

Chapter 1

INTRODUCTION: SOLAR PV TECHNOLOGY

The chapter outlines the evolution of solar PV technology and the waste generated from the solar modules. Further, the research work focuses on the need for the development of solar PV waste recycling policies. Purpose, motivation, and the need to carry out research work to develop a solar PV recycling framework for the Indian scenario are put forward. The literature was reviewed to identify the research gaps based on which research objectives are defined. Further, the chapter concludes with the scope, and limitations of the study.

1.1 Introduction

Among renewable sources of energy, Sun is the ubiquitous and easily available energy source to all life forms. With industrialization energy requirements have increased drastically. Solar photovoltaic technology can be exploited to convert solar radiation into electricity by the use of solar cells. A solar cell is a photovoltaic device that uses the photovoltaic effect to convert light energy into electrical energy. The photovoltaic effect refers to the creation of voltage across a junction in a semiconductor as a result of light absorption. A photovoltaic gadget is one that is based on this phenomenon.

With the rising over-exploitation of conventional energy sources and the deterioration of the earth's life support system, many industries and corporations have begun to examine the influence on the environment of their products. LCA, or life cycle assessment, is one such method used for this (Baharwani et al., 2014). LCA is a tool for assessing the environmental consequences and resources used throughout the life cycle of a product, taking into account all characteristics or aspects of the natural environment, human health, and resources. It can also be defined as a method for analyzing and assessing the ecological effects of a material, product, or service over its entire life cycle (ISO 2005).

Thus, ISO14040 defines LCA as the "compilation and assessment of a product system's inputs, outputs, and possible environmental consequences throughout its life cycle." (ISO 2006). LCA examines the environmental impact of products from raw material

acquisition to production, use and maintenance, and finally end-of-life management, whether via reuse, recycling, or reduction (Latanussa et al., 2016). Fig.1.1 depicts the stages of solar PV's life cycle.

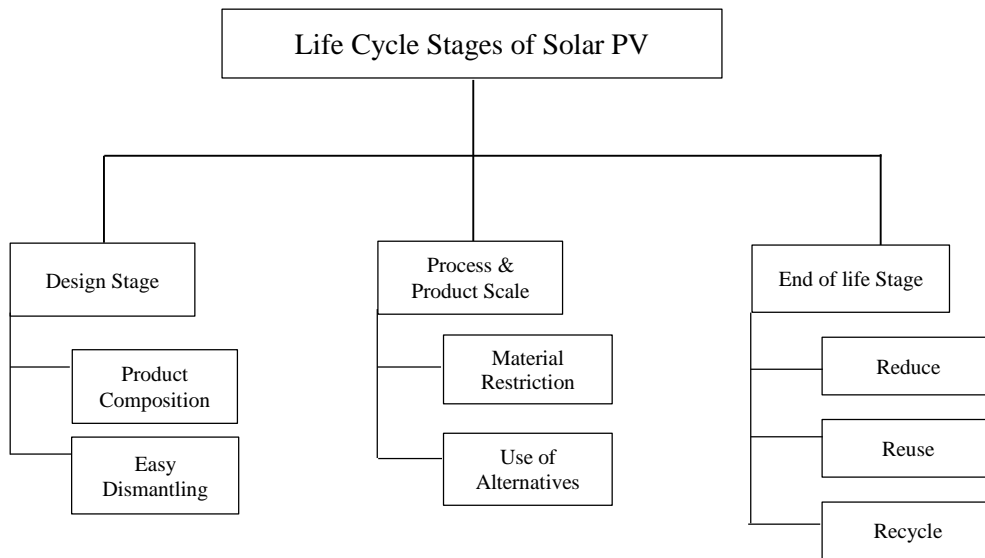


Fig. 1.1 Stages of Solar PV's Life Cycle

1.2 Evolution of Solar PV Technology

Photovoltaics (abbreviated PV) derives its name from the photovoltaic effect, which is the method of changing light (photons) to electricity (voltage). This effect was originally utilized in 1954 by Bell Laboratories scientists, who developed a functioning silicon solar cell that generated an electric current when exposed to sunlight (Sen et al., 2016). Solar cells were quickly employed to power space spacecraft as well as smaller goods like calculators and watches. The working of a solar cell is shown in Fig. 1.2.

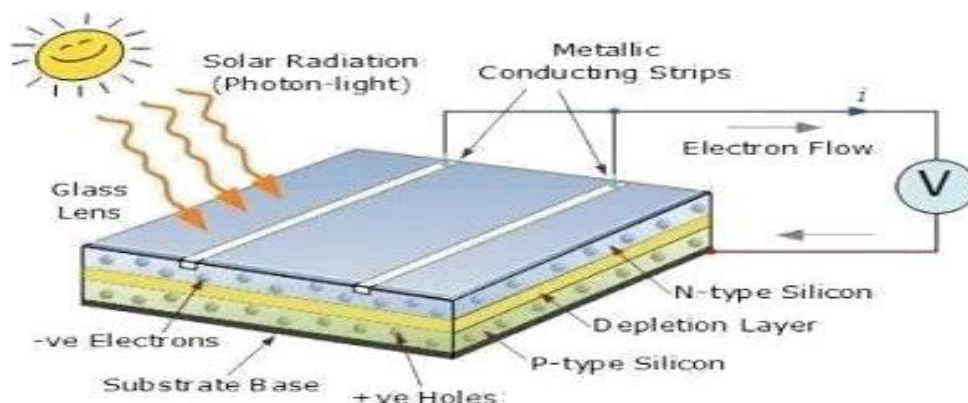


Fig.1.2 Working of Solar Cell

Source: www.electricalengineering123.com

Solar photovoltaic solar cells are categorized based on the materials they are made of and is shown below in Fig.1.3.

