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School Of Postgraduate Studies

**AN ASSESSMENT OF POTENTIAL NEGATIVE IMPLICATIONS OF
TRANSITIONING TO SOLAR PV ENERGY ON SOLAR PANELS WASTE
MANAGEMENT AT END OF SHELF LIFE IN LUSAKA**

BY

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@2023

DECLARATION

I, **VALENTINE PALANGWA MUTALE** do hereby declare that the contents of this study are my original work and that to the best of my knowledge have not been previously presented for any award in any other University. All the sources of information used in this piece of work have been duly acknowledged.

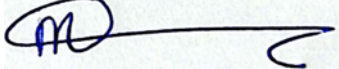
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DEDICATION

The happiness of those around you, including my family, is what offers the greatest delight. My wife and our son have been an important part of my academic success; therefore, I've dedicated this work to them. They served as my source of inspiration when I was working on the dissertation. My wife's encouragement and support have allowed me to put in long hours at the office and study while she watched over the house and our son. I genuinely appreciate you being there for me and may the good Lord graciously and abundantly reward you.

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ACRONYMS AND ABBREVIATIONS

ZPDF	Zambia's Power Development Framework
ZEMA	Zambia Environmental Management Agency
LISWMCL	Lusaka Integrated Solid Waste Management Company Limited
GW	Gigawatt
IEA	International Energy Agency
PV	Photovoltaic
EPIA	European Photovoltaic Industry Association
ZESCO	Zambian Electricity Supply Corporation
GwP	Global Warming Potential
OLDP	Ozone Layer Depletion Potential
AP	Acidification Potential
CIGS	Copper Indium Gallium Selenide
EVA	Ethylene/Vinyl Acetate
WEEE	Waste Electrical and Electronic Equipment
EPR	Extended Producer Responsibility
CE	Circular Economy
OECD	Organization for Economic Cooperation and Development
ESG	Environmental, Social, and Governance
CBD	Convention on Biological Diversity
SDG	Sustainable Development Goals
NGO	Non-Governmental Organizations
EoL	End of Life
IRENA	International Renewable Energy Agency
DfE	Design for Environment
MGEE	Ministry of Green Economy and Environment

ABSTRACT

The transition to solar photovoltaic (PV) energy is gaining traction as a sustainable solution to address energy challenges and reduce carbon emissions. However, as the adoption of solar PV energy expands, it is crucial to understand the implications of this transition on waste management practices for solar panels at the end of their shelf life. This research aimed to assess the potential impending negative implications of transitioning to solar PV energy on solar panels waste management at the end of their shelf life in Lusaka.

The study adopted a sequential explanatory mixed methods approach and design, combining quantitative and qualitative data collection methods. Questionnaires and interviews were used to acquire data from experts in the field. Descriptive statistical analysis was conducted to analyze the data and disclose the experts' input. The results indicate a moderate level of solar PV adoption (59%) influenced by various factors, including the political environment (78% agreement, mean=3.97, std=0.98), economic situation (90% agreement, mean=4.42, std=0.79), technological advancement (78% agreement, mean=4.03, std=0.96), and climate change (82% agreement, mean=4.24, std=0.92). The study found that there is a significant lack of awareness among the general public regarding the proper handling and disposal of end-of-life (EoL) solar PV panels, with 87% of respondents lacking this knowledge. Additionally, there is a shortage of waste management infrastructure and recycling facilities that are equipped to handle the disposal of solar panel waste, as reported by 59% of respondents. The investigation revealed a lack of legislation or recommendations for the management of PV waste. The lack of regulations and guidelines leads to uncontrolled transportation and monitoring of solar PV waste into Zambia, as well as within Lusaka and between the provinces. These findings led to the development of a proposed Strategic Framework for the management of solar PV waste in Lusaka, Zambia.

Keywords: *solar (PV) energy, PV waste management, environmental impact, solar PV adoption, Strategic Framework.*

CHAPTER ONE

INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION

Solar photovoltaic (PV) systems directly convert solar energy into electricity without the aid of any machines or moving parts. According to Parida et al. (2011) and Hosenuzzaman et al. (2015), it is an endless source of energy. Regional limitations do not apply to the installation of solar photovoltaic equipment in rural places, deserts, or on roofs (Chen 2014; Grossmann et al. 2013).

The transition to solar photovoltaic (PV) energy is gaining significant momentum globally as a sustainable alternative to conventional energy sources. In the context of Lusaka, Zambia, where solar potential is abundant, the adoption of solar PV energy is on the rise. However, as the solar PV industry expands, it is crucial to assess the implications of this transition on waste management practices. This research aims to explore the implications of transitioning to solar PV energy on waste management in Lusaka, Zambia. In order to achieve energy security and mitigate climate change, Zambia, like many other nations, understands the significance of renewable energy sources (Makasa, 2018).

Sustainable Development Goals (SDGs) of the UN is another priority for Zambia, especially those that have to do with access to clean energy. By facilitating greater access to sustainable and renewable energy sources, rooftop solar panel adoption contributes to the achievement of sustainable development goals. To encourage the use of solar energy, draw in investments, and expand the installation of solar PV systems in Lusaka, the government has launched programmes and policies (Mulenga et al., 2020). However, as a result of Zambia increasing use of solar power, disposing of solar panels may have detrimental effects on the environment. Materials found in photovoltaic panels, such as lead and cadmium, can leak into the environment and endanger ecosystems as well as public health if improperly managed (IREA, 2016). Electronic waste can accumulate due to ineffective disposal techniques or a lack of recycling facilities, which can contaminate the land and water. Therefore, in order to lessen the possible negative environmental consequences of end-of-life solar panels, Zambia must create effective and environmentally responsible waste management strategies, including recycling and safe disposal

techniques (IREA, 2016; Kanyerere et al., 2020). As a result, even if solar energy has clear environmental advantages, its possible effects on waste management should be considered. Solar PV systems have a lifespan of several decades, and at the end of their life cycle, they generate waste in the form of PV panels and batteries. Proper management of this waste is crucial to avoid environmental contamination and health hazards. The disposal of PV panels, which often contain hazardous materials, presents challenges in terms of appropriate recycling and safe disposal methods (Asghar et al., 2021; Sander et al., 2020). Therefore, it is essential to assess the waste management infrastructure and policies in Lusaka to accommodate the growing waste stream from solar PV systems.

The implications of transitioning to solar PV energy on waste management extend beyond waste generation and disposal. It is necessary to consider the entire waste management cycle, including collection, sorting, recycling, and the infrastructure required to handle electronic waste effectively. The existing waste management practices and facilities in Lusaka need to be evaluated for their capacity to handle the increasing waste stream associated with solar PV energy adoption (Mbvundula et al., 2016). By analysing the implications of transitioning to solar PV energy on waste management in Lusaka, this research aims to contribute to the understanding of the challenges and opportunities in sustainable waste management practices. The findings will provide insights for policymakers, waste management authorities, and stakeholders to develop strategies and policies that promote effective waste management in the context of solar PV energy adoption.

1.2 BACKGROUND TO THE STUDY

1.2.1 Solar PV energy

The transition from using the ordinary non-renewable sources of energy replacing it with renewable solar energy has increased across the globe. Photovoltaic energy production is accelerating all over the world, in order to reduce emissions from traditional sources that affect the increase in global warming. Many sources of energy are being replaced by photovoltaic energy at present in line with the world's view toward maintaining sustainable development and reducing global warming. Sustainable development goal number seven states that there should be affordable and clean energy. The research examines the transition to solar PV energy, which

aligns with the goal of ensuring access to affordable, reliable, sustainable, and modern energy for all (United Nations, 2015). By exploring the waste management implications of this transition, the study promotes sustainable practices that support the deployment of clean and renewable energy sources. Sustainable development goal number eleven - Sustainable Cities and Communities: By assessing the readiness of waste management infrastructure and proposing sustainable waste management strategies, the research contributes to creating sustainable cities and communities (United Nations, 2015). It aims to enhance waste management practices, which are crucial for the well-being and quality of life of urban populations.

Zambia, like many other developing countries, faces significant challenges in its energy sector, including unreliable electricity supply and a heavy dependence on traditional energy sources (Makasa, 2018). Recognizing the potential of renewable energy, the Zambian government has implemented policies and initiatives to promote the adoption of solar PV energy. For instance, the Scaling Solar Program has attracted investments and facilitated the development of solar power projects in the country (Mulenga et al., 2020). The use of clean energy is in line with the United Nations sustainable development goals and therefore this study aims at fulfilling the objectives united nation Sustainable Development Goals (SDGs), and contribute to the achievement of multiple SDGs, particularly.

