July – August 2020
ISSN: 0193-4120 Page No. 475 - 480

Life Cycle Environmental Impact Assessment of Crystalline Silicon Solar Panel

Manisha Sheoran , Susheela Sharma
Bhartiya Skill Development University, Plot 001-002, DTA Mahindra World City, Off, Ajmer Rd, Jaipur, 302037, Rajasthan, India
manisha.sheoran@ruj-bsdu.in; susheela.sharma@ruj-bsdu.in

Pancham Kumar
Bhartiya Skill Development University, Plot 001-002, DTA Mahindra World City, Off, Ajmer Rd, Jaipur, 302037, Rajasthan, India
pancham.kumar@ruj-bsdu.in

Article Info
Volume 83
Page Number: 475 – 480
Publication Issue:
July - August 2020

Abstract
Quantitative assessment of the environmental effects of crystalline silicon solar photovoltaic module is favored through life cycle assessment. For the manufacturing process life cycle assessment is carried out which brings out that effect of the production of crystalline silicon. Making of the solar cells and module fabrication holds for a greater contribution into the environment effect than in the processing of the silicon from the nature to further use in industry. Detrimental effect of crystalline solar photo-voltaic panel is highlighted in this paper laying emphasis on their decommissioning and recycling portion. Environmental effect is studied into various aspects. Toxicity effect and climate change are major drawback of the solar photovoltaic energy. While focusing on solar panel recycling it was revealed that lesser environmental effect is posed by it rather than landfill. Higher uncertainties are obtained for the crystalline Silicon production, manufacturing, recycling, solar cell processing and module fabrication due to greater environmental impact, also the parameter causing error are high. The study focuses on pollution causing process like production of crystalline silicon and solar cell processing. Emphasis is also laid upon the enhancement of material recovery rate and discovering environmentally amiable substance for recycling. Effect of recycling technologies on environment is assessed for c-Si and also policy guidelines are proposed.

Article History
Article Received*: 06 June 2020*
Revised*: 29 June 2020*
Accepted*: 14 July 2020*
Publication*: 25 July 2020*

Keywords— Life cycle assessment; Environmental impact; Recycling policy.

1. INTRODUCTION

For fulfillment of sustainable energy concerns renewable sources of energy were on hunt from past few decades. This hunt explored the wind energy, solar energy, hydro energy etc. In these energy sources solar energy came out to be the clean energy generating source. In terms of installations solar PV technology is also leading in world's energy market. Due to the booming requirement of energy solar PV sector had an influential rise in Japan, United States, Europe, India and China. Among these China expanded its manufacturing sector to meet the massive energy demands of the globe and its own nation. Due to greater availability of the raw materials in its own nation it rules the world in production of silicon based modules. While in the United States 32 % of thin film based modules were produced in 2014. In 2010 the

installations were 39,603 MW which got increased to 480,357 MW in 2018 as stated in. IRENA. With the increasing solar panel deployment across the world the waste generated will also increase. According to IRENA 1.7 million tons to 8.0 million tons of the solar PV waste will flock together by the extreme 2030 and 60-78 million tons by the arrival of 2050[1].

Solar cells had maximum outlet from China to other countries of the world in 2011. Due to the oversupply of solar modules from China the prices fell to 40% in the same year, this was a year of profit making for the solar PV system installers. On the other hand solar panel manufacturers from Europe and U.S faced severe financial losses. Even after the unification of solar panel manufacturer industries the condition wasn't improved. Ultimately the European companies have to shift towards the developing countries for incentives in manufacturing and cheap labour[2]. In the manner Asian region got the innovation of solar panel installations. Out of the total solar modules production, 90% Silicon based modules are produced in China. With the increasing solar installations in its home, demand of silicon based solar modules got enhanced. Though solar PV was regarded as clean energy however fabricating procedure bears detrimental environmental effects. Adequate end of life management for PV modules as recycling of solar PV modules is still not at commercial level with proper economic feasibility & adequate regulations[3]. Environmental conservation & resources recycling issues posed by huge solar PV waste support the quantitative basis to recycling of PV panels & directions for policy makers[4]. Development of recycling methods which will reduce the environmental impacts as the current recycling methods recover just a portion of materials from c-Si & thin film panels and also emphasized the overview of global recycling legislations[5]. Possible environmental impacts of solar PV materials in terms of Human toxicity potential, increased acidification and reduced the global warming by the use of renewable energy[6]. Recycling methods affect the environment, though they are better than landfilling but need added monetary cost[7].