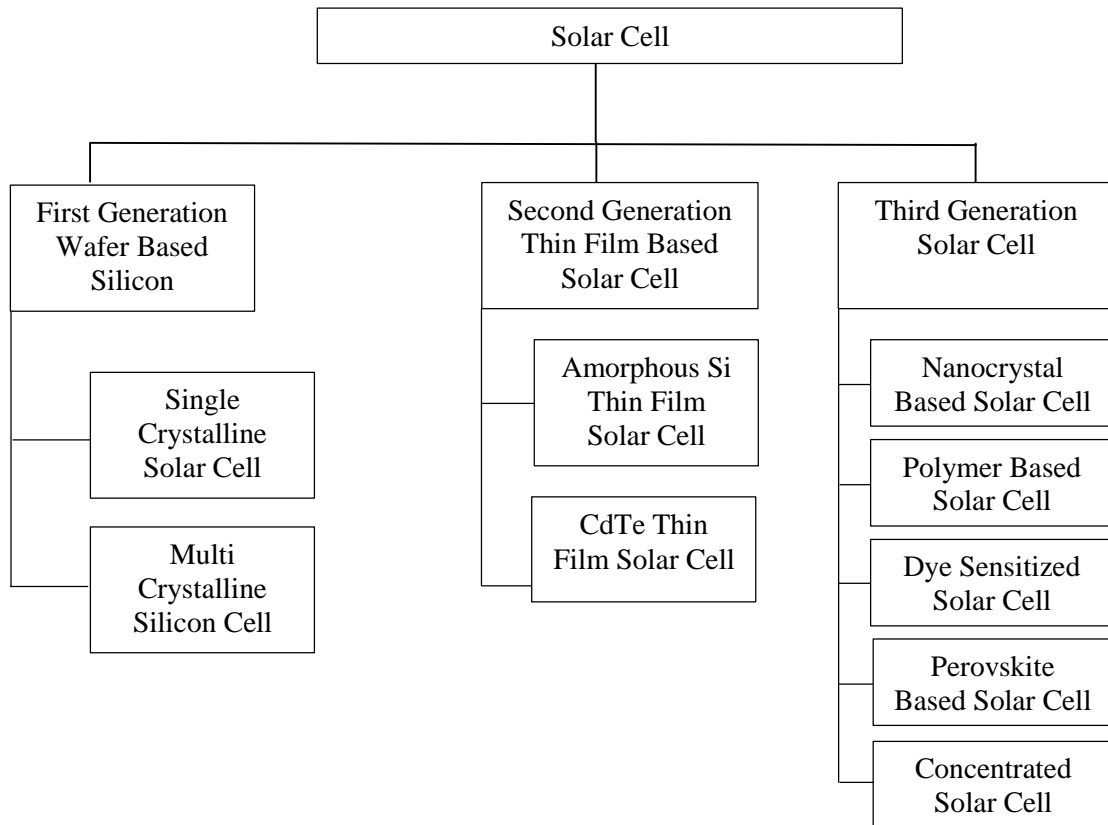


Fig.1.3 Types of Solar Cell

First Generation Solar Cell-Wafer Based:

These solar cells are produced using silicon wafers. Due to its extreme primitiveness and excellent efficiency, it is the most well-known technology. It is broken further into two categories:

1. Single Crystalline Silicon Solar Cell:

This type of solar cell is made from a single silicon crystal, and its efficiency ranges from 17% to 18%.

2. Multi-Crystalline Silicon Solar Cell:

A cell is created by combining several crystals. It is currently the most well-liked. In addition, they cost cheaper to make than single crystal solar cells and have an efficiency of only about 12% to 14%.

Second Generation -Thin Film-based Solar Cells:

Thin film solar cells have more economical aspects in comparison to wafer-based silicon cells, as a 350 micro-meter layer is present for absorbing the incident photons. Whereas only 1 micro-meter thick layer is present in the wafer-based cell. Solar cells made of thin film are further divided into –

1. Amorphous Silicon Thin Film (a-Si) Solar Cell:

Silicon atoms are placed randomly in the crystal's lattice. It was the most basic solar cell that was created first on an industrial scale. It is relatively having the nominal cost and is extensively available. Its efficiency is low from 4% to 8%.

2. Thin Film Cadmium Telluride (CdTe) Solar Cell:

Cadmium telluride solar cells are the most common variety of thin film solar cells. These are also economically feasible. In comparison to other solar cells, their price is significantly more affordable. Their productivity ranges from 9% to 11%. Despite the above benefits of using more CdTe solar cells, the transition element Cadmium found in them has a negative impact on the ecosystem's living things, including humans, animals, and plants. Cadmium reclamation is a time- and money-consuming operation with a low viability rate. Additionally, transitional elements are few in nature. Another area of worry is the hazardous impact of cadmium on the environment.

