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IMPACTS OF SOLAR ENERGY TECHNOLOGIES ON THE ENVIRONMENT

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Abstract- The sun provides a tremendous resource for generating clean and sustainable electricity without toxic pollution or global warming emissions which has only recently been tapped into. It provides immense resources which can generate clean, non-polluting and sustainable electricity, thus resulting in no global warming emissions. In recent years, it was discovered that the power of the sun can be collected and stored, to be used on a global scale with the purpose of eventually replacing the conventional sources of energy. As the world is turning its focus to cleaner power, solar energy has seen a significant rise in importance.Solar energy systems offer significant environmental benefits in comparison to the conventional energy sources, thus they greatly contribute to the sustainable development of human activities. At times however, the wide scale deployment of such systems has to face potential negative environmental implications. These possible problems may be a strong barrier for further advancement of these systems in some consumers.
Key words-Photovoltaic (PV) solar cells, Concentrating solar thermal plants (CSP), The Silicon Valley Toxics Coalition (SVTC), energy payback time (EPBT), National Renewable Energy Laboratory (NREL).

1. INTRODUCTION

Like everything in life, there are upsides and downsides especially when trying to generate enough energy to sustain a reasonable quality of life. Vast amounts of energy are required and many solar modules use toxic chemicals during the manufacturing process. The potential environmental impacts associated with solar power can be classified according to numerous categories, some of which are land use impacts, ecological impacts, impacts to water, air and soil, and other impacts such as socioeconomic ones, and can vary greatly depending on the technology, which includes two broad categories:
Photovoltaic (PV) solar cells or
Concentrating solar thermal plants (CSP).
Environmental Impacts of Solar Energy
Land Use and Ecological Impacts
Depending on their location, larger utility-scale solar facilities can raise concerns about land degradation and habitat loss. Total land area requirements varies depending on the technology, the topography of the site, and the intensity of the solar resource. Estimates for utility-scalePV systems range from 3.5 to 10 acres per megawatt, while estimates for CSP facilities are between 4 and 16.5 acres per megawatt.
In the point of generating electricity at a utility-scale, solar energy facilities necessitate large areas for collection of energy. Due to this, the facilities may interfere with existing land uses and can impact the use of areas such as wilderness or recreational management areas. As energy systems may impact land through materials exploration, extraction, manufacturing and disposal, energy footprints can become incrementally high. Thus, some of the lands may be utilized for energy in such a way that returning to a pre-disturbed state necessitates significant energy input or time, or both, whereas other uses are so dramatic that incurred changes are irreversible.

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Figure 1. Concentrating solar thermal plants

Unlike wind facilities, there is less opportunity for solar projects to share land with agricultural uses. However, land impacts from utility-scale solar systems can be minimized by siting them at lower-quality locations such as brownfields, abandoned mining land, or existing transportation and transmission corridors. Smaller scale solar PV arrays, which can be built on homes or commercial buildings, also have minimal land use impact.

Impacts to Soil, Water and Air Resources

The construction of solar facilities on vast areas of land imposes clearing and grading, resulting in soil compaction, alteration of drainage channels and increased erosion. Central tower systems require consuming water for cooling, which is a concern in arid settings, as an increase in water demand may strain available water resources as well as chemical spills from the facilities which may result in the contamination of groundwater or the ground surface.As with the development of any large-scale industrial facility, the construction of solar energy power plants can pose hazards to air quality. Such threats include the release of soil-carried pathogens and results in an increase in air particulate matter which has the effect of contaminating water reservoirs.

Solar PV cells do not use water for generating electricity. However, as in all manufacturing processes, some water is used to manufacture solar PV components.Concentrating solar thermal plants (CSP), like all thermal electric plants, require water for cooling. Water use depends on the plant design, plant location, and the type of cooling system.CSP plants that use wet-recirculating technology with cooling towers withdraw between 600 and 650 gallons of water per megawatt-hour of electricity produced. CSP plants with once-through cooling technology have higher levels of water withdrawal, but lower total water consumption (because water is not lost as steam).

