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ASSESSING THE SUSTAINABILITY IMPACT OF CADMIUM TELLURIDE SOLAR CELL DEPLOYMENT IN DELHI-NCT

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ABSTRACT
Electricity can be derived from various ways. This electricity is predominantly generated from thermal power plants, which has large share of 72.93% in power generation in India during 2024-25. It is very capital intensive and carbon emissive in nature caused global warming on earth. It has been found that share of power generation by solar photovoltaics primarily be first-generation silicon solar cells has 7.64%. The paper is trying to justify sustainability could be addressed by deploying cadmium telluride solar cells. Sustainability following Brundtland Commission's report, has envisaged with adoption of renewable energy within premises of their terms and conditions. The purpose of this paper is to affirm the adoption of Cadmium Telluride Solar Cells in Delhi-NCT in terms of sustainability. The paper has used qualitative document analysis, reports published from various organizations affiliated with the United Nations and literatures associated with advantages of Cadmium Telluride Solar Cells, and disadvantages of thermal power and first-generation silicon solar cells. This position paper will qualitatively justify the adoption of Cadmium Telluride Solar Cells in Delhi-NCT guided through Brundtland Commission Report which will help to realize sustainability in the form of clean and affordable energy, the Goal-7 of Sustainable Development Goals.

***Keywords—**Electricity, thermal power, first-generation silicon solar cells, cadmium telluride Solar Cells, sustainability, clean energy, power plants, solar energy, photovoltaic cells*

I. INTRODUCTION
Electricity is an important gift for the mankind. [1] Through this electricity, power can be transmitted and utilized in various machines, instruments and devices. [2] It is an important factor for urbanization. Urban areas provide varied growth opportunities to people and businesses to excel in their careers and domains. This led to development of the areas associated with the region and nation. [3]

The electrical power usage in Delhi-National Capital Territory (Delhi-NCT), is much higher than the any metropolitan cities in India. It is the judicial, legislative and executive capital of India. This entails the high priority required for electrical power to run their operations. The electrical power, for Delhi-NCT, is mostly catered from thermal power plants. Also, the demand for this power is still increasing year-by-year. The excessive increasing reliance on thermal power plant, since its inception in India, has led to an Anthropocene.

Global warming is becoming more persistent with the increase in the concentration of carbon dioxide. [4] The increase in the concentration of carbon dioxide caused the rise in the temperature of troposphere at the rate of 1 degree Celsius per decade from pre-industrialization level to at present. Climate related strain would escalate in progressive manner with uncontrolled future emission pathway. Climate-related risk on health, livelihoods, water supply, food security would increase with increase in global warming. If the increase in temperature can be reduced then adaptation by human and nature with temperature change would be easier. [5]

Electrical power sector is one of the major greenhouse emitters. [6] It has been seen that; economic development of nation is highly correlated with usage of energy. Per capita income of the nation is directly and positively correlated with its energy demand. [7] For that Brundtland Commission of the United Nations came with the term of sustainability, which got translated into Millenium Development Goals. The drive for sustainability is again redesigned and recalibrated to achieve the sustainability by 2030, through Sustainable Development Goals-2030, incepted in 2015. Secondly, India has also signed the Paris Agreement to transform its carbon emissive economy to net-zero carbon emissive economy, by 2050.

II. REVIEW OF LITERATURE
The coal is used for burning to boil the water to make steam. The steam is used to generate mechanical power to rotate the prime-mover of the turbines. The prime mover of turbine is connected with the rotor of the electric generator which generates electricity as explained by Faraday's Laws of Electromagnetic Induction. The entire process of thermal power generation has led to emission of water vapors after the usage of steam, carbon dioxide, oxides of nitrogen, Sulphur dioxide, Particulate matters of 2.5 parts per million to 5 parts per million from the burning of coal. Out of which the proportion of emission of oxides of nitrogen and particulate matter 2.5 parts per across the radius of thermal power station led to thermal heat stress, which is evident as urban heat islands.