3. Copper Indium Gallium Di-Selenide (CIGS) Solar Cell:

A solar cell of this sort is made up of tetra components that include representative elements and transition elements. In compared to CdTe solar cells, these cells have a 10% to 12% higher efficiency. These solar cells are also quite inexpensive in compared to other thin film solar cell equivalents.

Third Generation Solar Cells

This generation of solar cells is evolving at the most recent hour, both in the business and in research. This category includes the following types:

1. Polymer-Based Solar Cell (PSC) - A thin layer of polymer is wrapped around an absorbent layer in this form of solar cell.
2. Concentrated Solar Cells (CSC) - The most recent solar technology. The incident energy of photons is concentrated into a narrow region in this device.

3. Dye-Sensitized Solar Cells (DSC) - This technique includes dye molecules in the space between the collecting electrodes.
4. Perovskite-Based Solar Cells - Halogen ions such as iodide, bromide, and chloride, as well as two distinct cations of varying radius, are present in this form of solar cell. ABX_3 formula chemicals are typically included. This perovskite solar technology is a relatively new addition to the photovoltaic industry.
5. Nano Crystal Based Solar Cells: This type of solar cell is composed of nanometer-sized semiconductor material. Transition group elements are also present. Quantum dot cells are solar cells made up of nano crystals.

Waste from solar modules harms the environment, people, the ecosystem, and biodiversity. Major human aftereffects included the gastrointestinal tract effects of indium compounds, effects of germane, carcinogenic effects of Cd, Te, and Se, etc. (Strachala & Hylský, 2017; Wu et al., 2017). The current market share of the various solar PV technologies are as follows (2014-2030) in Fig.1.4.

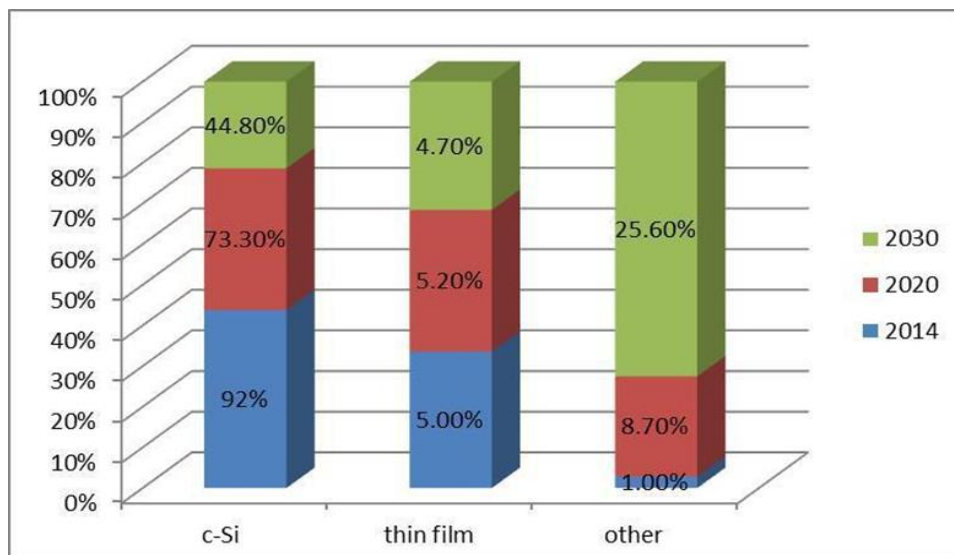


Fig.1.4 Market Share of PV Panels (2014-2030)

Source: IRENA 2016

1.3 Solar PV Waste Scenario

The first shipment of PV setups from the beginning of 1980 have already stopped operating. The need to manage the generated PV waste is also urgent. The waste so generated at the end is of two types:

- 1) Waste produced in manufacturing plant
- 2) End life generated waste

The estimation of PV panel waste can be executed by a three-tier approach as depicted in Fig.1. 5.

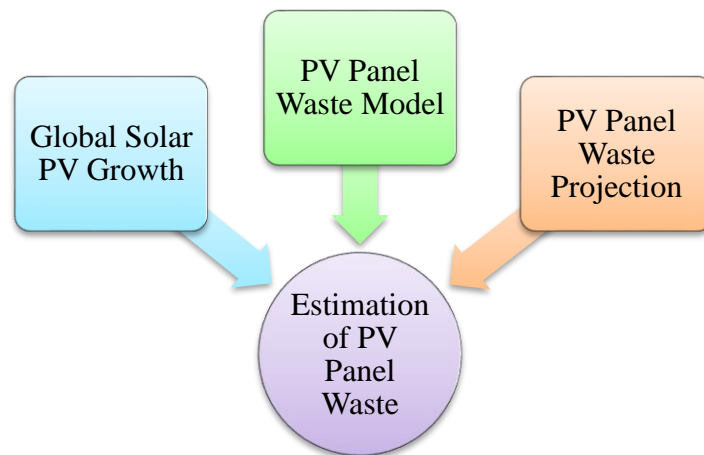


Fig.1.5 Three Tier Approach to Estimate Solar PV Panel Waste.