1. Sustainable development goal number twelve- responsible consumption and production the waste generation and management associated with solar PV systems, addressing the goal of promoting responsible consumption and production patterns (United Nations, 2015). By identifying potential environmental and health impacts and proposing sustainable waste management strategies, through research that support the efficient use of resources and the reduction of waste generation.
2. Sustainable development goal number thirteen talks about climate action: The transition to solar PV energy is a key measure to mitigate climate change and reduce greenhouse gas emissions. The research explores the waste management implications, enabling the adoption of sustainable practices that align with climate action efforts (United Nations, 2015). It contributes to the overall goal of combating climate change and its impacts.
3. PV solar panels do not last forever hence they are replaced during maintenance and also when they reach the estimated years of operation. Approximately about 80 GW by was

produced by 2020 and this number is likely to increase by 2050 to approximately 3,200 GW will be produced. With such increase in production there is also an increase in the number of panels to be used, increase maintenance schedules and the amount of waste produced increases. The accumulative volume of e-waste is likely to increase to 200,000 tons by 2030 and over seven million tons by 2050 will be produced Even though photovoltaic energy is considered friendly to the environment. Photovoltaic energy it is not without flaws, as the large use and installation of solar panels leads to an increase in waste generated after the end of life and has an impact on waste management and environment at large.

The life span of solar panels range between 25 and 30 years, and most distributors rely on an average of 20 years, which means that the panels that were installed in the early 21st century have almost stopped working. Although PV units last between 20 and 30 years of life, and manufacturers provide guarantees during this period, this does not mean that PV cells will last beyond the shelf life, as the guarantees provide that energy production will not decrease by about 20% of the electricity production during the life of the project, but it does not guarantee what will

While the environmental benefits of transitioning to solar PV energy are evident, it is crucial to assess the implications for waste management of panels which often contain hazardous materials, including lead, cadmium, and other potentially toxic substances, necessitating proper waste management to prevent environmental contamination and health risks (Asghar et al., 2021; Sander et al., 2020). The growth of the solar PV industry introduces new waste streams, primarily from the disposal of PV panels and batteries at the end of their operational life (Asghar et al., 2021) which end up into inadequate existing waste management infrastructure. Policies in Zambia may not be adequately prepared to handle the increasing waste stream from solar PV systems. Challenges such as inadequate recycling facilities, limited awareness of electronic waste regulations, and insufficient funding for waste management infrastructure have been identified (Mbvundula et al., 2016; Thomson et al., 2013).

Therefore, it is imperative to assess the readiness of waste management practices and infrastructure to effectively manage the growing volume of PV waste. Analysing the implications of transitioning to solar PV energy on waste management in Lusaka is crucial for

developing sustainable waste management strategies and policies and it requires a comprehensive understanding of waste generation from PV systems, the environmental and health impacts associated with PV waste, and the capacity of the waste management system to handle this waste stream effectively. According to Oteng et al. (2021), the end-of-life and waste management of solar panels have not received enough attention in the developing field of negative environmental repercussions of solar systems. This research aims to close this gap and by conducting research on this topic, valuable insights can be gained to inform decision-making processes and guide the development of appropriate waste management strategies in Lusaka. This will contribute to the overall sustainability of the solar PV industry and support the transition towards a cleaner and more environmentally friendly energy system.

1.2.2 PV module end-of-life

The occurrence of decrease in efficiency of PV solar panels is common around the world. The efficiency decreases every year hence a decrease in production of electrical energy until it reaches the minimum level of around 14% and the solar panel units do not provide the operating cost and stops working and process is called end of life. the average annual energy loss for the cell is approximately 0.5%, and after approximately 25 years of operation, the unit reaches an efficiency limit that is not sufficient to continue operating, which leads to the photovoltaic units stopping working and turning into waste. The decline in efficiency is largest during the first years reaching an average of 2.5%, and gradually decreasing over time. Several factors lead to an annual decrease in the efficiency of solar units, the most important of which is the exposure of the panels to ultraviolet rays in addition to various weather factors, dust, failure, or the presence of workmanship problem.

1.2.3 PV solar waste generation

There is currently a heavy reliance on the availability of raw materials from natural resources throughout the manufacturing phase due to the fact that waste is generated at various phases of the solar panel's life cycle and there are no substantial waste recycling mechanisms in place. The generation of waste persists alongside the manufacturing of new PV panels. Although the cycle shown by the continuous line is an open cycle, the use of raw materials is reduced and

environmental responsibilities are also reduced when dotted lines are included

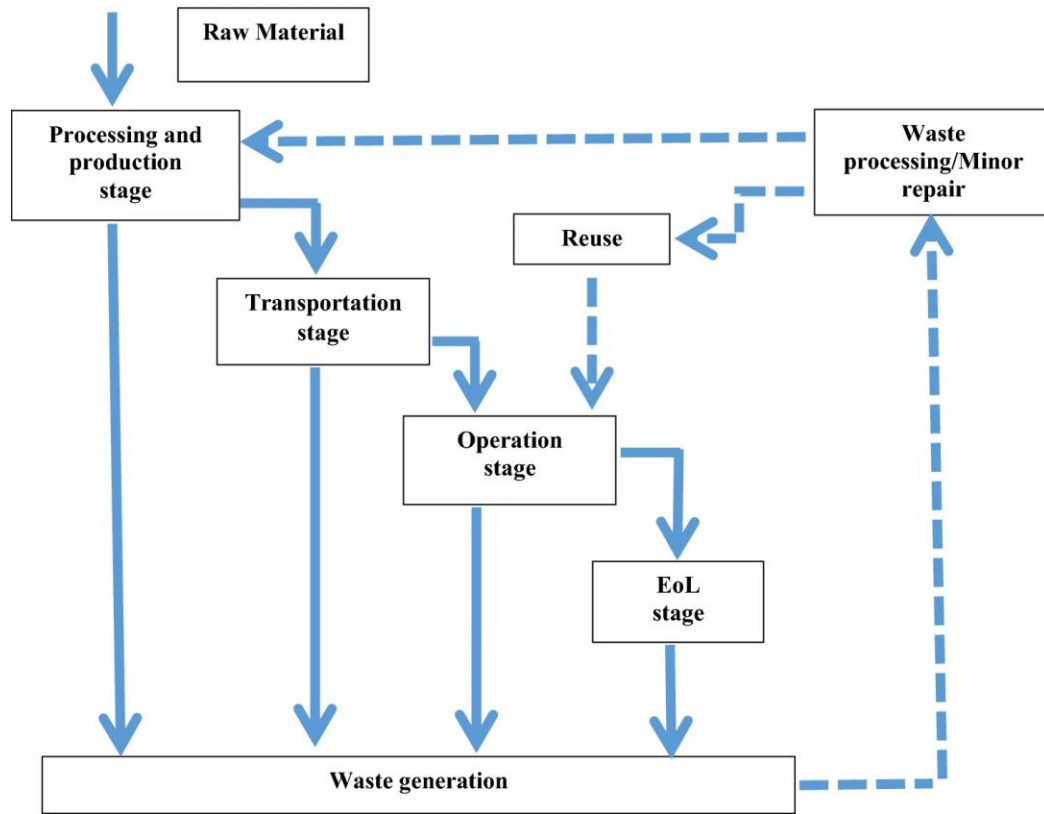


Figure 1.1 1: Stages of waste generation

Source IEA, (2016).

Figure 1.1 depicts the several phases of the generation of waste. The initial phase involves the processing and fabrication of PV panels, which generates a significant amount of waste due to the use of silicon and other elements that produce leftover scraps. Manufacturers are proficient in managing production waste, making it the least challenging type of trash to handle. Additionally, production waste does not pose a significant issue in terms of societal waste management (IEA 2016). The transportation phase also plays a role in the generation of garbage. Panels may sustain damage during their transportation from the manufacturing facility to the installation site, resulting from improper handling of the photovoltaic panels during the loading and unloading process.

In addition, improper installation methods combined with harsh weather events like hailstorms, floods, cyclones, and others may cause waste to be generated throughout the first and active phases of the life cycle of solar panels. The photovoltaic panels finally approach the end of their

useful life when their combined power output falls to less than 80% of the initial value declared at the time of production. The latter part of the solar PV module's life cycle, occurring after approximately 25-30 years, will result in the highest amount of trash generation. The significant surge in the deployment of photovoltaic (PV) capacity in recent years will therefore lead to a swift escalation in the quantity of panels approaching the end of their useful life phase. The depicted cycle in the solid line represents an open cycle. However, by incorporating dotted lines, the utilisation of raw materials is not only reduced but also the environmental impact is minimised. Currently, due to the lack of effective waste recycling methods, there is a strong reliance on natural resources for the supply of raw materials in the production process.