ISSN 2394 - 7780

The cumulative greenhouse gas emission must at least be reduced by 470 gigatons of carbon dioxide compared to business-as-usual projections. [5] Agriculture and animal husbandry, extraction of mineral and fossil fuel, processing materials, fuels, and foods are accounted for more than 55% of greenhouse gas emission. [8] Also, it has been observed that in 2017, approximately 90 gigatons of material resource were extracted, globally. [9] In 2023, 37.79 gigatons of carbon dioxide was produced from various sources as compared to 17.05 gigatons in 1975. [10] Cumulatively, it has been seen that 1321.46 gigatons of carbon dioxide has been emitted to the atmosphere since 1975. [10] It has been observed that, percentage of greenhouse gas emission from extracting materials has been increased from 15 percent (5 gigaton) in 1995 to 23 percent (11 gigaton) in 2015. [9]

The over-exploitation of materials in world is happened due to increase in population, gross domestic product, per capita income, and urbanization. [11] It has been observed that human population has increased rapidly in last few centuries. [12] In order to cater the needs of people Brundtland Commission Report has observed that human is dependent on age old traditional technologies and practices to prevail their livelihoods. [13] This usual approach has led to degradation of environment through triple-planetary crisis, e.g., climate change, biodiversity loss, and pollution. [14]

By seeing the predicament, reduction of proportion of carbon dioxide in the atmosphere can be done through reducing the carbon emission, capturing, storing and removal of carbon dioxide. [15] Reduction of carbon emission can be done by implementing the alternate renewable sources of energy, that emit less carbon dioxide and other greenhouse gases, and these sources of energies can be replenished in short span of time. It has been seen that increase in the consumption in renewable energy by people, along with trade openness and innovation has negative impact on carbon dioxide emission. [16]

Dr. Gro Harlem Brundtland in 1987 submitted a report at UN General Assembly on securing prosperity by inculcating latest and best scientific evidence. The report named as ‘Our Common Future’ which primarily addresses increase decay in environment, decrease in natural resources, poverty and hardship. The repot reinforcing economic interest, survival imperatives of people, reduction of poverty by alleviating environmental degradation, inequalities, resource optimization and inclusivity of multiple stakeholders in decision-making to ensure environmental, social and economic welfare. [13] It is also known as ‘Brundtland Commission Report’.

The trend of sustainability has developed into Sustainable Developmental Goals (SDGs) to be realized by 2030. The Goal-7 of SDG advocates for cleaner and affordable energy. [17]

III. COUNTER ARGUMENT

A. Thermal Power-Advantage

The coal is cheapest non-renewable energy sources. Its geographic spread and domestic access across the developing countries help them to preclude from any geopolitical meddling by any foreign power. A simple technology is used for extracting coal and relatively less specialized intervention is needed in transportation and storage. This makes cost of procuring and transportation of coal is cheaper than any substitutes. This still makes consideration for policy makers to ensure energy security by employing consumption of coal in country’s energy mix. [18]

B. Solar Power-Challenges

It is difficult to anticipate how much energy a solar power plant could generate. Performance parameters are developed by International Electrotechnical Commission (IEC) by a standard document termed as ‘IEC-61274-1’. Reference yield, Array yield, Final yield, performance ratio, Capacity utilization factor, photovoltaic module efficiency, inverter efficiency, system efficiency, array capture loss, thermal capture loss. [19] Reference yield is the ratio of entire in-plane solar irradiation and reference irradiation. Array yield is the energy output of PV array per kilowatt of installed capacity. It is the difference between rated photovoltaic power and amount of energy a photovoltaic plant generates in a month. Final yield is the total output of alternating current energy by installed direct current power written on nameplate of array. Performance ratio is the ratio of final yield of PV plant and reference yield of PV plant. Capacity utilization factor is defined as ratio of actual output of photovoltaic plant with theoretical output of that plant in a given time period. Photovoltaic module efficiency is ratio of conversion of solar energy into electrical energy in contrast to amount of irradiation. Inverter efficiency is ratio of alternating current power generated with respect direct generation by the solar power plant by an inverter. System efficiency is the product of photovoltaic module efficiency and inverter efficiency. The array capture loss is the difference between array yield and reference yield. The thermal energy loss occurs when the temperature of modules exceeds 25 degrees Celsius. It is calculated by subtraction of reference yield and adjusted reference yield. [20] The reference irradiation is considered as 1000 Watts per square meters as per standard document of ‘IEC-60904-3’. [21] The factors affecting the performance of solar power systems are the