The solar PV waste estimation needs to be carried out due to the increasing installations. With the successive years at an interval of five, the PV installations are significantly rising since the year 2015 (Chowdhury et al., 2020). The installations will further increase in 2050. The growth of the solar photovoltaic installations from the year 2015 to 2050 is depicted here in Fig.1. 6.

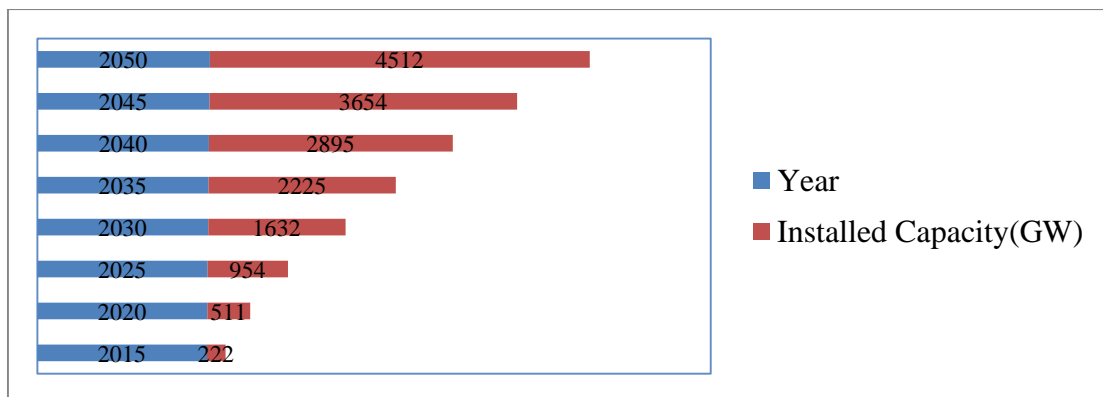


Fig.1.6 Solar PV Installations from 2015-2050 (Sica et al., 2018).

During the entire life cycle of solar PV panels, the waste so generated can be estimated based upon criteria of the under-mentioned factors in a PV panel waste model as shown in Fig.1.7.

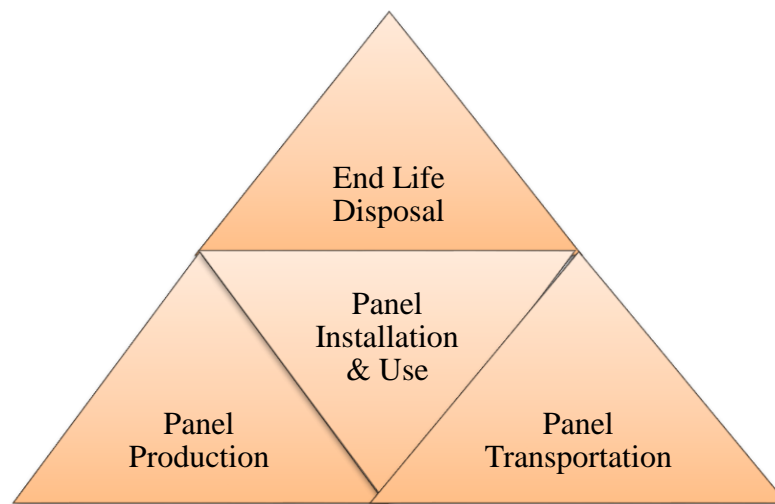


Fig. 1.7 PV Panel Waste Model (V. Fthenakis et al., 2016)

The model is using the following criteria for the estimation of PV waste. These factors have to be analyzed.

- 1) Production of the panel: Commercial and non-commercial solar panel manufacturing is getting increased i.e., Crystalline Silicon, Cadmium Telluride solar panels, etc.
- 2) Panel transportation: After the manufacturing of solar panels, they are to be transferred to the fabricator companies.
- 3) Panel installation & use: Once the transportation of the solar panels is done and they are to be installed for use.
- 4) End of life & disposal: After their lifecycle is over the disposal part also an important role in the estimation of the total PV waste.

This model is excluding waste generated during the production process as it can be easily managed by the producers. For the evaluation of the PV waste, the total positioned capacity of the solar photovoltaic panels is to be taken in terms of their mass in metric tons. Further end life cycle management also decides the overall financial requirement of the PV waste model. The waste is depicted in North America, Oceania, Latin America & Caribbean regions are taken here.