Dry-cooling technology can reduce water use at CSP plants by approximately 90 percent. However, the trade-offs to these water savings are higher costs and lower efficiencies. In addition, dry-cooling technology is significantly less effective at temperatures above 100 degrees Fahrenheit.

Many of the regions in the United States that have the highest potential for solar energy also tend to be those with the driest climates, so careful consideration of these water trade-offs is essential.

2. SOLAR PANEL MANUFACTURING PROCESS

To understand the positive and negative environmental impacts of solar power, it is important to realize what goes into producing a functional solar panel.

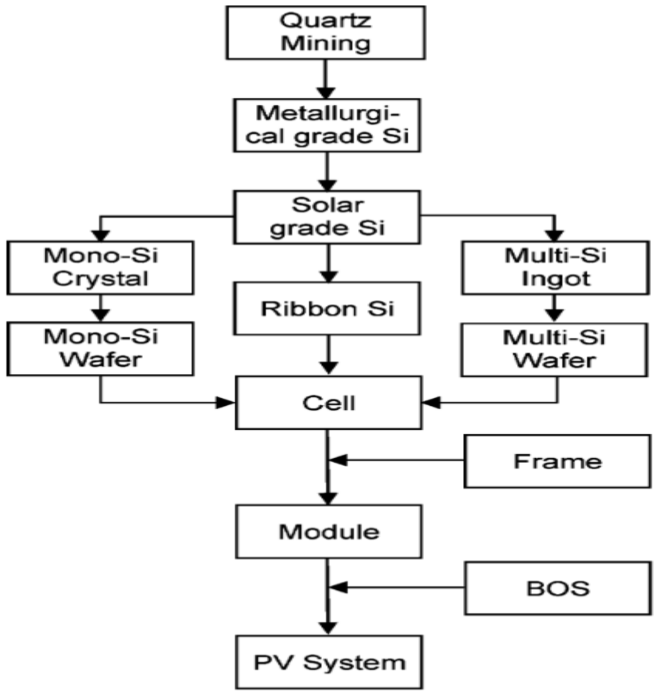

Figure 2. Solar Panel Manufacturing Process

First the raw material must be mined, this is predominantly Quartz which is processed into silicon. Aluminium, copper or silver are also key materials involved which must be mined, or obtained from recycled sources, but mostly they are mined due to the increased expansion of the PV industry in the last 10 years. Following the mining of raw materials, the quartz must be processed into electronic-grade silicon. This process involves heating the quartz in a high temperature furnace and reacting it with various chemicals.

3. CARBON FOOTPRINT OF SOLAR PANEL MANUFACTURING

In the graph below, Case 1 is a representation of Crystal Clear and Eco-invent Database set, Case 2 is a Union of Coordination of Transmission of Electricity and Eco-invent database set, and Case 3 is US grid mixture and Franklin database set. For simplification we will observe the average of the 3 data sets for polycrystalline silicon (Multi-Si). When the three multi-silicon values (~32, ~42, ~52 gC02/kWh) are average, the result is an average of 42 gC02-eq/kWh of energy generated. This value is approximately in line with more recent data from the World Nuclear Association which estimates the lifetime emissions output of solar PV to be ~70tC02-eq/GWh (g/kWh is an equal ratio to a t/GWh) which is discussed in detail later in this article.