1.2.4 Global PV solar waste management

On a global scale, photovoltaic solar power has emerged as the predominant alternative source of electricity. According to IRENA and IEA-PVPS (2016), the PV markets in Europe experienced a growth rate of over 5%, while the PV capacity in Asia saw a significant increase of 50% in 2015. The worldwide manufacturing of solar panels has undergone a significant increase in recent years, propelled by the increasing focus on renewable energy sources and the rising need for environmentally friendly and long-lasting power. The global installed capacity of photovoltaic (PV) systems rose from 23.0 GW in 2009 to 207.9 GW in 2016 (EPIA, 2015). As nations globally endeavour to shift towards low-carbon energy systems, solar photovoltaic (PV) technology has emerged as a leading contender, providing a hopeful alternative to decrease dependence on fossil fuels. Germany now has the highest installed capacity among all countries. However, its share of global installation declined from 27% in 2011 to 20% in 2015 (EPIA, 2015). Nevertheless, this unparalleled surge in solar panel production presents unique difficulties, particularly in the domain of waste generation.

The manufacturing of solar panels entails an intricate network of suppliers that extends across multiple countries. China has emerged as the leading solar producing country, with its share of the global PV market increasing from 4% to 22% between 2011 and 2015. China now dominates the market with a significant portion of global production. The United States, India, and several European nations also had a substantial share of the global PV market. However, in 2014, there was a significant shift as Asia surpassed Europe and now represents 60% of the global market (Weckend et al., 2016). The growth of solar panel manufacturing has undoubtedly helped

decrease greenhouse gas emissions in electricity generation. However, it has also raised concerns regarding the environmental consequences linked to the production and disposal of these panels. The production process entails the utilisation of raw materials such as silicon, metals, and other semiconductors, some of which may have environmental and social ramifications associated with their extraction and processing.

While solar energy has various environmental advantages, the disposal phase of solar panels presents a significant challenge. According to the Chinese Association of Renewable Energy, China started producing solar-panel waste in 2015. The amount of waste will increase significantly from 2020 onwards, reaching a critical level around 2030. Consequently, the disposal and recycling of solar panels will become a crucial environmental concern in China for the next decade or so (Feng, 2011; Wang et al., 2014). As solar panels get older, there will be a significant increase in the number of panels that need to be decommissioned. This will result in a larger amount of waste being generated. It is estimated that by 2050, the total weight of end-of-life PV panels would be over 9.57 million tonnes (Monier and Hestin, 2011). The proper management of solar panels poses distinct difficulties owing to its makeup, which encompasses possibly hazardous substances (Xu et al, 2018). With the increasing amount of discarded solar panels, it is crucial to develop strong waste management plans, effective recycling methods, and global cooperation. This is necessary to protect the environmental benefits gained from using solar energy and prevent any harm caused by improper disposal practices (Eberspacher & Fthenakis, 1997).

The convergence of global solar panel production and the resulting waste generation highlights the significance of establishing all-encompassing, sustainable methods to handle the complete life cycle of solar PV technology. Multiple studies have asserted that policies driven by economic incentives are necessary to stimulate the development of sustainable methods in the PV industry (Besiou & Wassenhove, 2015; Tao & Yu, 2015; Zeng, Duan, Wang, & Li, 2017). A workshop report published in 1992 emphasised the importance for the photovoltaic (PV) industry to incorporate both Environmentally Conscious Manufacturing (ECM) and Design for Environment (DfE) principles in order to reduce environmental harm (Moskowitz & Zweibel, 1992). The research suggests that the PV sector should prioritise the design of easily disassembled modules that can be recycled by recyclers. Additionally, the materials used in these

systems should be recyclable. The industry should also focus on minimising waste generation throughout the manufacturing process and reducing the number of rejected modules through effective quality control measures (Moskowitz & Zweibel, 1992).

While Japan has also been a PV industry pioneer contributing to a lot of research and development in the PV industry, the Japanese PV market is small compared with other countries. Japan has no specific regulations for PV solar waste management hence all the waste generated is considered as or treated as general waste under the general waste management rules (Xu et al, 2018). However, the government of Japan through the Japanese Ministry of Economy, Trade, and Industry and the Ministry of the Environment have been working jointly to address the decommissioned energy equipment regulations since 2013 has increased its market of PV waste recycling projects under the New Energy and Industrial Technology Development Organization (NEDO) regulation. Long-term tests are expected in order to verify the performance at industrial scale (Xu et al, 2018).

Furthermore, the United States of America have engaged the solar manufacturers to finance or manage a product stewardship program for their sold units within the state. New York State also reintroduced the “Solar Panel Collection Act” in 2018 by working with manufacturers to collect and recycle the out of service solar modules in order to prevent PV waste from being disposed into landfills. However, this shows that before engagement they used to consider PV waste as general waste and disposed in landfills (Xu et al, 2018). In general, there are no specific regulations for PV waste on a national scale. California’s solar energy generating capacity is greater than any other state (U.S. Energy Information Administration, 2016), but the state has no documented research regarding PV waste management or stakeholders’ perspectives for EPR within the state. The DTSC is expected to list PV waste as universal waste, which will separate PV waste from the general hazardous waste and landfill classifications.

This lack of an effective PV waste management strategy suggests that more efforts are needed to investigate PV waste management in California and understand stakeholder perspectives with respect to EPR to protect human and environmental health and conserve resources. The exploratory nature of a case-based research design is a practical method to obtain direct information from the PV industry (Besiou & Wassenhove, 2015). Besiou and Wassenhove (2015) conducted their study by interviewing several global PV industry stakeholders—

manufacturers, installers, e-waste recyclers, and PV-related organizations. Research conducted by Hendrickson et al. (2015) used Geographic Information Systems (GIS) to optimize the dismantling facilities' location between collection points.

India is expected to encounter significant hurdles in determining the strategies to be employed for managing PV solar waste. Its disposal is seen as a neglected sector because of following regularized, unscientific informal approach of waste management (Sheoran, Sharma and Kuma 2020). India has implemented E-waste management laws in 2016 and 2011, which differ in terms of the provision of extended producer responsibility (EPR). The purpose of EPR is to ensure that electronic devices are recovered and safely recycled (CPCB, 2018). However, the regulations do not address the issue of solar PV waste, leaving room for the possibility that discarded PV modules may be improperly disposed of in unregulated or environmentally unsound methods, such as unlawful landfills or open areas. The absence of motivating factors, regulatory frameworks, and awareness regarding the significance of recoverable substances and their associated environmental implications pose significant obstacles in the secure management of PV waste material (EU 2021).

The Indian government uses the e-waste management rules of 2016 in the absence of other laws which guide on how the waste is supposed to dispose. India encounters difficulties in managing waste disposal at landfill sites, particularly in the case of e-waste. This leads to ground contamination, air pollution, and exacerbates the deterioration of groundwater quality. In addition, solar panels include lead components, and lead leaking into the environment causes habitat damage, the growth of plants and animals, and harmful health effects on the immune, kidney, neurological, and reproductive systems of humans. Additionally, it can lead to compromised cognitive growth in youngsters. Cadmium is a potent carcinogen that is strongly associated with the development of lung, prostate, and renal cancer (BTI, 2019).

1.2.5 Ways of PV solar waste management

While landfill may be the most convenient method for disposing of solar waste, it not only leads to the depletion of valuable resources but also incurs economic losses. Therefore, it should be considered the least favourable alternative when developing plans for solar waste disposal. Improper handling of PV waste can lead to the loss of valuable materials such as aluminium and

glass, which account for 88% of the total weight (Latunussa et al., 2016). In addition, the landfill will lead to the depletion of valuable and essential metals, including silicon metal and precious metals such as silver, which are renowned for their conductivity, albeit in limited quantities. The WEEE directive, which is based on Extended Producer Responsibility (EPR), promotes resource efficiency by advocating for the reuse, recycling, and reduction of waste disposal in landfills (Farrell et al., 2020).

For instance, the guidelines of Solar Energy Corporation of India Limited specify that the solar power developer must ensure proper disposal of all solar PV modules from their plant after they reach their end of life (EoL), in compliance with the electronic waste rules of 2011 as alerted by the federal government, and any subsequent revisions or amendments. Therefore, implementing a controlled approach to photovoltaic waste management has the potential to bring about environmental advantages and improve the circular economy by replacing the production of new materials with recycled materials. The subsequent segment examines the potential options for waste reduction in India, together with their associated constraints (Farrell et al., 2020).

In the context of Lusaka, Zambia, where solar potential is abundant, the adoption of solar PV energy is on the rise. However, as the solar PV industry expands, it is crucial to assess the implications of this transition on waste management practices. This research aims to explore the implications of transitioning to solar PV energy on waste management in Lusaka, Zambia. Zambia, like many other countries, recognizes the importance of renewable energy sources in mitigating climate change and achieving energy security (Makasa, 2018). Government initiatives and policies have been introduced to promote solar energy adoption, attracting investments, and increasing the deployment of solar PV systems in Lusaka (Mulenga et al., 2020).