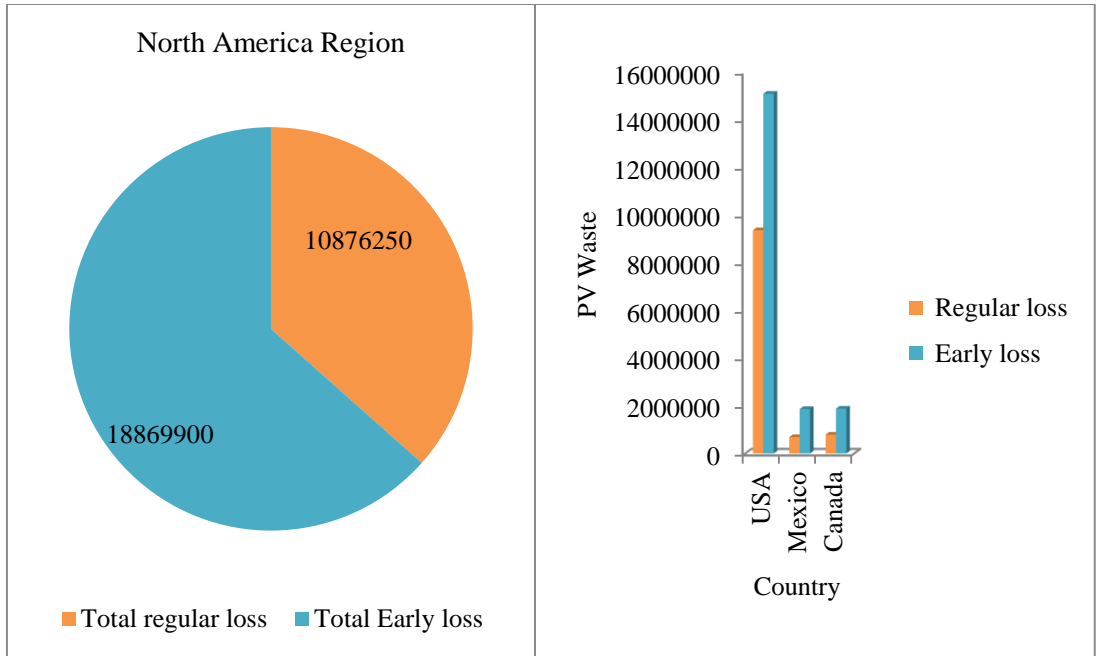


Fig.1.8 PV Waste from 2016-2050 in North America Region (Sica et al., 2018)

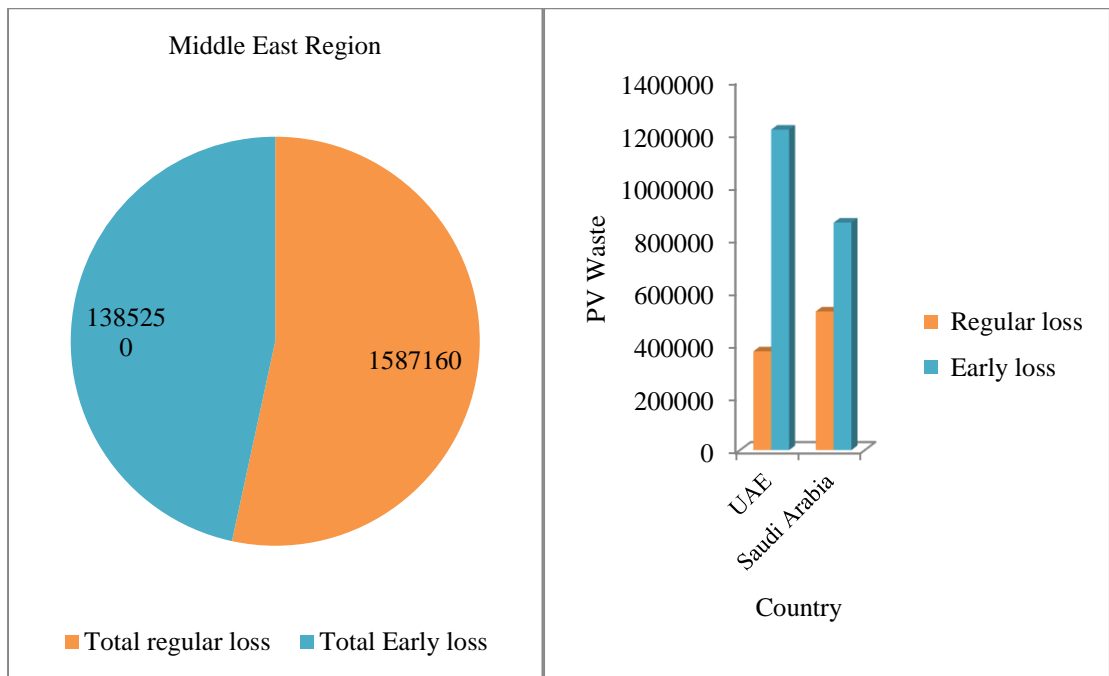


Fig.1.9 PV Waste from 2016-2050 in Middle East Region (Sica et al., 2018)

