (Pehl *et al.*, 2017). So, they are can be a good solution to decrease the carbon emissions for power generation. But energy generation from renewables like solar and wind are intermittent. The traditional power plants running in non-renewable energy can easily handle the change in power demand. The power output can be altered by the operator to support the variation of demand. The energy can be stored through fuels for grid flexibility.

However, solar power output varies greatly throughout the day. The power from PV is mostly governed by the intensity of sunlight falling upon the panels and cell temperature. The power from PV cell is not under the control of plant operator and during night no power is generated from the plant. The greater grid penetration of solar power causes overgeneration of power and affects the system stability. Such conditions have been observed in California and other places, and the power curve is termed 'Duck Curve'. The solar generation is maximum during the midday, but the power demand is seen more prominent during the night (6-10 pm) (Denholm *et al.*, 2013). This creates useless generation during the day, which could have been stored with storage systems. A study by NREL (Chernyakhovskiy *et al.*, 2021) shows that storage is very essential to improve the flexibility of solar power, it also indicates that a proper synergy between solar and storage systems such as Battery Energy Storage Systemd (BESS) can help in overall cost reduction of solar as well as storage systems. The study by (Chernyakhovskiy *et al.*, 2021) on future energy system of India, shows that with increase of renewable energy like solar the requirement of storage system becomes essential to adjust the variability and integrate more solar power into the system.

There are different types of energy storage like pumped hydro, flywheels, batteries, fuel cells, super capacitors, etc. However, rapid development in technology, price competitiveness and different constraints of other storage systems, Battery energy storage system (BESS) is favoured globally (Goldar and Singhal, 2021). There has not been significant progress in terms of Pumped Hydro storage in India due to various issues (India Smart Grid Forum, 2019). Other technologies like super capacitors, fly wheels or concrete stones are either in testing phase or expensive to batteries. So, this paper is focused on the BESS technology.

A scenario analysis study on 40% non-fossil fuel-based electricity in Indian energy mix, shows requirement of considerable capacity of storage system. A capacity forecast on required storage capacity for India was prepared by India Smart Grid Forum (ISGF) and India Energy Storage Alliance (IESA) (India Smart Grid Forum, 2019). According to the projection shown below in Table 1, India requires 33 GWh (Giga-Watt hours) battery storage by 2032. Hence, this large capacity of storage that is required can be a barrier for solar energy development in India.

Table 1. Energy storage size forecast for renewable in India (India Smart Grid Forum, 2019, p. xx)

Energy Storage Estimations for MV/LV Grid (MWh)

Estimates	2019	2022	2027	2032
Generation (GW)				
Thermal	209	NA	NA	NA
Hydro	43	NA	NA	NA
Nuclear	6	NA	NA	NA
Solar	26	107	244	349
Ground Mounted Solar	24	68	148	206
RTPV	1.5	40	98	144
Connected to EHV	14	34	66	94
Connected to MV	11	35	84	112
Connected to LV	2	40	98	144
Wind	35	NA	NA	NA
Small Hydro	4.5	NA	NA	NA
Biomass & Biopower	10	NA	NA	NA
Peak Load (GW)	192	333	479	658
Energy (BUs)				
Annual Energy Requirements	1192	1905	2710	3710
Storage Recommended (MWh)				
Battery for LV Grid	241	5908	14617	21484
Battery for MV Grid	1054	3482	8393	11191
Total Storage (MWh)	**1295**	**9390**	**23010**	**32675**
Approximate (GWh)	**1 GWh**	**10 GWh**	**24 GWh**	**33 GWh**

Handling of Photovoltaic (PV) Wastes and Batteries recycling

With growth of PV installations one of the major challenges is the management of the panels after at the end of their life cycle. The regular life span of PV panels is 30 years, but they also can fail earlier due to wear out (IRENA and IEA-PVPS, 2016). As the installation of panels grow all over the world, at higher rates the amount of panel wastage is sure to rise. A study in 2016, (IRENA and IEA-PVPS, 2016) projects if the growth of solar power grew in linear rate by 2050, there will be 4,500 GW of installed solar capacity all over the world and the amount of PV panel wastages is bound to be 60 to 78 million tons. Interestingly based on the projection by IRENA and IEA-PVPS for 2050, India ranks fifth globally with 7.5 million to 4.5 million tons of waste PV. This is a huge amount of waste that needs to recycle for a sustainable energy sector.