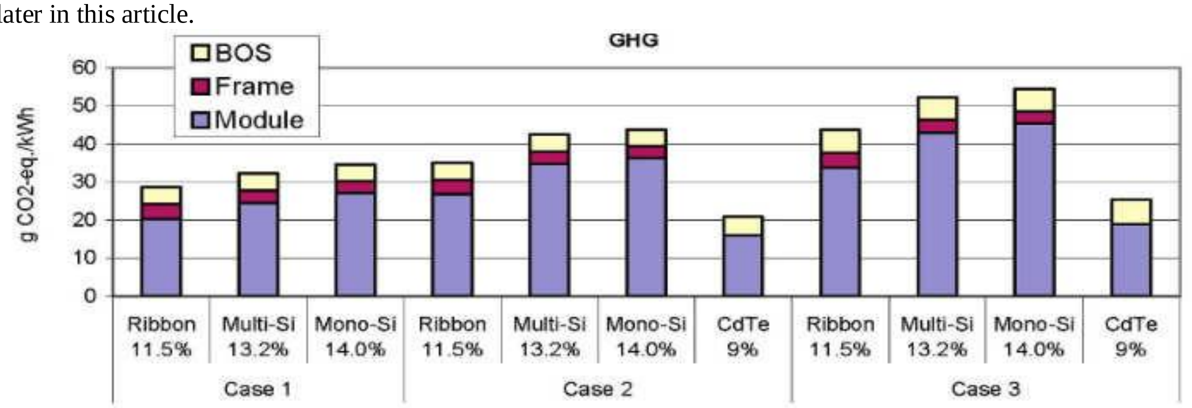

Figure 3. Carbon Footprint of Solar Panel Manufacturing

4. NEGATIVE ENVIRONMENTAL IMPACTS SOLAR PANELS

Solar power is not without its downsides. Let's examine them here:

Energy - The manufacturing of solar panels requires more energy up front to produce than other forms of energy generation. This is due to the manufacturing process required to transform raw minerals into usable photovoltaic. Quartz must be processed, and cleaned and then manufactured with other components which may come from different facilities (aluminium, copper etc.) to produce a single solar module whereas coal is mined, cleaned and burned on a mass scale typically in a single

location. Heating the quartz during the processing stage requires very high heat. Manufacturing requires combining multiple materials with incredible precision to produce high efficiency panels. All of this requires lots of up-front energy.
Chemicals – To produce solar-grade silicon, semi-conductors processing typically involves hazardous chemicals. Depending on the solar panel manufacturer, these chemicals may or may not be disposed properly. The Silicon Valley Toxics Coalition (SVTC) presents an annual report on the environmental records of major solar manufacturers. Like every industry, there are companies leading by example, and others which cut corners to save money. Not every company will dump chemicals, or recycle their by-products improperly, but there are a few bad apples out there fuelling the anti-green bandwagon.
Recycling – Although solar panel recycling has not become a major issue yet, it will in the coming decades as solar panels need to be replaced. Technology does however tend to keep up with demand. The automobile recycling industry did not begin until the auto industry was well underway. The same can be said for other recycling industries such as bottle depots, biofuel, and electronics. Companies such as PV Cycle are already thinking ahead to mitigate this problem.
These are the major environmental concerns surrounding the PV industry but overall, the downsides are minimal compared to the downsides associated with common forms of generating energy such as coal and natural gas.
Although solar panels do require a great amount of energy up front, they do have a very short energy payback time (EPBT) as is explored in the section below.
Toxic chemicals are required during the manufacturing stage, but hazardous materials are required for almost every type of energy generation. Coal must be cleaned with chemicals and burned. Natural gas must be extracted and burned. Nuclear energy itself requires a highly radioactive material. Wind turbines use metal which must be mined, and processed too. No energy form is perfect, but some are better than others. To tell the difference we will explore the carbon emission intensity of each of these fuel types below.

5. HAZARDOUS MATERIALS

The PV cell manufacturing process includes a number of hazardous materials, most of which are used to clean and purify the semiconductor surface. These chemicals, similar to those used in the general semiconductor industry, include hydrochloric acid, sulfuric acid, nitric acid, hydrogen fluoride, 1,1,1-trichloroethane, and acetone. The amount and type of chemicals used depends on the type of cell, the amount of cleaning that is needed, and the size of silicon wafer. Workers also face risks associated with inhaling silicon dust. Thus, PV manufactures must follow U.S. laws to ensure that workers are not harmed by exposure to these chemicals and that manufacturing waste products are disposed of properly.
Thin-film PV cells contain a number of more toxic materials than those used in traditional silicon photovoltaic cells, including gallium arsenide, copper-indium-gallium-diselenide, and cadmium-telluride[5]. If not handled and disposed of properly, these materials could pose serious environmental or public health threats. However, manufacturers have a strong financial incentive to ensure that these highly valuable and often rare materials are recycled rather than thrown away.