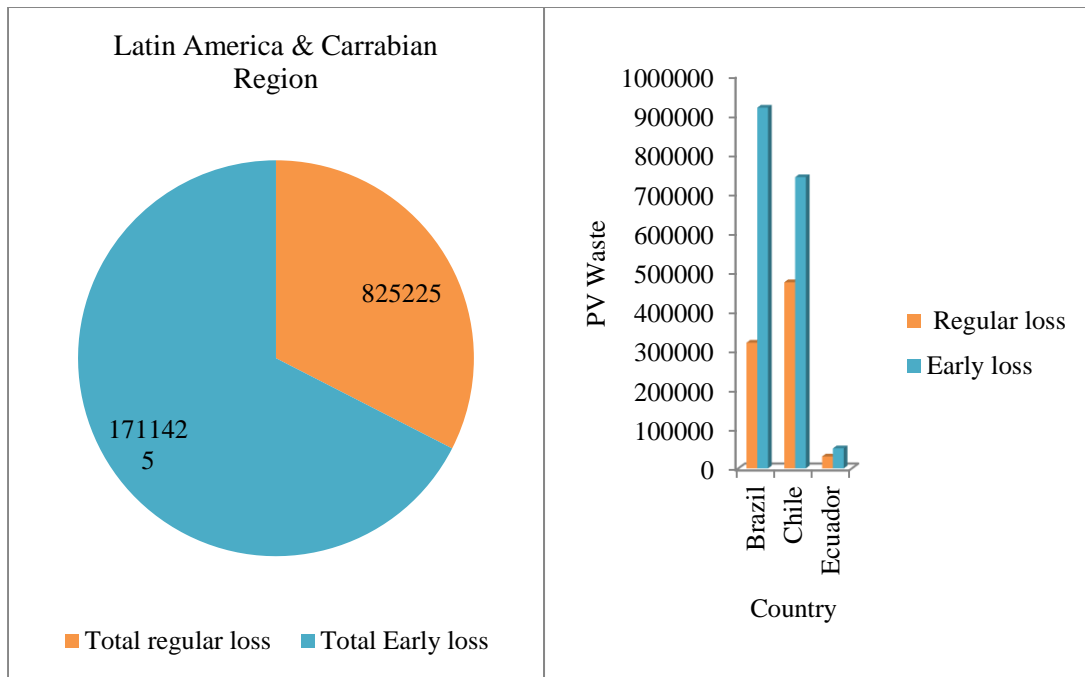


Fig.1.10 PV Waste from 2016-2050 in Latin America & Caribbean Regions (Sica et al., 2018)

The regular losses include the waste generated after the life cycle of the solar panels is over. The life cycle of the solar panels is estimated to be 30 years (Suresh et al., 2019). Whereas the early losses include the PV waste generated during the operational phase of the solar panels. This phase includes the infancy lifetime to the middle life up to the completion of the life span of 30 years. The early loss of PV waste in the year 2016 was 250,000 million tons whereas the regular loss was 43,500 million tons. In 2030 the regular loss was 8 million tons and the early loss was 1.7 million tons. By the extreme of 2050 regular loss was estimated to be 78 million tons and the early loss was 60 million tons (Weckend et al., 2016).

1.4. Need to Develop Solar PV Waste Recycling Policies:

To manage the rising amount of solar PV waste it becomes stringent to look after the environment, management of resources, and socio-economic factors. The constituent elements of solar panels are sturdy even though they can bring harmful consequences upon exposure to the environment. With this concern towards the environment, they need to be responsibly held in disposition to put out least impact on the environment. Elements present in the solar panels are economically important to be lost. These can be utilized for the needs of other industries. It's quite essential to look after their

recovery from the solar waste modules. Collecting the waste solar panels and then sending them to the recycling center is a great job accomplished. This process influences the employment sector of India. Hiked solar PV waste would bring forth beneficiary outcomes to informal recycling centers. With an efficient regulative approach, formal recycling processes would be established. There would be multiple beneficiary outcomes of the proposed regulative framework for India as discussed below.

Environmental impact:

Different variety of elements utilized in the solar PV modules on their detrimental outbreak from the solar panels would cause effective ecological damage and to prevent this PV panel disposal needs to be followed within the effective regulative framework.

Resource management benefits:

Recovering the elements from the waste solar panels is essential for continuous production and their utilization in the manufacturing of solar PV modules. Metal recovery from the disintegrated solar panels is important for minimization of resource loss to continue their supply in a sustained manner.

Socio-economic benefits:

Generation of employment and aspects of welfare are inculcated among the socio-economic benefits encompassed by the recycling of waste solar PV modules. Even though the solar PV market is rising in terms of installation in India but it still lacks the establishment of a proper manufacturing industry to meet the needs of the country. Here only the parts are assembled which are supplied from China, the Philippines, etc.

1.5. Statement of the Problem

Developing policies for the end-of-life assessment of solar photovoltaic modules by analysis of various recycling methods, dealing with their environmental impacts.

1.6. Purpose of the Study

The use of the renewable energy sources used wisely will bring about dramatic

improvements in the improvement of energy concerns in a cleaner manner. It is necessary to use renewable energy sources in every sector of the global economy. The use of solar energy was quite helpful in completing this task. The government's push for more PV installations is causing a macroscopic increase in the amount of solar photovoltaic waste that is accumulating in the nation. This is an urgent problem that needs to be addressed by PV scrap management and recycling legislation. The major PV module recycling processes are examined, and the material recovery in economic terms is documented. With the rising PV scrap turmoil obliged to inclination toward the PV recycling policy framework.

Overconsumption of fossil fuels leads to their exploitation and paved way for the alternative renewable sources of energy. Among this solar energy is considered to be a clean and prominent source of energy as it's freely available from the Sun. Being free from harmful gaseous emissions during the operational phase solar photovoltaic technology is considered an important clean source of energy among the other renewable technologies. Due to their restricted lifespan of twenty-five to thirty years the amount of waste accumulation has been left unnoticed. The amount of solar photovoltaic waste accumulated is directly proportional to their installation. Due to further negligence solar photovoltaic waste will become a disaster in approaching times. Though recycling could result in less environmental burden than landfilling but at an added monetary cost. So, the need of the hour is to build up effective PV waste management.