The implications of transitioning to solar PV energy on waste management extend beyond waste generation and disposal. It is necessary to consider the entire waste management cycle, including collection, sorting, recycling, and the infrastructure required to handle electronic waste effectively. The existing waste management practices and facilities in Lusaka need to be evaluated for their capacity to handle the increasing waste stream associated with solar PV energy adoption (Mbvundula et al., 2016). The findings will provide insights for policymakers, waste management authorities, and stakeholders to develop strategies and policies that promote effective waste management in the context of solar PV energy adoption.

1.2.6 Solar panel recycling market

The market for recycling panels is still relatively new and growing steadily which has led to various researchers to actively start developing recycling processes that can economically recover most of the components from a solar panel. However with such in process, it has led some countries to implemented design laws to ensure the recycling of PV panels, which will take effect in July 2025 and Other countries are also focusing on addressing the management of PV waste. (Attila, 2023). Solar material globally has less market; however there has been a witnessed growth of solar panel recycling market. In 2022, the market was valued at £250 million. It is projected to reach £1.29 billion by 2028. As the amount of panel waste continues to increase, recycling these panels can offer a source of materials that would otherwise need to be mined, thereby contributing to a more sustainable approach towards solar energy. Currently, the state of solar panel recycling in the UK is relatively limited, with a few companies providing services and inadequate infrastructure to manage the rising volume of solar waste. Some notable firms offering recycling services in the United Kingdom are unable to

The United Kingdom has an estimated generation of 30,000 tonnes of waste over the next decade. Furthermore, there is an expected surge in panels hitting the market in the 2030s as older millennium era solar panels begin to deteriorate. This creates a demand for the panel recycling sector to expand its capabilities in managing the growing number of outdated panels and assisting in producing solar panels (Attila, 2023).

The transition to solar photovoltaic (PV) energy is gaining momentum in Zambia as a sustainable solution to mitigate climate change and reduce reliance on fossil fuels. Lusaka, the capital city of Zambia, is characterized by abundant solar resources, making it an ideal location for the adoption of solar PV energy. However, as the shift towards solar PV energy accelerates, it is essential to understand the implications of this transition on waste management practices in Lusaka. Zambia, like many other developing countries, faces significant challenges in its energy sector, including unreliable electricity supply and a heavy dependence on traditional energy sources (Makasa, 2018). Recognizing the potential of renewable energy, the Zambian government has implemented policies and initiatives to promote the adoption of solar PV energy. For instance, the Scaling Solar Program has attracted investments and facilitated the development of solar power projects in the country (Mulenga et al., 2020).

While the environmental benefits of transitioning to solar PV energy are evident, it is crucial to assess the implications for waste management. The growth of the solar PV industry introduces new waste streams, primarily from the disposal of PV panels and batteries at the end of their operational life (Asghar et al., 2021). These panels often contain hazardous materials, including lead, cadmium, and other potentially toxic substances, necessitating proper waste management to prevent environmental contamination and health risks (Asghar et al., 2021; Sander et al., 2020). The existing waste management infrastructure and policies in Lusaka may not be adequately prepared to handle the increasing waste stream from solar PV systems. Challenges such as inadequate recycling facilities, limited awareness of electronic waste regulations, and insufficient funding for waste management infrastructure have been identified (Mbvundula et al., 2016; Thomson et al., 2013). Therefore, it is imperative to assess the readiness of waste management practices and infrastructure to effectively manage the growing volume of PV waste.

Analysing the implications of transitioning to solar PV energy on waste management in Lusaka is crucial for developing sustainable waste management strategies and policies. It requires a comprehensive understanding of waste generation from PV systems, the environmental and health impacts associated with PV waste, and the capacity of the waste management system to handle this waste stream effectively. By conducting research on this topic, valuable insights can be gained to inform decision-making processes and guide the development of appropriate waste management strategies in Lusaka. This will contribute to the overall sustainability of the solar PV industry and support the transition towards a cleaner and more environmentally friendly energy system (World Bank Group, 2020).

The rapid increase in current solar panel installation in Zambia will cause massive production in quantity of PV waste in nearby future. Since it is a large volume of waste which is hard to recycle, the trouble of solar waste discarding will detonate with full force and wreck the environment. The waste PV has the ability to generate a perilous waste management problem because the substances present in PV panels can leak into soil and groundwater creating environmental pollution and safety concern (World Bank Group, 2020).

According to Oteng et al. (2021), the end-of-life and waste management of solar panels have not received enough attention in the developing field of negative environmental repercussions of solar systems. This research aims to close this gap and by conducting research on this topic,

valuable insights can be gained to inform decision- making processes and guide the development of appropriate waste management strategies in Lusaka. This will contribute to the overall sustainability of the solar PV industry and support the transition towards a cleaner and more environmentally friendly energy system.

1.3 STATEMENT OF THE PROBLEM

To address the global energy demands of the future, there has been a significant increase in the production of solar energy systems in the last decade. The energy from renewable sources, specifically the solar photovoltaic (PV), has undergone significant growth due to increasing energy demand and decreasing material production prices (Mahmoudi et al., 2019a, b; Nain & Kumar, 2020b). Within the next century, solar photovoltaic electricity is predicted to overtake other energy sources as the world's main source (Xu et al., 2018; Hosseini-Fashami et al., 2019) and clearly Lusaka's switch to solar photovoltaic (PV) electricity has the potential to transform the energy industry and lessen the negative environmental effects of conventional energy sources. However, solar panel disposal presents a significant threat to the environment due to its intricate makeup and potential for the release of harmful materials into the environment (Chancerel et al., 2017). Owners face significant challenges in resolving these difficulties due to their lack of knowledge regarding panel management (Goe and Gaustad, 2016a; Oteng et al., 2021).

Nain and Kumar (2020c) emphasise the necessity of assessing the potential hazards to both the environment and public health, in addition to the consequences of releasing metals into landfills and their fate in actual environmental conditions. This is particularly important due to the growing number of decommissioned solar panels that require appropriate disposal. Hence, recycling is typically advised as a means to avert the transmission of adverse effects to individuals and the environment (Choi and Fthenakis, 2010). Recycling is not, however, practised in Zambia. Motta et al. (2016) found that there is limited focus on evaluating the improper disposal of solar PV systems and the resulting environmental hazards. This study's primary goal is to assess the potential impending implications of transitioning to solar PV energy on waste management in Lusaka, which remain un-investigated, as there are no studies that show peoples readiness to the PV solar energy technology transfer and its benefit. The results of this

study will improve knowledge about policy formation, proper disposal, and recycling of solar PV. It backs Zambia's efforts to shift to sustainable energy and protect the environment.

1.4 RESEARCH OBJECTIVE

Main objective

The main aim of the study is to assess potential negative implications of transitioning to solar PV energy on solar panels waste management at the end of shelf life in Lusaka.

Specific objectives

1. To ascertain the extent of adoption of solar PV in Lusaka.
2. To determine the waste management challenges of PV solar in Lusaka.
3. To develop a Strategic Framework for Solar Photovoltaic (PV) waste management.

1.5 RESEARCH QUESTIONS

- i. What is the extent of adoption of solar PV in Lusaka?
- ii. What are the existing waste management challenges of PV solar in Lusaka?
- iii. What Strategic Frameworks for Solar Photovoltaic (PV) waste management are available?

1.6 SIGNIFICANCE OF STUDY

The study will address key issues in waste management, as supported by relevant literature. The findings will contribute to the existing knowledge and have practical implications for policymakers, waste management authorities, and stakeholders in the following ways:

- i. **Policy Development:** The research will provide valuable insights into the implications of transitioning to solar PV energy on waste management, enabling policymakers to develop informed policies and regulations that address the specific waste management challenges associated with solar PV systems (Makasa, 2018). It will assist in formulating sustainable waste management strategies that align with the goals of the energy transition. Zambia's energy policies need to be

operationalized and refined in practice to have the desired impact on clean energy investments. There is a need to restructure power sector institutions and adjust electricity tariffs to improve the performance of the sector. There is a need for a truly open-access market regime and regulations including a transmission pricing methodology that guarantees equal access to the grid for all actors. Zambia's Power Development Framework (ZPDF) should be revised to reduce project risks and check for consistency with other national regulations

- ii. **Infrastructure Planning:** By assessing the readiness of the existing waste management infrastructure, the study will guide the planning and development of necessary facilities and systems to handle the increasing waste stream from solar PV energy adoption. This includes improving waste collection, sorting, recycling, and disposal facilities (Mbvundula et al., 2016). The research will support infrastructure investments that are aligned with sustainable waste management practices.
- iii. **Environmental Protection:** Understanding the environmental impact associated with the waste generated from solar PV systems is crucial for effective environmental management. The research will help identify potential environmental risks and guide the implementation of measures to minimize pollution and contamination caused by the disposal of PV panels and batteries (Asghar et al., 2021). It will promote the sustainable integration of solar PV energy while safeguarding the environment.
- iv. **Health and Safety Considerations:** The study's insights into the health risks and hazards associated with solar PV waste will contribute to ensuring the safety of waste handlers, nearby communities, and the public. It will facilitate the adoption of proper waste management practices, including appropriate handling, recycling, and disposal methods, to minimize potential health impacts (Sander et al., 2020).
- v. **Sustainable Development:** By exploring sustainable waste management strategies, the research will highlight opportunities for resource recovery, circular economy approaches, and job creation within the waste management sector (Makasa, 2018). It will support the overall goal of achieving sustainable

development in Lusaka, Zambia, by integrating solar PV energy and waste management practices effectively.