ISSN 2394 - 7780

type of photovoltaic technology, solar irradiance, ambient cell temperature, tilt angle orientation, dust accumulation, shading. Performance ratio and energy conversion efficiency are primarily for employing a type of technology. However, it must include the remaining factors for employing the type of solar cell or photovoltaic technology. If the irradiance is high then the power production would be high. It has high coefficient of determination for employing solar power in any region. The value of solar irradiance should have some proximity to reference irradiance for efficient power production. Ambient and cell temperature is one of the parameters that must be considered for deploying solar energy. The incomplete utilization of solar irradiation by solar photovoltaic power system causes overheating of solar cells. [22] Ambient temperature is the surrounding air temperature where solar panels of solar power plants are installed. Power output of solar power plant decreases with increase in ambient temperature. The ideal ambient temperature for solar photovoltaic cells is 25 degrees Celsius. [23] Tilt angle of solar photovoltaic cells should be such way that solar radiation falls vertically on its surface. Latitudinal angle of that region is considered to be set at which solar photovoltaic cells should be installed. The deviation of tile angle from the latitudinal angle to be considered from +15 degrees in winters to −15 degrees in summers for exposures of vertical falling of solar radiations during these seasons. Deposition of dusts is climate specific. It depends upon location, type of dust like soil and sand, clay, bacteria, carbon. Other parameters of deposition of dust includes are wind speed, wind direction, temperature, irradiation, air pressure, air pollution, dust storms, humidity, types of installation site, type of photovoltaic cells, height, tilt angle, orientation, exposure time on front surface of photovoltaic modules, and latitude and longitude. Shading happens due to bird sitting and bird droppings, falling of leaves on the solar panels. As the photovoltaic cells are coupled in series in connection, if the current flow in one of the cells stop then it halts the current flow in unshaded cells. One of the studies has mentioned about the reduction of performance by 75% in solar power plant if the panel area is shaded with 2%. [24]

Output Power from solar cells depends upon shading effects, employed semi-conductor materials, temperature, the intensity of radiation received, parasitic resistance, weather condition, solar cell design, doping level, material properties and quality. Soiling is major issue faced in operation of solar cells as dust on the solar cell blocks the absorption of solar radiation. Location of installation of solar cells is another issue since solar radiation varies with seasons. Power conversion efficiency of solar cells on solar modules is dependent on its way of its mounting. Quality of semi-conducting materials is also a major concern in solar energy. Its manufacturing defects in creating p-n junction diode as well as at the cell edges, causes losses in power production. [25]

End-of-Life (EoL) management is one of the major challenges in solar photovoltaic energy. Proper disposition of solar cells after their product life must be addressed. 45,000 tons of photovoltaic wastes generated in 2016. Additionally, amount of photovoltaic waste projected to reach 1.7-8 million tons by 2030 and 60-78 million tons by 2050. Limited study on EoL of photovoltaic wastes is done. The negative effect of cadmium, chromium, nickel in photovoltaic wastes on human health and environment in EoL management needs to be addressed. The minerals used as raw materials employed in solar cell have high importance to economy and they are associated with high risk of supply chain disruptions. These are known as critical minerals or critical raw materials. Its manufacturing stage involves significant challenges in environmental impact, responsible for substantial green house gas emissions, human toxicity and ecotoxicity in solar energy life cycle. The socio-economic risk is high in operation and maintenance phase because of unpredictability of weather conditions. Additionally, socio-economic frameworks should be used for calculating economic viability of solar power plants, with costing methodologies, and establishing economic policy instruments to incentivize for adoption of solar technologies by consumers and businesses. [26]