1.7. Motivation

With the new solar PV plant achieving its daily goals, the waste pile has accumulated to an expected quantity in tons. Till now recycling methods have received very less emphasis. The decommissioning of solar PV materials produces dangerous planetary waste that cannot be dumped in the trash. A strict strategy must be in place for managing them. The establishment of a legal framework for PV recycling in emerging countries, particularly in the case of India, would be a crucial lifesaver in addressing the calamity that will inevitably arise in the future. Ongoing PV recycling techniques are thoroughly analyzed out of the thermal method is good enough with some demerit. This research work highlights the environmental and socioeconomic disturbance that the clean energy

source causes as a result of the growing market share of PV technology. The Indian government's response to this legislation will have a significant impact in reducing the PV scrap disaster predicted in the future. An innovative policy framework for solar PV recycling in both rural and urban India is presented in this article.

1.8 Methodology

The research methodology takes into account using a deliberate sampling method based on expert samples from secondary sources, such as journal articles, government publications, thesis, reports, and authorized websites. The study fills a knowledge vacuum in the EoL of solar PV panels in emerging nations. Following that to provide a conceptual framework for developing economies, the available data was assessed and triangulated, which was then followed by a careful content analysis based on the study's key objectives. The methodology takes into account using a conscious sampling method based on expert samples from secondary sources, such as journal papers, government publications, theses, and approved websites, this study fills a knowledge vacuum in the EoL of solar PV panels in emerging nations.

The secondary data analysis resulted in the determination of precise handling procedures for waste management, both hazardous and non-hazardous. To acquire data for the article, the study intends to use three approaches. The strengths and drawbacks of the methodology were a deciding element in the decision. A comprehensive desktop search is available, as well as document analysis.