6. LIFE-CYCLE GLOBAL WARMING EMISSIONS

While there are no global warming emissions associated with generating electricity from solar energy, there are emissions associated with other stages of the solar life-cycle, including manufacturing, materials transportation, installation, maintenance, and decommissioning and dismantlement. Most estimates of life-cycle emissions for photovoltaic systems are between 0.07 and 0.18 pounds of carbon dioxide equivalent per kilowatt-hour.
Most estimates for concentrating solar power range from 0.08 to 0.2 pounds of carbon dioxide equivalent per kilowatt-hour. In both cases, this is far less than the lifecycle emission rates for natural gas (0.6-2 lbs of CO2E/kWh) and coal (1.4-3.6 lbs of CO2E/kWh) [6].

7. OTHER IMPACTS

Besides the aforementioned environmental impacts, solar energy facilities also may have other impacts, such as influencing the socio-economic state of an area. Construction and operation of utility-scale solar energy facilities in an area would produce direct and indirect economic impacts.
The direct impacts would occur as a result of expenses on wages and salaries as well as the attaining of goods and services which are required for project construction and operation.
Indirect impacts would occur in the form of project wages and salaries procurement expenditures, which create additional employment, income, and tax revenues. Facility construction and operation would require in-migration of workers, affecting housing, public services, and local government employment.

8. CARBON EMISSION INTENSITY

The values observed here are paramount to understanding the lifetime emission profile from solar energy and other energy generating methods. Although all data has a fair degree of variance, which is expected for a rapidly progressing industry, the general trends in comparison remain identical. Both the emission intensity profiles show solar PV being 3x to 10x more environmentally friendly over a 30 year time span compared to energy generated from coal. Solar PV does require heavy amounts of energy up front to mine and manufacture the materials, but when that emission is dispersed over a 30 year generation profile the emissions/kWh are much more favourable. This key metric must be considered when evaluating the environmental impacts of solar panels.

9. ENERGY PAYBACK TIME OF SOLAR PANELS

The energy payback period for solar power depends on your location and what the typical form of energy generation. If your home is powered 100% by wind and hydro energy, then replacing that with solar will not provide much environmental benefit (although there will be other benefits such as relieving pressure on the electric grid, and providing you ownership of your energy). But if your home is powered by coal, then solar power will have a very fast environmental payback period.

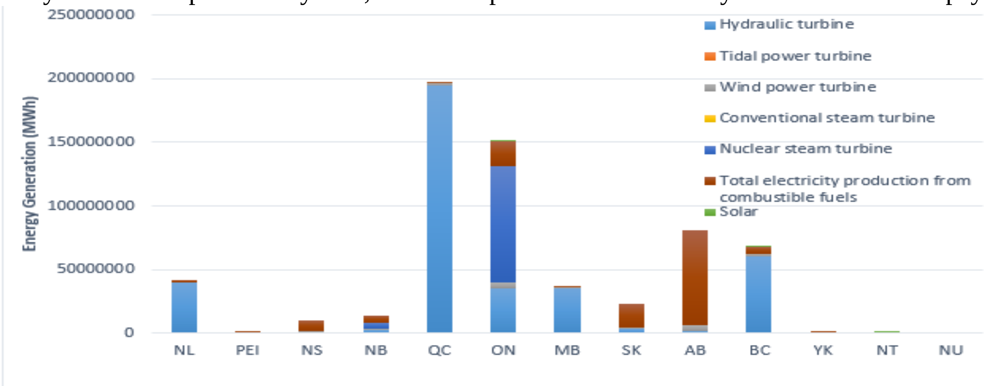

Figure 4. Energy Generation by Province and Fuel Type

Canada's energy generation by province and fuel type. Compiled by Kuby Renewable Energy.Provinces such as Nova Scotia, Saskatchewan and Alberta would benefit from solar power since most energy in these provinces come from fossil fuels. To provide some general context, the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) provides some noteworthy data. Poly-Crystalline solar panels have an energy payback period of 2 to 3.5 years. This value includes the manufacturing of the module, frame and the balance of the system components.