2. LIFE CYCLE ASSESSMENT

With the increasing over exploitation of conventional energy sources and degradation of earth's life support system, many industries and businesses have started to assess their product's environmental impact. One such tool used for this is LCA i.e. Life cycle assessment [8], [9]. LCA is a tool to assess the environmental impacts and resources used throughout a product's life cycle and consider all attributes or aspects of natural environment, human health, and resources and can be defined as a method for analyzing and assessing environmental impacts of a material, product, or service along its entire life cycle (ISO 2005). Thus, ISO14040 defined LCA as the "compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle". LCA analyzes the environmental burden of products from cradle to grave, from raw material acquisition, manufacturing of product, use and maintenance of product and finally to its end of life management, either by reuse, recycle or reducing [10]. Various types of solar cells are used for the generation of electricity. On commercial scale crystalline Silicon technology is leading due to the lower costs and better efficiency. With the onset of newer technologies thin film solar cells have also entered the commercial sector. Thin films like amorphous silicon, Copper Indium Gallium Diselenide, Copper Telluride, all these are categorized under second generation solar cells. Due to the hindrance in obtaining material for establishing solar cells, toxicity in the elements and the cost of manufacturing the market ratio of the second generation solar panels is less in the present hour. For

the manufacturing of crystalline thin film panels silicon is used. The extraction of silicon requires large amount of energy and time. The amount of silicon used in the manufacturing of the panels is quite substantial.

3. ENVIRONMENTAL IMPACT

Various impacts like global warming potential, Photochemical ozone creation potential, Acidification potential, Human toxicity potential, Abiotic resource depletion potential, Eutrophication potential are assessed depicted in Fig 1. Specific Categories of impact are listed in Table 1. Human toxicity from different materials utilized in the production of solar panels is depicted in Table 2.

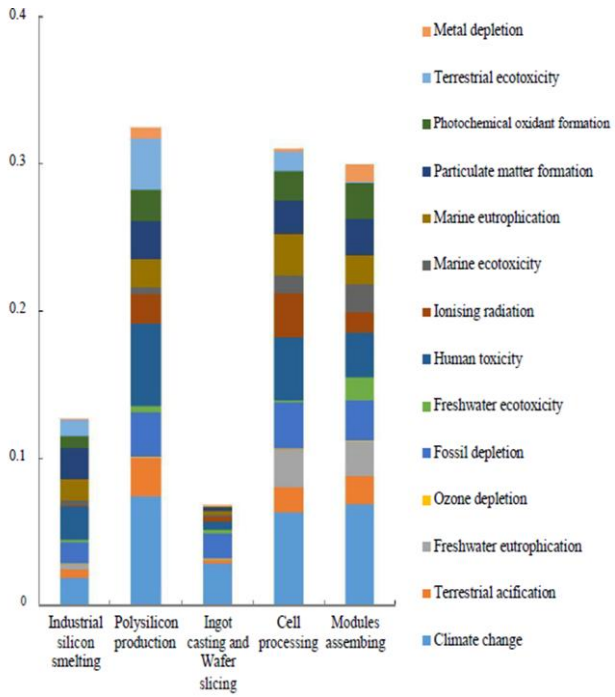

Fig.1. Overall environmental impact of crystalline PV module in the production process [11].

Crystalline Silicon is the most widely used technology in the PV market and its life span is estimated to be 25-30 years. The first installations of the solar panels date back to the early 1980's. The first lot of the installations is thorough by its life span and have taken off to waste chunk [12]. The waste chunk so generated is at the manufacturing time in the plant itself and at the end of the life span. This waste chunk will be accumulated to large extent by the onset of 2050.