- vi. The significance of this research lies in its potential to inform decision-making processes, guide policy development, and foster sustainable waste management practices in the context of transitioning to solar PV energy in Lusaka, Zambia. By addressing the implications of this transition on waste management, the study aims to contribute to a more sustainable and environmentally conscious energy future.

1.7 SCOPE OF THE STUDY

The study focused specifically on the waste generated from solar PV systems particularly PV panels and how they are managed in Lusaka. It is important to note that the scope of this study was limited to the negative implications of PV solar waste management in Lusaka. The population of study was conducted in selected parts of Lusaka namely Kanyama and woodlands. The two were used to validate the assessment of the results. The research primarily relied on data and information specific to Lusaka and the extent of usage and disposal of the PV solar. Questionnaires were administered to selected residents of both Kanyama and Woodlands areas. Another set of questionnaires were administered to key informants from local waste management authorities in Lusaka, such as Lusaka Integrated Solid Waste Management Company Limited (LISWMCL), Zambia Environmental Management Agency (ZEMA), renewable Energy Experts, Professionals or researchers with expertise in renewable energy, Waste Management Service Providers involved in waste collection, recycling, and disposal services in Lusaka.

1.8 KEY TERMS AND CONCEPTS

1.8.1 Solar energy

The sun's rays are used in solar energy systems to generate electricity or heat. Solar energy can be utilised directly or indirectly, according to Samo (2012). Using a photovoltaic cell, a direct system can convert solar energy directly into electricity.

1.8.2 Solar photovoltaic (PV)

Solar photovoltaic (PV) systems directly convert solar energy into electricity without the aid of any machines or moving parts. According to Parida et al. (2011) and Hosenuzzaman et al. (2015), it is an endless source of energy. Regional limitations do not apply to the installation of solar photovoltaic equipment in rural places, deserts, or on roofs (Chen 2014; Grossmann et al. 2013).

1.8.3 Waste management

Waste management refers to the collection, transportation, treatment, and disposal of waste materials in an environmentally and socially responsible manner to minimize the negative impacts on human health and the environment (UNEP, 2005). It involves various processes, including waste generation, segregation, recycling, reuse, and appropriate disposal methods.

1.8.4 Environmental impact

Environmental impact refers to the effect of human activities on the environment, including the physical, chemical, and biological changes that occur as a result of these activities (USEPA, 2020). It encompasses the alterations in ecosystems, natural resources, air quality, water quality, soil health, biodiversity, and overall environmental sustainability.

1.8.5 Waste management infrastructure

Waste management infrastructure refers to the physical facilities, systems, and structures that are put in place to manage and handle waste effectively and safely (EC, 2004). It encompasses a wide range of components, including waste collection systems, transfer stations, recycling facilities, treatment plants, landfill sites, and associated equipment and technologies.

1.8.6 Waste generation

Waste generation refers to the process of producing or creating waste materials because of human activities, consumption patterns, and production processes (UNEP, 2011). It encompasses the initial production and accumulation of waste before any waste management practices are implemented.

1.9 DISSERTATION OUTLINE

The study has seven thematic chapters and the outline below shows the summarized highlights of each chapter:

Chapter One

The problem statement of the study and how useful it will be in filling the study gaps are highlighted in the first chapter of the study, which also includes a section where the research objectives have been very carefully outlined, research questions have also been discussed, and the justification and scope of the research. The study's essential concepts were also defined and covered in this chapter for ease of understanding

Chapter Two

A thorough analysis of the body of research on waste management and solar PV energy is presented in the second chapter. It looks at waste management practices, highlighting any gaps and difficulties that could emerge during the transition to solar PV electricity. Other academic works have also been cited in this chapter. This chapter has examined the conceptual and theoretical underpinnings of the study.

Chapter Three

Theoretical and Conceptual Framework: This chapter provides a comprehensive overview of the theoretical and conceptual framework that is relevant to the investigation.

Chapter Four

Research methodology: This section specifies the chosen approach for conducting the study and outlines the specific strategy to be employed throughout the research process. The text discusses several aspects of the study, including the research approach, research design, study philosophy, epistemology, ontology, study population, sample size, data collection tools, data analysis methods, reliability, validity, and ethical considerations.

Chapter Five

Data Finding and Presentation: delivers a comprehensive presentation of the study's findings, which are derived from questionnaires and key informant interviews conducted with eligible respondents. The analysis of responses will rely on the perceptions of specifically chosen participants on the variables that were determined. This analysis will be conducted using the Microsoft Excel software package.

Chapter Six

Discussion and Analysis: This section examines the significance of the research findings in relation to the existing knowledge about the research problem being investigated. It provides a thorough analysis and interpretation of the study findings, and elucidates any new insights gained about the research problem as a result of considering the research findings. This chapter will establish a connection between the introduction, research questions, and the examined literature. To be specific, the discussion focused on addressing the research questions.

Chapter Seven

The research's main conclusions are outlined in the last chapter, which also highlights any potential drawbacks for Lusaka's waste management from transitioning to solar PV energy. To promote a sustainable and well-managed transition to solar PV energy, it finishes with recommendations for policymakers, waste management authorities, and other stakeholders

1.10 CHAPTER ONE SUMMARY

In conclusion of this chapter, the researcher has provided and explained the background to the study, statement of the problem, and significance of study, the research objectives, research questions, and scope of the study. Next chapter, the researcher reviews the literature review, theoretical framework and conceptual framework to the study

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents the background against which the study was conducted, as well as a comprehensive examination of pertinent literature. The adoption of solar energy for power generation has experienced a significant and rapid increase during the past decade. The global cumulative solar power capacity reached around 600 GW (Gigawatt) by the end of 2019. Anticipated growth is the sole expectation for this share.

PV panels are expected to have a higher potential, even though the present life of solar panels, which is approximately 25 years, is a good number to sustain investors' interests. This leads to an overwhelming desire to invest in the possible recycling of solar panels, creating a demand and the necessity for the creation of policies that govern the obligations of key players. The driving force behind this motivation was a grave worry about the volume of waste that solar panel disposal was expected to produce (Majewski et al, 2021). This necessitates an assessment of the potential impending negative implications of transitioning to solar PV energy on waste management in Lusaka, a city experiencing rapid modernization and growth.

The objective of this study is to gain a comprehensive comprehension of the level of adoption of solar systems and the challenges encountered in managing waste from PV solar panels. Furthermore, the global stance on the development of a Strategic Framework for managing solar panel waste will be addressed.

2.2 OVERVIEW

The global adoption of renewable energy technology for the production of electricity has been steadily increasing, and this is mostly due to the growing use of solar photovoltaic panels. In an attempt to increase the generation of clean energy worldwide, the use of PV electricity has increased dramatically over the last few decades and has a huge market potential. According to Bachiya et al. (2014), PV power is predicted to generate a sizable amount of electricity consumed

globally and rank among the main global energy sources this century. To boost the PV business, developed nations like the US, Japan, and Germany have started implementing expansive strategies for PV development (Chi et al., 2014). From 1 GW (GW) in 2004 to 57 GWs in 2015, the global demand for PV electricity grew at an annual growth rate of over 20%, outpacing that of any other industry, including other developing renewable energy sectors. It has been predicted that in the future, photovoltaic electricity will lead the way in new energy development (Luo et al., 2008; Winneker, 2013).

2.3 THE EXTENT OF ADOPTION OF SOLAR PV

The use of solar photovoltaic (PV) systems has experienced substantial increase, both globally and at regional levels. The growth of the solar industry is driven by the pressing demand for renewable energy and the growing competitiveness of solar technology (Bakhiyi et al., 2014). Globally, there has been a significant and rapid increase in the installation of solar photovoltaic (PV) systems. According to the International Energy Agency (IEA), solar capacity expanded by more than one hundred gigawatts in 2019 alone (IEA, 2020). An estimated 580 GW of operational solar PV power will exist by the end of 2019 (IRENA, 2020). China leads the world in the percentage of PV panels installed 35.3% ahead of the United States (19%), Japan (10.6%), Europe (19%), and India (6%).