10. RECYCLING SOLAR PANELS

Currently the recycling of solar panels faces a big issue, specifically, there aren't enough locations to recycle old solar panels, and there aren't enough non-operational solar panels to make recycling them economically attractive. Recycling of solar panels is particularly important because the materials used to make the panels are rare or precious metals, all of them being composed of silver, tellurium, or indium. Due to the limitability of recycling the panels, those recoverable metals may be going to waste which may result in resource scarcity issues in the future.

Looking at silicon for example, one resource that is needed to make the majority of present day photovoltaic cells and which there is currently an abundance of, however a silicon-based solar cell requires a lot of energy input in its manufacturing process, the source of that energy, which is often coal, determining how large the cell's carbon footprint is.

The lack of awareness regarding the manufacturing process of solar panels and to the issue of recycling these, as well as the absence of much external pressure are the causes of the insufficiency in driving significant change in the recycling of the materials used in solar panel manufacturing, a business that, from a power-generation standpoint, already has great environmental credibility.

Case study:kochi airport becomes world's first to completely operate on solar power

Cochin International airport, the country's first airport built under PPP model has scripted another chapter in aviation history by becoming the first airport in the world that completely operates on solar power. The 12 MWp solar power plant inaugurated on 18th August 2015, comprising of 46,150 solar panels laid across 45 acres near cargo complex. Now, Cochin airport's solar power plant is producing 50,000 to 60,000 units of electricity per day to be consumed for all its operational functions, which technically make the airport 'absolutely power neutral. 1.01 crore unit electricity was produced from the plant and the company saved nearly rupees seven core in terms of power expenditure.

Inspired by the success of the above plants, CIAL decided to set up a larger scale 12MWp solar PV plant as part of its green initiatives. With the commissioning, this installation is expected to generate around 48000 units per day, which along with the electricity generated from the existing 1.10 MWp plants, making the total output around 52,000 units a day, and would be sufficient to meet the power requirement of the Airport. This is a grid connected system without battery storage and a power banking module with the Kerala State electricity board (KSEB)has been worked out; wherein, CIAL gives as much power it produces (in day time) to (the grid of)KSEB and ' buy ' back the power from them when needed (especially in night).

This plant will produce 18 million units of power from ' sun ' annually-the power equivalent to feed 10,000 homes for one year.Over the next 25 years, this green power project will avoid carbon dioxide emissions from coal fired power plants by more than 3 lakh metric tons, which is equivalent to planting 3 million trees or not driving 750 miles.

Cochin International Airport Ltd forays into organic farming, plans bigger:

The Cochin International Airport Ltd, which created a national model for harnessing solar energy, forayed into organic farming and plans commercial sale of the own branded through measures such as setting up vegetable sale outlets at airport premises.

"The first attempt at organic farming done in three-acres near cargo complex is a success and the reaping of the same was done. The authority plan to extend the cultivation to the whole of the 45-acre land where the 12 Megawatt solar plant is set up, the first of its kind initiative and also to go for modern agricultural practices besides seeking co-operation of leading agricultural research centres. The organic products will then be commercially marketed. They implemented drip irrigation for climbing plants requiring water on a daily basis. For others, water used to clean solar panels (over 46, 000) will be used. Growing of plants will also ensure the panels are dust free.

11. ECONOMIC AND ENVIRONMENTAL BENEFITS

After commissioning, these plants have so far saved more than 550MT of CO2 emission contributing to the efforts of CIAL towards minimizing environmental degradation.

The solar plant will be able to prevent 3,00,000 tons of carbon emission from coal-fired power plants over a period of 25 years, which is equivalent to planting 3 million trees or eliminating 750 million miles of driving a fossil-fuel burning car in that same time frame. In other words, apart from saving money, the plant will significantly reduce global warming by producing greener and cleaner energy, hopefully inspiring others to follow suit.

12. CONCLUSION

Solar power is not perfect, but overall it provides a positive net environmental impact and excellent long-term financials. The energy required to create a solar panel will be recouped after just 2 to 4 years. Even considering the manufacturing and processing stage of solar, the emissions generated are 3x to 10x less than generating the same amount of energy from fossil fuels. Naturally, the benefits will vary depending on the energy generation and solar irradiance of you location but overall solar panels provide a positive net impact.

13. ACKNOWLEDGMENT

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15. BIOGRAPHY

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