Environmental Impact	Cell Production (%)	Modules Assembling (%)	Glass (%)	Al (%)	Plastic (%)	Electricity(%)
Climate change	90	10	9	51	17	23
Human toxicity	98	2	2	8	89	1

Table 1. Production phase origin portion in toxicity and climate change

Chemical	Utilisation	Hazard category				
		Asphyxiant	Corrosive	Irritating	Flammable	Explosive
Argon gas	Thin film deposition			■		■
Ammonia	Anti-reflective coating	■				
Diborane	a-Silicon dopant			■	■	
Helium gas	Thin film deposition	■				
Boron trifluoride	Dopant		■	■		
Hydrochloric acid	x-raw material etching and cleaning		■	■	■	
Hydrofluoric acid	x-cleaning and etching		■	■	■	
Hydrogen Selenide	CIS sputtering			■	■	
Hydrogen gas	a-deposition				■	■
Hydrogen Sulphide	CIS sputtering			■	■	
Nitrogen trifluoride	Si wafer plasma etching	■				
Methane gas	a-Si & GaAs manufacturing	■			■	■
Phosphine gas	Thin film dopant			■	■	■
Phosphorous oxychloride	x-Si dopant			■		
Selenium	CIS & CIGS raw material			■		
Silane gas	Intermediate product in x-Si production			■		■
Silicon tetrachloride	x-Si & a-Si deposition		■	■		
Tellurium	CdTe & CIS raw material			■		■
Trichlorosilane	x-Si & a-Si deposition			■		
Alkali	Cleaning		■	■		

Table. 2 Potential toxicity of materials utilised in solar photovoltaic panels[13]

3. RECYCLING OF WASTE SILICON PANELS

At the end of the life span recycling is the ultimate scenario which is to be taken for the treatment of the PV waste chunk. Thermal and chemical treatment methods were utilized. For the use of these methods dismantling is the first prior step to be executed. It will result in the separation of components like PVC sheets, steel material, EVA layer, silicon, aluminium sheets etc. Removal of the junction box, cables will

July – August 2020
ISSN: 0193-4120 Page No. 475 - 480

lead to the separation of copper wires**[14]–[16]**. After dismantling the leftover materials of the solar panel is to be taken out and this is accomplished by the use of thermal and chemical method. Utilization of the thermal method involves the use of high temperature up to 400 degree celsius. This way PV cells can be recovered. Further concentrated acids like Nitric acid, hydrochloric acids are utilized for the recovery of silver and other glass components**[17]**. Widespread implementation of the solar photovoltaic systems across the world occurred due to the reason of its being a clean energy source**[18]**. Further the increasing toxicity levels in the new generation of the solar panels, their cost of manufacturing and the material procurement are of greater interruption in this regard. Though CdTe can be replaced by Zn_3P_2 and CIGS can be replaced by the CZTS. Substantial apprehension calls for figuring out the environmental aftereffects of the new solar technology. Cd and Ga have environmental repercussions. Henceforth the enhancement is to be made in the manufacturing procedure especially the substrate used for cleaning and the absorber layer **[19]**.

5. PROPOSED END LIFE MANAGEMENT POLICY FOR SOLAR PHOTOVOLTAIC WASTE PANELS

a) Regulative framework:

- The manufacturing firm should be registered with a license.
- Constituent components utilization should also be familiarized.
- Prohibit the use of low abundant elements.
- Warranty of accomplishing environmentally loyal materials
- Provision of end life sketch for retiring panels.
- Comprehensively manufacturing should be amiable to nature.
- Provision of analytical testimony from birth to retirement.
- Gross production & import of all PV material trading routes should be monitored.

b) Layout the accountability & obligation of the collaborator for scrap handling & operation:

- Establishment of a joint collection ventures across India for the retired and distorted solar panels between the producer and the recycler.
- Consumers should be provided some incentives for waste deposition in collection centres.
- Collected waste material can then be auctioned for the recyclers or tenders can be directed.
- Collection centres should have familiarity with waste disposal regulations.
- Alimony to such joint ventures should be provided

c) Compose model for PV waste compilation:

- B2B (Business to Business) and B2C (Business to consumer) firms should be utilized[20].
- A municipal collection point is utilized.

d) Launch of treatment method:

- A combination of both mechanical & thermal method should be registered commercially.
- Method should deal with hazardous & non-hazardous waste.
- Risk factors of treatment of the wastes should be established to the recyclers
- Standardized infrastructure for the treatment should be available.

e) Disposition corporation endowment:

- Survey usual recycling methods.
- Analyse the expenditure and the industrial need for the efficient PV recycling system.
- Develop units to accumulate recycling materials.
- Supply recycled products to related industries for further profit gain.

f) Manufacturer Liability System (MLS) constitution:

July – August 2020
ISSN: 0193-4120 Page No. 475 - 480

- Abide the manufacturer to ensure lesser impact of hazardous materials.
- Utmost stringent responsibility of producer to take back its product from the market after its complete life end.

g) Set up of a head body over all the solar PV industry:

- Monitor the overall activity of the solar firms and knock out offenders from registration.
- This organization should also promote the use of sustainable materials in the designing.

h) Financial aid:

- A federal government agency should be set up for the financial assessment to PV industry.
- Indian government should inculcate various monetary schemes for recyclers.
- These way hazardous effects of the clean energy source are totally culminated out from the environment.

i) Recycling institution set up:

India should establish institutes which will impart professional skills among the people involved in this field. It will also be a boon for employment[18].

6. CONCLUSION

Appropriate end life management is to be ensured for the solar panels in order to manage their waste. All-together up-to the current times use of three R's is most prevalent which includes reduce, reuse and recycle. Recycling is the last alternative for sustainable management of waste. To maintain solar energy into clean energy category efficient waste management is the utmost necessity of the hour. Solar energy has turned out to be lucrative technology for the production of energy in the form of environmental amiable conditions. With the increasing installations the number of solar panels reaching their end life will also heighten. Along with this their management at this stage will demand an compulsory treatment. Upon their disintegration stage solar panels evolve in their utmost harm. At this stage recycling promises as the most effective remedy for the handling of the waste. A promising management prevails as the need of hour. Management of the solar waste is discovered as the new age of sustainable development achievement. A new industry can be set up for effective management of the solar panels. With the growth of such a thought socio-economic benefits can prevail for longer times. This will uphold a new era of industrial revolution all over the world in the end life management of the solar panels. With the aim of achievement of sustainability recycling of the solar panels is to be ensured in a very effective and clean manner with a lower cost investment than only an effective strategy of waste management will prevail.

REFERENCES

[1] K. Komoto et al., ‘End-of-Life Management of Photovoltaic Panels: Trends in PV Module Recycling Technologies’, IEA-PVPS, NREL/TP-6A20-73847, 1561523, Jan. 2018. doi: 10.2172/1561523.

[2] S. Weckend, A. Wade, and G. Heath, ‘End-of-Life Management of Solar Photovoltaic Modules’, IEEE, 2016.

[3] M. M. Lunardi, J. P. Alvarez-Gaitan, J. I. Bilbao, and R. Corkish, ‘A Review of Recycling Processes for Photovoltaic Modules’, in Solar Panels and Photovoltaic Materials, B. Zaidi, Ed. InTech, 2018.

[4] Y. Xu, J. Li, Q. Tan, A. L. Peters, and C. Yang, ‘Global status of recycling waste solar panels: A review’, Waste Management, vol. 75, pp. 450–458, May 2018, doi: 10.1016/j.wasman.2018.01.036.

[5] M. Lunardi, J. Alvarez-Gaitan, J. Bilbao, and R. Corkish, ‘Comparative Life Cycle Assessment of End-of-Life Silicon Solar Photovoltaic Modules’, Applied Sciences, vol. 8, no. 8, p. 1396, Aug. 2018, doi: 10.3390/app8081396.

[6] T. Y. A. Quek, W. L. Alvin Ee, W. Chen, and T. S. A. Ng, ‘Environmental impacts of transitioning to renewable electricity for Singapore and the

July – August 2020
ISSN: 0193-4120 Page No. 475 - 480

surrounding region: A life cycle assessment', Journal of Cleaner Production, vol. 214, pp. 1–11, Mar. 2019, doi: 10.1016/j.jclepro.2018.12.263.