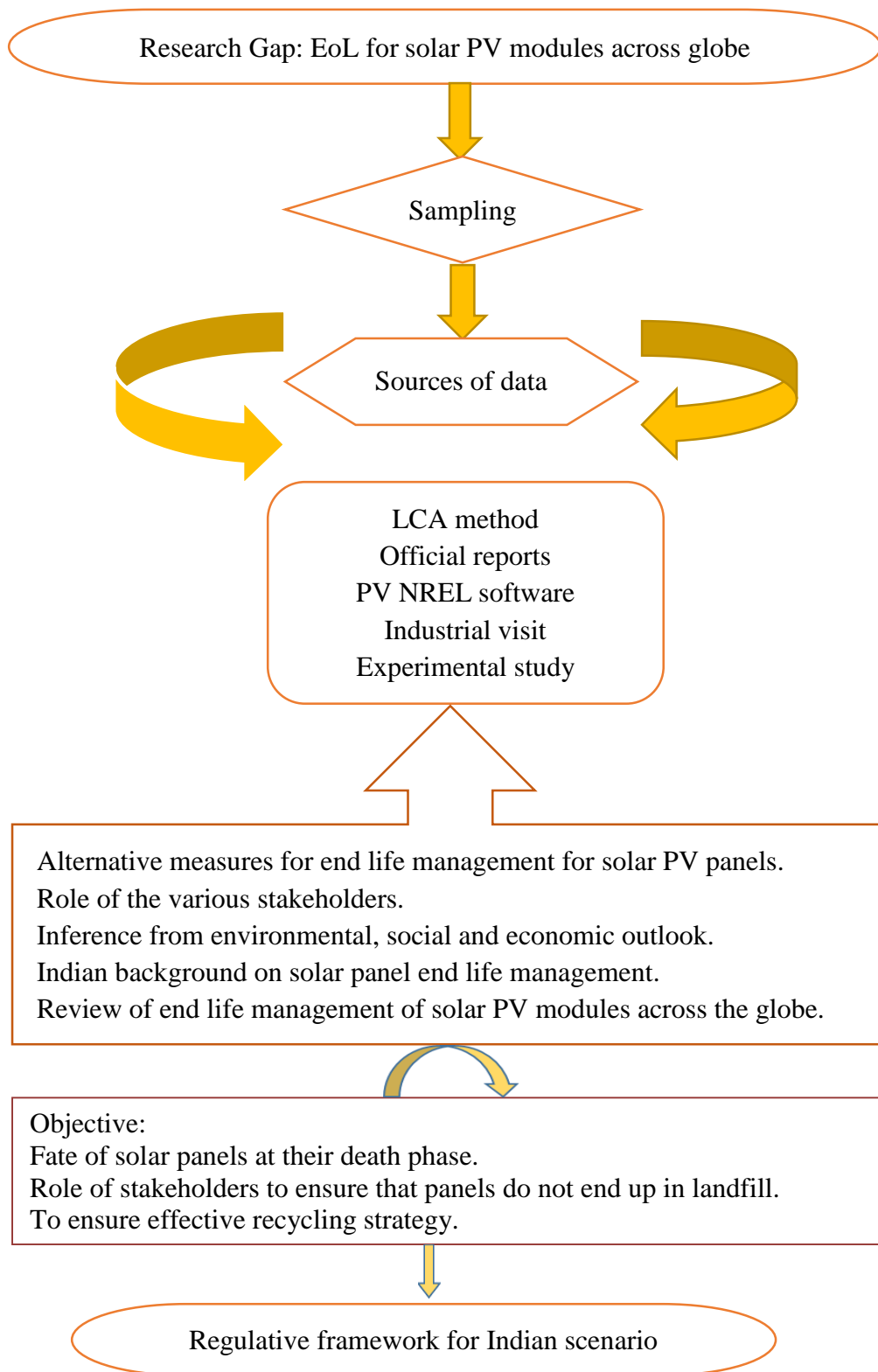


Fig.1.11 Methodology of Research Work

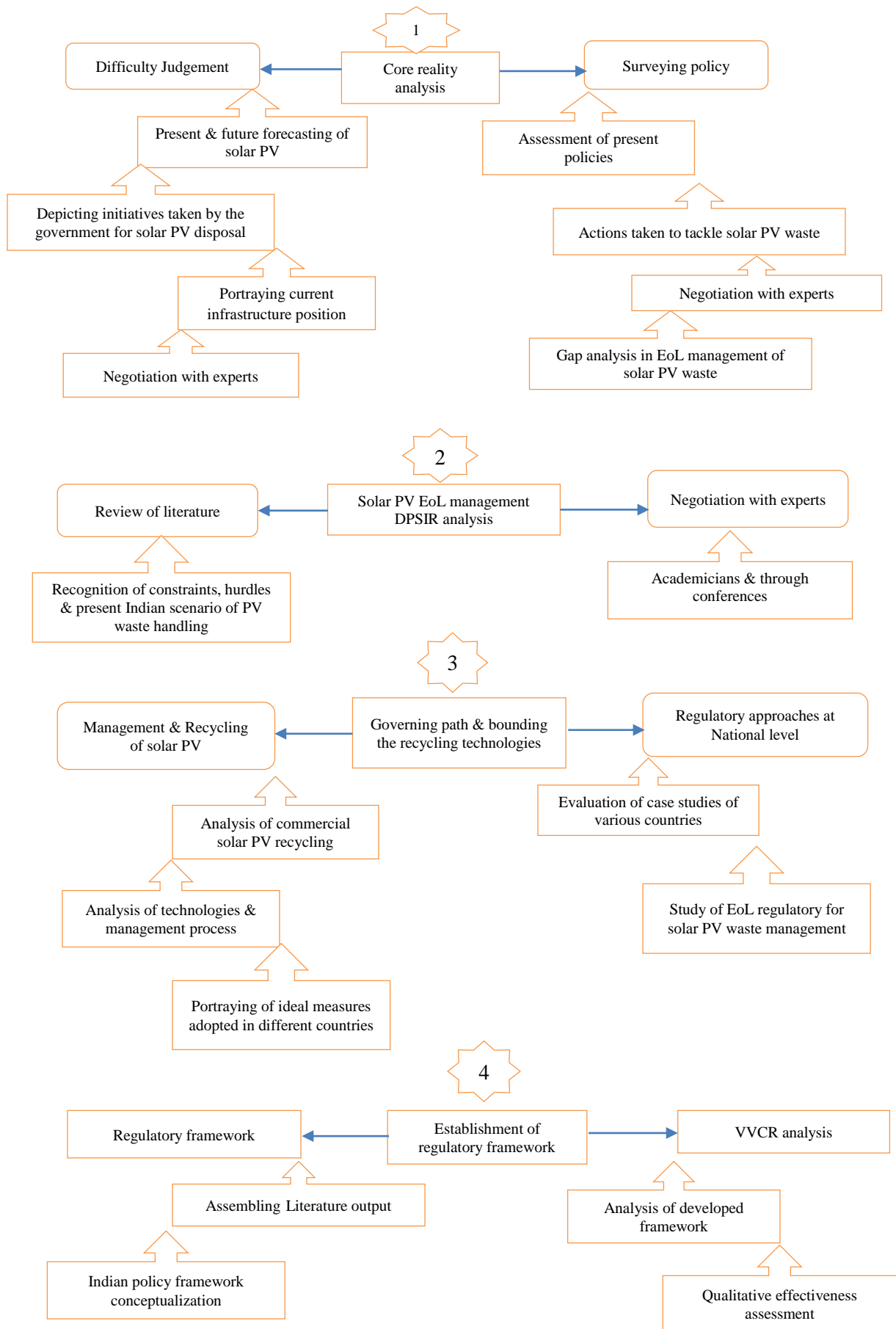


Fig. 1.12 Methodology for Policy Framework

1.9. Objectives of the Study

1. To study the utilization and properties of three generations of traditional solar cell materials used in solar photovoltaic systems with the help of available resources.
2. To review the existing policies and guidelines available in other countries and India for solar PV recycling.
3. To develop a framework to ensure safe and efficient recycling of the waste solar PV modules and study their environmental impact.
4. To develop a novel Indian policy option to create a sustainable condition for the proper treatment of solar waste.

1.10. Scope of the Study

1. The study will highlight and demonstrate the importance and benefit of developing flexible regulatory frameworks.
2. It will ensure sustainable PV end-of-life management.
3. It will enable economically efficient processes and technologies for product and material recovery processes.
4. It will stimulate associated socio-economic benefits like the recovery of valuable materials, and foster new industries and employment.

1.11. Limitations of the Study

1. End-of-life waste management is not considered for the emerging solar cell materials, as they are not yet commercialized.
2. Cost of labor is not included in the economic analysis of the solar module waste at the end life of the power plant.
3. Economic analysis of the recycling method is not included in the study.