To make the solar power to be sustainable, the panels should not end up in landfills after they lose their life. The panel recycling industry looks like a new growing area and that holds good prospects for future. Recycling can reduce the demand of new raw materials for manufacture of PV. It is predicted that with proper recycling techniques we can gain used raw materials equivalent to 60 million panels by 2030 and this recovery can grow up to 2 billion panels by 2050 (IRENA and IEA-PVPS, 2016). In economic and figurative terms, it shows a huge potential for new industries to work in this field. The end-of-life management process for PV can be summed up into simple 3 R's, Reduce, Reuse and Recycle. The first R, reduce is more concerned with increasing the panel efficiency, while reuse is using the panels by repairing if they get damaged during their operation and recycling as mentioned above is extracting the materials from the panels when they get broken.

Likewise, the Battery Energy Storage System (BESS) are required to increases the flexibility of the grid, but it is also important to properly manage these batteries after their life span. Normally, the life cycle of batteries depends on their usage and chemistry. Lithium-ion batteries can last up to 500 to over 1000 duty cycles so, batteries use for energy storage might last over 20 years (Melin, 2018). The batteries are manufactured using some of the rare earth metals, so it is vital for recycling of the batteries for their sustainable use. So, management of such huge amount of PV panel waste and batteries after their end life is another challenge that stands on sustainable clean energy transition of India.

6. Suggested policies for achieving carbon neutrally

Solar PV is identified as serving a market that is very crucial in growing countries—the electrification of rural and pre-urban regions that don't have access to the electrical grid. Solar home systems have been recommended in the rural regions to increase the rural electrification agenda. However, the rural and preurban regions are classified with the aid of low-income families that won't be capable of managing to pay for solar electricity technology until it's substantially subsidized. Today, the aim is to offer subsidies either via government funds or through international donors that may help in growth, even though these policies are not a long-term solution in the country (Choudhary, Sadhu & Chakraborty, 2014).

Change in roof top policy

A solar photovoltaic (SPV) power plant consists of different components, i.e., photovoltaic modules, mounting system, DC to AC converter, and electrical connections. Rooftop PV (RTPV) systems are smaller PV systems in comparison to land-mounted ones, and are installed on the rooftops of residential, commercial, or industrial building complexes. It comprises a solar inverter, meters for regulating electricity generated and various components for modification of electrical output and input rate in kWp (Goel, 2016a). A net metering mechanism allows for a two-way flow of electricity wherein the consumer is billed only for the "net" electricity supplied by the electricity distribution companies (DISCOM). Such RTPV systems could be installed with one integrated net meter or two separate meters, one for export to the grid and one for self-consumption. The cost is high, but with some financial support provided by the state to promote their use, such systems are considered most appropriate for rural and remote areas. In the regions of power shortages, the performance reliability of non-grid RTPV can also be improved with at least 1 h of backup battery, which helps in bringing down the cost (Goel, 2016b).

To generate solar power by installing solar panels on the roofs of houses, the Ministry of New and Renewable Energy, Government of India is implementing the Grid-connected Rooftop Solar Scheme (Phase-II). Under this scheme, the ministry is providing a 40% subsidy for the first 3 kW and a 20% subsidy beyond 3 kW and up to 10 kW. The scheme is being implemented in the states by local DISCOMs. This scheme is being implemented in the state only by DISCOMs. The DISCOMs have empanelled vendors through a bidding process and have decided rates for setting up a rooftop solar plant. The solar panels and other equipment to be installed by the empanelled vendors shall be as per the standards and specifications of the Ministry and shall also include 5-year maintenance of the rooftop solar plant by the vendor. It has also been brought to the notice of the Ministry that some vendors are charging more than the rates decided by DISCOMs for domestic consumers, which is incorrect. Consumers are advised to pay only according to the rates decided by DISCOMs. This leads to the same positive trend for rooftop solar capacity addition. The average of all the responses indicates an estimated rooftop capacity of +14 GW by 2022. Rapidly falling costs and government efforts to boost demand in the public sector have improved growth prospects in this market (MoP,2021).