[7] C. C. Faircloth, K. H. Wagner, K. E. Woodward, P. Rakkwamsuk, and S. H. Gheewala, 'The environmental and economic impacts of photovoltaic waste management in Thailand', Resources, Conservation and Recycling, vol. 143, pp. 260–272, Apr. 2019, doi: 10.1016/j.resconrec.2019.01.008.

[8] V. Baharwani, N. Meena, A. Dubey, D. Sharma, U. Brighu, and J. Mathur, 'Life cycle inventory and assessment of different solar photovoltaic systems', in 2014 Power And Energy Systems: Towards Sustainable Energy, Bangalore, India, Mar. 2014, pp. 1–5, doi: 10.1109/PESTSE.2014.6805302.

[9] V. M. Fthenakis and H. C. Kim, 'Photovoltaics: Life-cycle analyses', Solar Energy, vol. 85, no. 8, pp. 1609–1628, Aug. 2011, doi: 10.1016/j.solener.2009.10.002.

[10] C. E. L. Latunussa, F. Ardente, G. A. Blengini, and L. Mancini, 'Life Cycle Assessment of an innovative recycling process for crystalline silicon photovoltaic panels', Solar Energy Materials and Solar Cells, vol. 156, pp. 101–111, Nov. 2016, doi: 10.1016/j.solmat.2016.03.020.

[11] B. Huang, J. Zhao, J. Chai, B. Xue, F. Zhao, and X. Wang, 'Environmental influence assessment of China's multi-crystalline silicon (multi-Si) photovoltaic modules considering recycling process', Solar Energy, vol. 143, pp. 132–141, Feb. 2017, doi: 10.1016/j.solener.2016.12.038.

[12] P. Gangwar, N. M. Kumar, A. K. Singh, A. Jayakumar, and M. Mathew, 'Solar photovoltaic tree and its end-of-life management using thermal and chemical treatments for material recovery', Case Studies in Thermal Engineering, vol. 14, p. 100474, Sep. 2019, doi: 10.1016/j.csite.2019.100474.

[13] B. Bakhiyi, F. Labrèche, and J. Zayed, 'The photovoltaic industry on the path to a sustainable future — Environmental and occupational health issues', Environment International, vol. 73, pp. 224–234,Dec.2014,doi:10.1016/j.envint.2014.07.023

[14]S.-M. Nevala et al., 'Electro-hydraulic fragmentation vs conventional crushing of photovoltaic panels – Impact on recycling', Waste Management, vol. 87, pp. 43–50, Mar. 2019, doi: 10.1016/j.wasman.2019.01.039.

[15]D. Strachala and J. Hylský, 'Methods for recycling photovoltaic modules and their impact on environment and raw material extraction', Acta Montanistica Slovaca, vol. 22, no. 3, p. 13, 2017.

[16] P. Dias, L. Schmidt, L. B. Gomes, A. Bettanin, H. Veit, and A. M. Bernardes, 'Recycling Waste Crystalline Silicon Photovoltaic Modules by Electrostatic Separation', J. Sustain. Metall., vol. 4, no. 2,pp.176–186,Jun.2018,doi:10.1007/s40831-018-0173-5.

[17] Y. R. Smith and P. Bogust, 'Review of Solar Silicon Recycling', in Energy Technology 2018, Cham: Springer International Publishing, 2018, pp. 463–470.

[18] A. Kumar and B. Turner, 'Sociomaterial Solar Waste: Afterlives and Lives After of Small Solar', in Energy Justice Across Borders, G. Bombaerts, K. Jenkins, Y. A. Sanusi, and W. Guoyu, Eds. Cham: Springer International Publishing, 2020, pp. 155–173.

[19] F. Corcelli, M. Ripa, and S. Ulgiati, 'End-of-life treatment of crystalline silicon photovoltaic panels. An emergy-based case study', Journal of Cleaner Production, vol. 161, pp. 1129–1142, Sep. 2017, doi: 10.1016/j.jclepro.2017.05.031.

[20] S. Suresh, S. Singhvi, and V. Rustagi, 'Managing India's PV Module Waste', Bridge To India, India, Analytical, 2019.