Based on 2019 estimates, the global photovoltaic (PV) output is estimated to be slightly below two billion solar panels (Majewski et al, 2021). This is indicative of a global trend towards renewable energy sources as countries pledge to lower their carbon emissions. Conversely, solar panels provide an additional environmental concern after they reach the end of their lifespan, as they transform into a type of hazardous waste. Even though sizable portions of the original batch of solar panels placed are now being retired, recycling waste panels was not a worry during the first 25 years of their development because solar panels have a lengthy lifespan. Furthermore, according to IRENA's report in 2016, it is estimated that by 2030, China, Germany, and Japan will be the top three countries with the highest cumulative projected photovoltaic waste. By the end of 2050, China is projected to continue hold the highest quantity of waste, while Germany is surpassed by the United States of America (US). Japan is the subsequent country, with India following, as illustrated in figure 2.1 below. This demonstrates the increasing significance of

effectively managing the disposal of solar panels at the end of their lifespan, as highlighted by Aman et al. (2015).

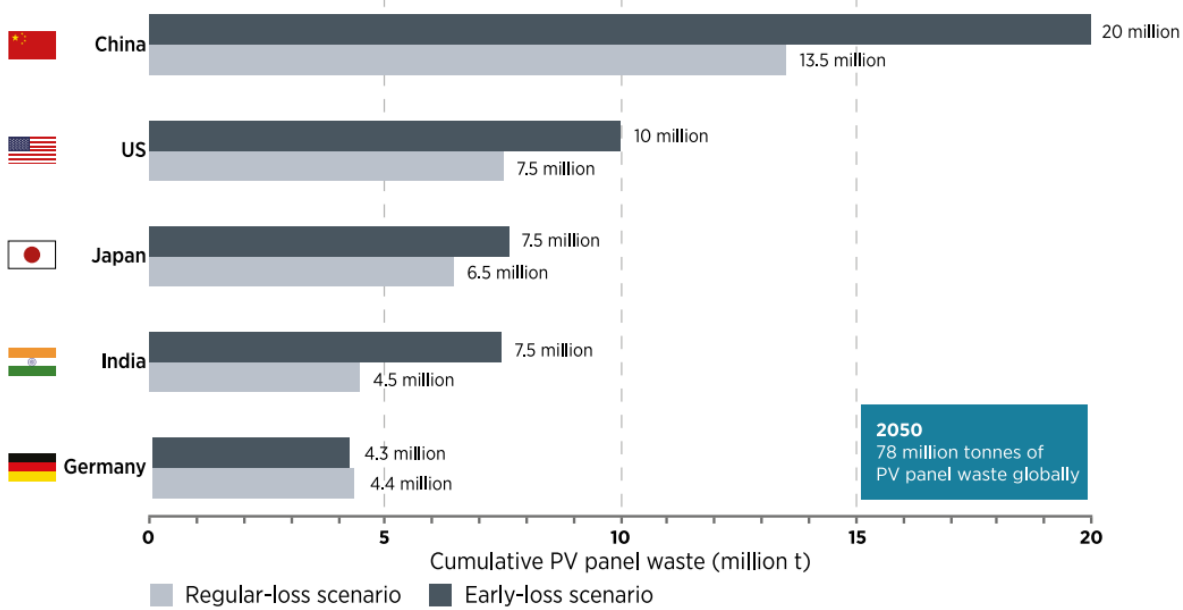


Figure 2.1 1: PV panel end-of-life waste quantities cumulatively for the top five nations by 2050 (IRENA, 2016)

The expansion of solar-friendly regions has been significant on a regional scale. To boost the PV business, developed nations like the US, Japan, and Germany have started implementing expansive strategies for Solar PV systems development (Chi et al., 2014). Solar energy demand grew at a pace of over 20% per year, surpassing that of all other businesses, including other developing renewable energy sectors, from 1 gigawatt (GWs) in 2004 to 57 gigawatt (GWs) in 2015. PV power is projected to be the dominant form of renewable energy generation in the years to come, according to suggestions made by Luo et al. (2008) and Winneker (2013). In 2020, the European Photovoltaic Industry Association (EPIA) stated that the total solar power capacity exceeded 130 gigawatts. Germany, Spain, and Italy were the leading countries in this regard (Solar Power Europe, 2021).

Germany and Australia exhibit the highest per capita adoption of solar photovoltaic (PV) power, considering the mean output of a typical solar Photovoltaic panel (Majewski et al., 2021). According to the Energy Balance Sheet of 2016, there are already more than 4 million tonnes of photovoltaic (PV) panels erected in Europe. This depicts the expected 43,500 tonnes of waste

solar panels will create when they eventually ought to be changed in the next several years. It is projected that by 2050, almost 60 million tonnes of EoL photovoltaic panels will have joined the world's waste pool if nothing changes (Weckend et al., 2016) as shown in figure 3. The amount of waste generated worldwide by disposing of photovoltaic (PV) panels is seen to be increasing for every region. Asia is projected to make the largest contribution, with over 25 million tonnes of photovoltaic panel waste. This raises the question of what would happen if there was a substantial amount of disposal and if anything ought to be done to stop it.

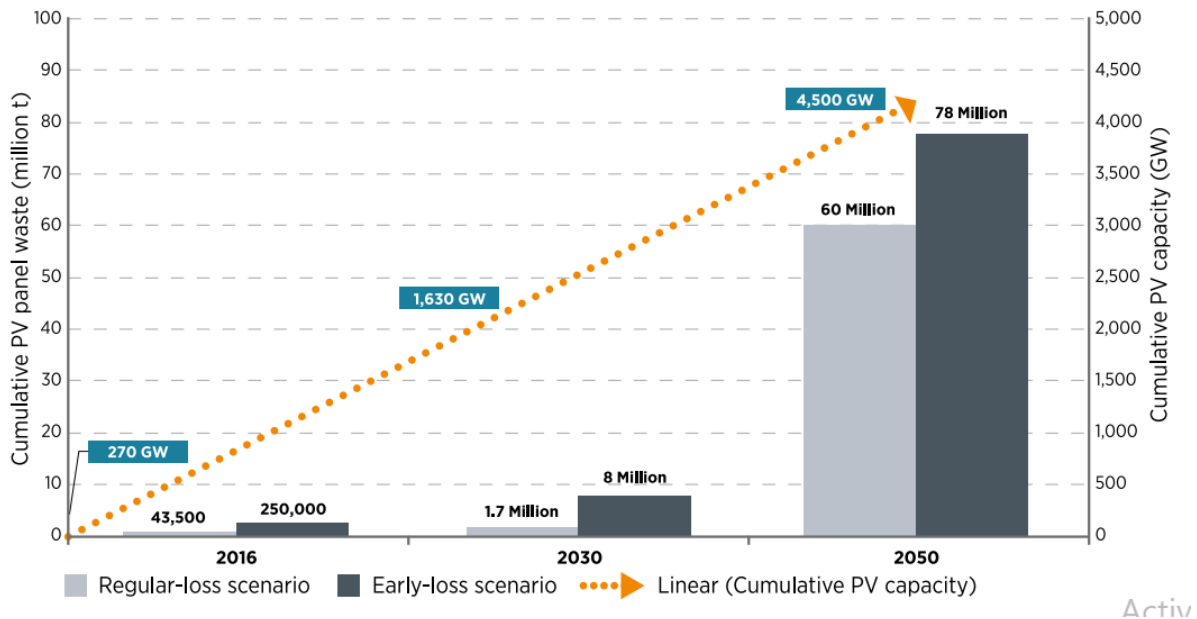


Figure 2.2 1: Global solar panel waste projection up to 2050 (IRENA, 2016)

In 2020, the United States installed a record breaking 19.2 gigawatt of solar power, setting a new record for the country in North America (SEIA, 2021). Similarly, China and India, both Asian nations, have made significant investments in solar photovoltaic (PV) technologies. China, in particular, stands as the world's largest solar market, having expanded its solar output by more than 48 GWs in 2020 (IRENA, 2021). The expansion in this specific area can be ascribed to causes such as government subsidies, declining costs of solar panels, and increased public awareness of the environmental advantages of solar energy. Nevertheless, there are still obstacles to overcome, such as the incorporation of solar Photovoltaic systems into existing power grids, the development of efficient energy storage solutions, and the formulation of effective policies. These issues underscore the significance of on-going collaboration at both global and regional

levels to fully harness the potential of solar photovoltaic systems in the shift towards cleaner and better renewable power resources.