The high capital cost prohibits the consumers to adopt them as consumers prefer to keep primary cost low instead of reduction of operation and maintenance costs. Lack of proper access to cheap capital parameters like rate of inflation and interest influence high costs. There is a lack of awareness and information of financing from banks, this makes high costs in debt and equity financing. Also, banks tend to fund small projects instead of large projects. Huge economic support in research through public and private financing is desired so that absorption of risk for introduction of new technology, with technically trained candidates to manage and develop these solar energy projects could be possible. These things are currently insufficient because of inadequate guidance and technical backing for engineers due improper planning of training and development of personnel required to solarize the power sector. Clearance for acquiring land required for making solar farm with proper radiation data and hotspot are the major problems. [27]

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The problem of poor performance of solar power plants in Delhi-NCT, based on the above-mentioned points is observed on first generation silicon solar cells, which recommended a formulation of standard operating procedure to check its poor performance. [28]

C. Cadmium Telluride- Challenges
Limited availability of tellurium is affecting the production of cadmium telluride solar cells. For that stakeholders have to ensure, 50 times more reserves of tellurium for cadmium telluride solar cells. [29] The electronic grade tellurium is refined form of tellurium produced by China, Japan, Russia, Sweden, Canada, Bulgaria, Germany and Belgium. [30]

IV. ARGUMENT

A. Thermal Power- disadvantage
Health burden is higher in coal-fired power plants by causing very high outdoor pollution. These power plants expose surrounding communities that may affect the health, since amount of coal dust are released during extraction, transportation, handling process led to xenobiotic effects on surroundings. [31] Xenobiotic effect and the form of xenobiotics are the man-made substance that are completely foreign to biological system. They are chemically stable in nature and that does not dissolve in water, even degradative micro-organisms do not recognize as substance, due to its large molecular weights. Their molecular weight is high because it contains radicals like halogens, sulphonate, nitro, amino, methoxy and so on. Cycloalkanes, aromatic and heterocyclic compounds attracts more calcium, where linear branches present in these compounds reduce degeneration of compounds through biodegradation. This causes biomagnification among food chains and food web. The xenobiotic effects start with aquatic microorganism where the water used to generate thermal power, but it gets washed away through water to nearby water bodies. The water from these water bodies is then used by aquatic organism and irrigation in agriculture. The xenobiotic compound gets incrementally accumulated on higher stages of food chains, where human belongs. [32] The human beings are affected by xenobiotics in the form of headaches, dizziness, muscular weakness and nausea, damage to the liver, kidneys, and nervous systems, other includes, osteoporosis, disruptive fetal growth, premature puberty, and obesity. The process of xenobiotic happens due to local effects where injuries caused by these chemicals at the site of first contact, systematic effect includes absorption of harmful effects when they absorbed and distributed from the point of entry to distant site. The effects may be immediate or delayed and reversible or irreversible. It affects through interfering in the activity of enzymes, synthesis and function of nucleic acid, and proteins, blocking oxygen transport, that causes hypersensitivity, allergies and irritation in human body. [33] Long term indirect exposure of coal results into chronic obstructive pulmonary disease (COPD), asthma, lung cancer, and respiratory infection, in children and elders. Chronic coal inhalation causes modulation of immune system by alteration of lungs between immune cells and environment; such exposures change in structure of heart. In children it has been seen its exposure impairs the development of memory. Outdoor air pollution causes decreasing fertility of human beings as result of reduction of gametes (the cell in reproduction of organisms) and epigenetic modification by methylation of DNA, increased occurrence of additional diseases like hypertension, diabetes and obesity, due to complex clinical management in them. [34]

As per the point 3.9 of Goal 3 Ensuring healthy lives and promote well-being for all at all ages in the context of 'Transforming Our World: The 2030 Agenda for Sustainable Development', envisages reduction of death and illness from hazardous chemicals and air, water, soil pollution and contamination. [35] As per the point 6.3 of Goal 6 Ensure availability and sustainable management of water and sanitation for all, envisages improvement of water quality by reduction of pollution, elimination of dumping and minimization of release of hazardous chemicals and materials, halving the proportion of untreated waste water and substantially increment in recycling and safer re-usage globally. [36] It is required to reduce the production of electricity from coal-based thermal power plants.