Efficient Land use for solar installation

The availability of land per capita is low in India. Dedicating land near substations for the exclusive installation of solar cells may have to compete with other land-required necessities. The land issue was the most discussed issue among developers. Each state has its own process for acquiring land. The state of Gujarat gave developers the freedom to choose based on their criteria (the types of land they needed), but the state of Rajasthan selected government waste land for solar power development and allotted it to various developers. It can take anywhere between six and twelve months to acquire land in some states, sometimes even longer. As far as infrastructure issues are concerned, half of developers said land was the most important barrier (Anon, 2021).

Along with large-scale electricity generation and localised generation using rooftop PV plants, floating PV plants are also being considered to address certain issues pertaining to PV electricity generation (Raina & Sinha, 2019). With large bodies of water surrounding India and several rivers flowing within its borders, floating PV can and should be utilized to increase the PV installed capacity in the country. Floating PV not only helps overcome the land unavailability; it also provides an easy solution to the temperature rise problem in PV with the flow of water acting as a natural coolant, hence providing a higher energy output. Floating PV plants can be installed on dams, which would help in increasing the energy generating capacity of that hydro power plant (Na & Kim, 2019). The natural flow of water over the floating PV plants can help clean the panels of any dust that would otherwise cause shading of the panel, reducing its conversion efficiency. While the abundance of water bodies around the country can help facilitate solar PV installations, the lack of water in regions where most of the PV plants are located causes a major problem as regular cleaning and maintenance is not possible.

Policies to facilitate rapid development of Battery energy storage systems

For efficient integration of solar power into the existing grid necessary policies to ease development of storage systems will be required. India can take necessary lessons from countries like Korea, China, United States, Germany, and Australia. A policy review paper on Indian energy storage system by (Goldar and Singhal, 2021) provides some useful suggestions to future storage policies that India can adopt that has been successful in other countries. As India lacks the required mineral reserves for battery manufacturing new policies that support a strong supply chain system should be developed. Based on above Table 1 it can be easily predicted that India is booming market for grid storage systems plus with rise in Electric Vehicles (EV) the demand for batteries is certain to rise in India. Presently, India is importing batteries form other countries mainly China, the recent tenders to set up 50 GW battery manufacturing bases with 50 USD billion investment is positive step to minimize the imports (Jyoti Gulia and Jain, 2019). Realizing the market potential and strategic location of India, the national and international manufacturers are increasing the battery production capacity in India (Jyoti Gulia and Jain, 2019). This positive momentum of market must be protected by the Indian government through correct plans and policies. India can utilize its relations with African and South American countries for smooth trading of raw materials. Learning from the United States, an industry alliance like US Energy Storage Association should be created. This enables different stake holders to come together and discuss under a common canopy. Likewise, the legislation must be made favourable and encouraging to adapt Energy storage systems as in Korea, Germany, and states of US. There should be a long-term road map and vision from the side of government, that encourages the growth of Energy storage systems in India.

Management of PV waste

The rate of recycling process can be made effective with proper policies from the government. India requires strong legislation to ensure that the panels do not end up in landfills. However, currently only European Union (EU) has proper policies for recycling of the PV waste. The EU have a regulatory called Waste from Electrical and Electronic Equipment (WEEE) directive which mandates the recycling of PV panels (Clyncke *et al.*, 2014). Based on this legislation Germany has an efficient recycling process. So, Germany is the first market to make profit by end of cycle recycling of PV (IRENA and IEA-PVPS, 2016). The UK is a young growing market in comparison to Germany. It has made laws making the producers responsible for recycling their PV.

In case of India, the significant growth of solar power installations started from 2016. So, the amount of PV waste in India is not seen in considerable amount (Clyncke *et al.*, 2014). A report on PV waste management in India states, presently the country does not have specific policy for managing the PV waste. The existing policy seems ambiguous and current E-waste rules does not apply to PV product (IRENA and IEA-PVPS, 2016). Likewise, solar waste is not covered by the industrial waste rules as well. There is lack of a proper rule to regulative efficient collecting, transporting and recycling of PV panels. Hence, it is right time for Indian government to make proper plans to manage this huge amount of waste.