On the other hand, Zambia's adoption of solar photovoltaic (PV) systems has also been rising rapidly in recent years due to the nation's dedication to boosting renewable energy sources, resolving issues with electricity access, and lowering its carbon footprint. Through programmes like the Scaling Solar programme, which aims to enable private investment in solar projects, Zambia's government has demonstrated support for the use of solar energy (World Bank, 2021). To improve access to electricity for underprivileged populations and off-grid locations, the Zambian Electricity Supply Corporation (ZESCO) has also been supporting small-scale solar systems (ZESCO, 2021). Zambia's energy policy, as outlined by the Government of Zambia in 2019, prioritises renewable energy and sustainability, which is shown in the increasing usage of solar power. Nevertheless, there remain obstacles to be surmounted, including the requirement for enhanced legislative frameworks, increased financial accessibility, and the construction of infrastructure to provide effective grid integration and energy storage. Zambia's adoption to solar usage has been influenced by the density of the population of a town below shows the main towns that are using PV solar system in households and commercially.

2.4 SOLAR PV WASTE MANAGEMENT CHALLENGES

2.4.1 Technological Challenges

The separation of encapsulant layers has consistently presented a notable technological obstacle in the recycling of photovoltaic (PV) components. The encapsulant protective function necessitates exceptional durability to safeguard PV cells from exterior factors and harm. Therefore, the encapsulant presents significant challenges for recycling operations in completely removing the encapsulant from the glass (Farrel et al, 2020). Extensive study is being conducted on the use of various methods, such as thermal or severe chemical treatments. Furthermore, the encapsulant and back sheet foils possess duopolistic characteristics, rendering them incapable of dissolution or melting without undergoing disintegration. As a result, these components cannot be recovered for recycling and typically break down into toxic emissions during treatment. Another problem is the intricate nature of recycling various types of materials included in a PV module.

The hermetically sealed configuration of a photovoltaic module adds complexity to the recycling procedures. Nevertheless, the PV modules contain other metals such as Si, Ag, Cd, and Te, which necessitate further and more sophisticated methods of extraction. In addition, in order to lower the cost of PV technology, PV manufacturers opt to reduce the concentration of valuable elements in the PV modules, resulting in a higher utilization of "earth-abundant" materials in the modules. The researchers noted that the recycling process for these novel modules is more intricate because of their multi-element design strategy (Farrel et al, 2020). Moreover, the diminished quantity of precious materials diminishes the end-of-life (EoL) values of these modules, resulting in a reduced probability of recycling. Technological advancements in PV modules alter their material composition, thereby influencing the necessary recycling treatments. Additionally, the diverse PV modules available in the market vary in dimensions, cell types, and module structures, requiring customized recycling processes to ensure appropriate treatment. This matter exacerbates the establishment of photovoltaic (PV) recycling infrastructure (Farrel et al, 2020).

2.4.2 Financial challenges

The financial obstacle presented by recycling photovoltaic (PV) resources is primarily the collecting and transportation system for end-of-life PV panels. The collection phase of EoL photovoltaic panels poses a significant challenge, particularly when PV installations are widely scattered throughout a vast geographical expanse and located at a considerable distance from the storage or recycling facility. The expenses associated with gathering and conveying these photovoltaic modules are significant, as a large amount of area needs to be covered. Establishing appropriate collecting networks requires making informed decisions on the participants in the reverse-logistics network, as well as determining the optimal locations and capacities of the relevant facilities. Hence, there is an additional difficulty in improving the placement of the collection and recycling facilities to improve the efficiency of transportation while minimising expenses. Additionally, the coordination among various photovoltaic waste management organisations participating in the collection and transportation system may present a difficulty for PV recycling (Mahmoudi et al., 2021).

Furthermore, the significant expenses related to the gathering, transportation, treatment, as well as shipment of PV waste provide a major obstacle in the handling and management of PV solar

waste universally. The small quantity of off-grid solar goods hinders the financial sustainability of recycling and collection operations, resulting in reduced economies of scale (Mahmoudi et al., 2021). Many countries face budgetary constraints or short financing cycles from organisations or within their own government. In addition to the significant expenses linked to producer-led take-back programmes, particularly in remote displacement areas.

2.4.3 Policies and legislation

A significant hurdle in managing end-of-life waste from solar photovoltaic (PV) systems is the absence of nationally mandated rules that enforce and encourage proper PV solar waste management in the nations where these systems are installed. Inadequate waste management practises and the absence of solar PV waste management initiatives in various host countries pose a significant challenge. Additionally, the lack of private actor involvement in displacement settings hinders the development of financially viable solutions, given the limited funds available, low purchasing power, and restricted employment opportunities for displaced communities (Majewski et al., 2021).

Similar to Zambia, India lacks specific legislation to regulate the management of end-of-life solar modules. However, the Indian government has implemented the e-waste (Management and Handling) Rules of 2011, which were revised in 2012, 2016, and 2018. The changes mandated that makers and importers establish a comprehensive strategy for managing and transporting electronic waste to recycling facilities. Regrettably, the government omitted solar PV cells and modules from the draught e-waste guidelines on May 19, 2022. PV modules were excluded from the category of e-waste, as the classification of e-waste was limited to IT, telecom, and consumer devices. Consequently, the end-of-life (EoL) modules are either disposed of in landfills or undergo processing with reduced rates of recovery (Mahmoudi et al., 2021).

2.4.4 Environmental/social planning

One of the problems most nations have with PV solar waste, particularly in developing nations, is environmental planning for towns and cities. The actual collections of waste, recycling, and vendors availability are all constrained in the cities. There is a lack of sufficient waste collection, waste treatment and recycling plants as well as vendor to provide services. This lack of recycling plants that adhere to minimum requirements, prolonged storage periods for solar lanterns due to

the accumulation of products for possible emergencies, leading to battery degradation and reduced product lifespan, result in a higher rate of solar photovoltaic waste generation (Mahmoudi et al., 2021).

2.4.5 Environmental Challenges

Recycling PV modules may result in higher environmental implications relative to landfills disposal, primarily attributed to the energy utilized throughout treatment operations. In their study, Vellini et al. (2017) found that reusing modules resulted in a small rise in some environmental effect indicators, such as global warming potential (GWP) by 4.71%, abiotic depletion fossil potential by 4.19%, and ozone layer depletion potential (OLDP) by 3.42%. A greater reliance on fossil fuels to power recycling operations was the primary cause of the increase in these indices. In addition, the recycling process for copper indium gallium selenide (CIGS) modules, which includes the recovery of metal treatment, has a greater negative effect on the environment in terms of acidification potential (AP) when compared to landfilling and traditional recycling of PV solar waste. This is mostly because, in high-value recycling as opposed to bulk recycling, the metal recovery stage requires a greater amount of energy and raw materials (Vellini et al, 2017). Yin and Hao (2009) found that pyrolysis, or thermal treatment, requires more energy than chemical and mechanical treatment because it requires greater temperatures in order to effectively disintegrate the ethylene/vinyl acetate (EVA) encapsulant.

The primary sources of hazardous compound emissions are the thermal disintegration and chemical processing of EVA. Etching solutions used in chemical treatment frequently contain perilous substances, such as nitric acid, which have the ability to produce poisonous vapours. If these emissions are not appropriately handled, they may cause adverse impacts on human health in addition to environmental problems like acid rain. Research has revealed that the harmful cancerous effects on human health resulting from the use of hydrogen peroxide in the recycling of PV panels were not counterbalanced by the environmental benefits of recovering materials. Therefore, in order to stop more environmental deterioration and health concerns to humans, these chemical wastes need to be collected and disposed of properly. Furthermore, the thermal treatment of delamination, although it avoids the use of chemicals, can release harmful gaseous molecules that necessitate appropriate handling. Acetic acid, propene, ethane, and hexene-1 are among the chemicals released when the EVA polymer degrades thermally, leading to gas

emission. In addition, the polymer back sheet of c-Si PV module, known as Tedlar, emits fluorine-containing chemicals like HF when it undergoes heat disintegration (Majewski et al., 2021).

2.5 STRATEGIC FRAMEWORK FOR SOLAR PHOTOVOLTAIC (PV) WASTE MANAGEMENT

Although there is a global need for a comprehensive framework to handle the establishment of recycling facilities and standards for managing solar waste, the attention has been limited to specific regions (Mahmoudi et al., 2021). Regulations in countries like the United Kingdom and European Union require the recycling of solar photovoltaic (PV) panels once they reach their maximum lifespan. Meanwhile, countries like Australia and Japan are actively pursuing similar legislation (Majewski et al., 2021).

2.5.1 Current regulatory status

All the PV solar components will now fall under the waste electrical and electronic equipment categories after the European Union formally changed the (WEEE) guideline in July 2012. In the future, solar PV components will be incorporated into the electronic waste management system, and it will be mandatory to gather and recycle them (Bio Intelligence Service, 2011; McDonald and Pearce, 2010).

Due to wear or damage, every photovoltaic module that have hit the end of their useful life and whose guarantee has expired must be appropriately disposed of, according to the recently implemented PV waste management laws (Czanderna and Pern, 1996). In addition, a recycling charge must be paid by all PV panel producers who supply parts to the European market. However, very few nations outside of the EU are acting. This is mainly due to the very small amount of waste photovoltaic panels that may be recycled, as well as the expensive cost of recycling the panels, which makes the process not economically viable (Yamashita et al., 2003; Wambach, 2004). The processing and recycling of photovoltaic panels is a relatively new topic that requires more study and development, and there are just a few facilities in the world dedicated to this task.