B. Solar Power-benefits
Solar energy in the form solar photovoltaic converts energy present in the sunlight into electricity by photovoltaic cells. [37] These cells are made up semi-conductor materials whose elemental atomic or compound molecular structure contains four electrons in their outer-most orbit. It is a diode, where impurity of electron rich materials on one side and electron-deficient materials on other side is doped. A junction formed in between these sides, which is known as depletion layer. This can be used to conduct the electric current only in one direction. When sunlight is incident on this junction, electron moves towards the electron rich side of the electrode by accumulating energy from sunlight. This photovoltaic current is employed in electrical circuits and systems. It is cheapest option for electricity generation as cost of generating electricity from 2010 to 2018 has reduced to 77%. With this progress on cost reduction, the installation of solar cells expanded 100-fold from

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2005 to 2018. The installed capacity during 2010 was 40,334 Mega-Watts (MWs) which got increased up to 7,09, 674 MWs during 2020. This technology is widely employed as standalone or grid connected. Standalone solar power system is not connected with any electrical grid and solely generating power at the installation site. Grid-connected solar power system has a supportive connection that can complement the power generation of itself and the grid. [38]

C. First Generation silicon solar cells disadvantages

The solar cell should be made optically thick and electronically thin. Absorption capability of incident sunlight refers here for optical thickness. Collection of photo-excited electron hole pairs with minimal losses means its electronic thinness. [39] The first-generation silicon solar cells use thick wafers which increases material costs. It has limited capability to capture low-energy sunlight, its efficiency limits due to different types of recombination and losses. [40] Silicon diode is made through complex process. It is comprising of production of electronic grade silicon, crystal growth, cropping, rod grinding for making ingot. Then undergoes wafering processes comprising of slicing, edge profiling, lapping or surface grinding, etching, edge polishing, polishing, and cleaning. Later epitaxial deposition of metals, and other materials followed by insulator layer transfers for making applicable for photovoltaic applications. Silicon is best suited for radio frequency for its intrinsic material characteristics. [41] Manufacturing of first-generation crystalline silicon modules have significant impact on environment. A study on first generation monocrystalline silicon modules accounted for 81% of energy use. Production of high purity electronic grade silicon requires significant energy that requires usage of fossil fuel resources. Prices of these solar cells are higher because of its energy intensive process of production. [42] Also, e-waste generated from first-generation silicon solar cells is much higher than solar cells of any technology. Also recycling of this e-waste requires multiple methods which are costly and requires special attention to address. It has lot of macroeconomic barriers, geographical challenges, and legislation and regulation drawbacks. [43]

D. Second Generation Cadmium Telluride Solar Cells advantages

Reserve for tellurium can ascertained by Global tellurium Stock consists of stockpiled tellurium and tellurium in stockpiled anode slimes. Its demand is estimated for photovoltaic and non-photovoltaic applications like metallurgy, thermo-electric device, rubber applications. Tellurium is secondary mineral extracted from electrorefining of copper ore. [44] The remaining 10% of world's total tellurium is derived from skimming from lead refineries and flue dust and gases liberated from smelting of bismuth, copper, lead and zinc ores. Minerals like bismuth telluride and gold telluride are also considered for production of tellurium. Conventionally, digital video disks (DVDs) are composed of small amounts of tellurium in the form of alloys. [30] Abundant amount of cadmium is derived from refining zinc from its ore. [45] Manufacturing of cadmium telluride solar cells involves physical vapor deposition or chemical vapor deposition that enables its large-scale production at lower costs. It is different from wafer-based material by employing chalcogenides for its process in its production, make it more affordable with respect to market dominant first-generation crystalline silicon solar cells. [46] Also, production of these modules impacts less on the environment due to lower production costs based on reduction in of these semiconductor usage in production, lower energy employed in its manufacturing, elimination of aluminum on its edge and in panes along with consumables required for production. [42]

The band gap, the energy required for electron to conduct within the diode. [47] Here diode as cadmium telluride solar cells has 1.5 electron Volts which is same as that of energy present in solar irradiance. It makes optical efficiency maximum in these cells. [48]

V. CONCLUSION

Based on the impact on environment and its usage, deploying cadmium telluride solar cells is found to be more sustainable than coal-fired thermal and first-generation silicon solar cells.

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