Opportunities and Infrastructures for Batteries recycling

Currently, Indian government has rules for recycling of lead acid batteries because these batteries have environmental as well as health impacts. There have been complications for implementing these rules, as per the information from various sources 85% of lead-acid batteries are recycled in India (Jyoti Gulia and Jain, 2019). The use of Lithium batteries in India is increasing for EV and energy storage, which calls for effective plans to recycle them. The Government of India announced it is working on policy for tax sops for recyclers and make the producers responsible for recycling of their products Extended Producer Responsibility (EPR) (Jyoti Gulia and Jain, 2019). The present E-wastage policy has no rules for safe disposal of recycling of batteries. There are some state based regulations, still ground implementation of these is not easy. Hence, the government needs to come up with clear policies and framework for encouraging the recycling of used batteries in India. The laws against land filling of batteries must be created, tax and subsidies can encourage recycling, reducing some cost. Making the producers or supplier responsible for their batteries through Extended Producer Responsibility (EPR) helps to bring in private sector investment and liability for battery recycling. So, to achieve carbon neutrality it is essential to draft policies to facilitate proper recycling of waste batteries.

7. Conclusion

The contribution of renewable energy has increased exponentially in the previous couple decades. India's policies play a significant part in that. The current energy market is dominated by coal and India imports around 30% of its coal requirements but the future trends look promising and the country will be able be produce all of its power requirement within the next decade. Solar energy will play a significant role in adhering to this trend. The reference models predict that India can become energy sufficient in the time domain 2025 to 2030 by eliminating its coal import requirement. This energy deficit will be contained by the increasing share of renewables in India. In order to facilitate this transition, significant action is required in policies, economics and technology.

It is very important to make this transition sustainably, with proper plan to overcome different economic barriers, land constraints, technical difficulties and waste management issues. With technological advances also are required to help meet the targets of solar PV installations. With the correct policy implementation and proper financial schemes to address the issue of funding for PV installations, solar energy generation can accelerate the development process in India. The Indian government should create future policies towards the more solar power energy and regulations for panels and batteries recycling. In addition to that, the power storage facilities should be created for increased solar power integration in the grid without disturbing the stability. So, the way to go forward is to identify current problems that the solar market faces and drafting the future policies measures to combat these drawbacks with sustainable solutions.

8. Appendix

BESS: Battery Energy Storage Systems

CIL: Coal India Limited

COP: Conference of Parties

CSP: Concentrated Solar Panels

DISCOMs: Electricity Distribution Companies

EPR: Extended Producer Responsibility

FIT: Feed in Tariffs

GW: Gigawatts, 1 GW = 109 Watts or 109 Joules/second

GOI: Government of India

IEA-PVPS: International Energy Agency- Photovoltaic Power Systems Program

IESA: India Energy Storage Alliance

IPCC: Intergovernmental Panel on Climate Change

IREDA: Indian Renewable Energy Development Agency

IRENA: International Renewable Energy Agency

ISGF: India Smart Grid Forum

JNNSM: Jawaharlal Nehru National Solar Energy Mission

MNRE: Ministry of New and Renewable Energy Sources

Mtoe: Mega tonnes of Oil equivalent

NAPCC: National Action Plan for Climate Change

NREL: National Renewable Energy Laboratory

PV: Photovoltaic

PPA: The Power Purchase Agreement

RE: Renewable Energy

RPO: Renewable Purchase Obligations

RTPV: Roof Top Photovoltaics

SCADA: Supervisory Control and Data Acquisition

WEEE: Waste from Electrical and Electronic Equipment

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Changes made:

1. Abstract and keywords added.
2. Added page numbers in the direct references for the figures.
3. Titles and subtitles changed according to suggestions of peers and teacher.
4. Separated storage issue into two parts barriers and policies. In barriers explained why storage is required and in policies gave some insights on what kind of important roles policies can play to facilitate the development of BESS.
5. Had this question running on my mind, there are many technologies for storage why focus on Batteries only? Added one small paragraph on barriers that BESS is first choice globally cited this from the papers
6. Combined PV and batteries recycling under same heading in Challenges
7. Removed some part previously on battery recycling challenges and took them to chapter 6 as opportunities for batteries recycling.