However, in the case of Zambia, this issue has not received the necessary attention, raising concerns about the country's preparedness to manage the growing accumulation of solar panels, which poses potential risks to the environment and human health. In order to provide an economically viable environment for PV waste management, lawmakers must implement appropriate regulations and laws, as well as research and development initiatives, financial incentives, and end-of-life PV treatment. Factors such as the valuable materials present in solar PV waste, the availability of nearby recycling facilities, and the amount of end-of-life panels in specific locations are crucial for determining the economic viability of managing solar PV waste. This is also applicable to the situation in Zambia. Presently, there are on-going endeavours to recycle solar photovoltaic (PV) waste, with certain corporations establishing recycling facilities on a global scale. Australia serves as a notable illustration of this which involves establishing a reverse logistics network and collecting system to handle the recycling and recovery of discarded solar panels in Australia (Oteng et al, 2022).

Rooftop solar panels are gaining popularity in Zambia due to, their ability to provide decentralised electrical access, reduce reliance on fossil fuels, and enhance energy security (World Bank, 2018). This decision is in line with Zambia's larger dedication to the Sustainable Development Goals of the United Nations, particularly SDGs 13 and 7, which are focused on climate action and affordable and clean energy, respectively (UNDP, 2020). Adoption of solar power has positive effects on the environment, society, and economy, putting Zambia on the path to a more secure and sustainable energy future. Nevertheless, Zambia continues to encounter obstacles such as initial costs and regulatory frameworks.

2.5.1.1 Informal Handling of PV Waste

Despite some portions of the PV panels being extracted and recycled, a significant portion of the waste is treated informally, leading to the accumulation of waste in landfills and polluting the surroundings.

2.5.1.2 Limited Market for Reusing Recycled PV Waste

The market to reuse recycled PV waste is currently extremely small in India due to a lack of suitable incentives and schemes in which businesses can invest. The lack of central insurance or regulatory body to protect against financial losses incurred in waste collection and treatment.

2.5.1.3 Lack of Specific Guidelines for PV Waste Treatment

Simply clubbing PV waste with other e-waste could lead to confusion, and there is a need for specific provisions to be formulated and implemented within the ambit of the e-waste guidelines. Need for specific provisions for PV waste treatment within e-waste guidelines to avoid confusion.

2.6 INITIATIVES TO IMPROVE PV WASTE MANAGEMENT

The global adoption of solar (photovoltaic) energy signifies a favourable shift towards sustainable and renewable energy sources. However, it is crucial to comprehend the complete magnitude of these energy requirements. It is necessary to comprehend the production, use, and eventual management of photovoltaic (PV) panels in the city of Lusaka, Zambia as their useful lives are coming to an end. In addition to posing a risk to human and environmental health, PV waste is a loss of precious materials that could be recycled back into the manufacturing sector.

2.6.1 Germany

The German market for photovoltaic waste has matured over time, with the implementation of EU rules specifically targeting this type of waste. The growth of waste projection in Germany began in the 1990s. During that decade, the initial assistance programmes were implemented, specifically aimed at residential applications, and there were scientific evaluations of the practicality of grid-connected, decentralised rooftop photovoltaic (PV) systems. An instance of this is the 1,000 Rooftop Programme, as mentioned by Hoffmann in 2008. The rooftop PV support scheme was expanded to include 100,000 roofs in the early 2000s, ultimately resulting in the promotion of renewable energy.

2.6.1.1 National regulation

In October 2015, Germany implemented a nationwide registration system to effectively handle photovoltaic (PV) waste. This was done by incorporating the updated EU WEEE Directive into German Law through an amendment to the Electrical and Electronic Equipment Act (Elektroaltgerätegesetz or ElektroG). The legislation mandates the gathering and reprocessing of photovoltaic (PV) panels and it has been in force since 2015. Germany's handling of electronic waste is overseen by the Stiftung Elektro Altgeräte Register (Stiftung EAR), which serves as the

National Register for waste Electrical Equipment. Stiftung EAR was established by producers during the introduction of the original WEEE Directive.

In addition to the execution of WEEE, a directive that addresses the process of collecting, recovering, and recycling PV panels, Germany has implemented a distinct collection category for PV panels, ensuring that waste panels are collected and treated separately at municipal collection points. This allows every owner of a PV solar panel to easily dispose of their panel at the municipal council collection point without incurring any costs. This initiative specifically benefits private customers who own residential PV systems.

2.6.2 India

In the absence of specific regulations for managing waste from photovoltaic (PV) panels, the Indian government and its solar industry have adopted the E-Waste Management Rules 2011 as a guiding law. The e-waste management and handling rules, 2011 which are notified by the government and are periodically revised and amended; for example, make sure that all solar PV modules from their plant are disposed of in compliance with them after their EoL when they become defective, non-operational, or non-repairable. The requirements of Solar Energy Corporation of India Limited for establishing grid-connected solar PV facilities stipulate that the solar power developer must verify their adherence (Sharma et al., 2023).

2.6.2.1 Reduce

India has implemented a waste management plan focused on reduction, with the main principle being to minimize the amount of waste generated. The volume of solar waste can be significantly decreased by enhancements in product design and manufacturing methods. Extensive research and development can also restrict the presence of dangerous materials like lead, cadmium, and selenium in solar panels. Furthermore, the utilization of silver can be circumvented as a result of developments in inkjet and screen-printing technology. According to Perez-Santalla (2013), there are new and innovative methods in printing and pastes that are expected to decrease the amount of silver used from 0.16 g/Wp in 2005 to below 0.1 g/Wp by 2020. Consequently, India has implemented several initiatives to develop products with reduced quantities of harmful substances.

2.6.2.2 Reuse

The objective of managing waste is what reuse attempts to accomplish. Reuse is a strategy to prevent waste from going to landfills, either by using it for its original purpose or repurposing it for a different function. This practice enhances the occupational well-being of residents by taking valuable things that people no longer desire and giving them to those who do. This has been achieved by increasing the longevity of photovoltaic (PV) panels. As a result, a market can be established where refurbished PV panels can be sold at a reduced market price compared to new or used panels. A secondary market can be established for refurbished panels and for panels that have reached their expected lifespan, following required repairs. The identified deficiencies and blemishes encountered in the initial stage of a photovoltaic panel's lifespan can be effectively addressed through the provision of specialized training and expertise in photovoltaic panel maintenance (Ministry of Environment, Forest and Climate Change, 2016a).

2.6.2.3 Recycle

Recycling prevents waste including the waste from solar panels from ending up in landfills. India has extensively implemented the recycling of non-reusable PV solar panels. The construction of solar panels is not only highly energy intensive, but it also involves the use of dangerous compounds such as lead and cadmium. If these materials are released into the environment when the panels reach the end of their life, they can create substantial pollution and health problems. Recycling waste solar panels can effectively minimize energy wastage and mitigate environmental damage (Fthenakis, 2000). Reutilizing the constituent materials of solar PV in the manufacturing process will reduce the need to import natural resources. There is a possibility to decrease the amount of end-of-life (EoL) solar photovoltaic (PV) waste by 60% to 90% because the materials used in solar PV systems have a great potential for being recycled at high rates (Fthenakis, 2000).

In light of the methods undertaken in India, it is necessary to establish PV panel recycling facilities, despite the fact that waste recovery models are currently not financially feasible due to the relatively low to moderate levels of PV waste creation. The government may contemplate providing incentives to waste recovery units during the initial years. The management of solar PV waste is of utmost importance due to its environmental benefits and economic relevance.

Proper treatment of waste allows for the recovery of elements that may be utilized as raw materials in various stages of solar PV panel production. The solar PV waste recycling sector can be regarded as a secondary mining industry (Sharma et al., 2023).

2.6.2.4 Landfill

Lead and cadmium will leak into groundwater as a result of improper waste disposal at dump sites, as is the case with solar PV waste disposal, further degrading the quality of groundwater (Farrell et al., 2020). The process of lead leaching can lead to diminished growth of plants and animals, habitat degradation, and negative health risks to the neurological, renal, immunological, and reproductive systems in humans. Additionally, it might lead to compromised cognitive development in young children. Cadmium is an extremely poisonous substance that is known to cause cancer, specifically in the lungs, human prostate, and kidneys. Utilizing landfills for solar waste disposal is the most convenient approach to execute. However, it not only leads to the depletion of valuable materials but also causes economic detriment. Therefore, it should be given the lowest priority when devising strategies for solar waste disposal. The inadequate handling of PV waste can lead to the depletion of valuable components such as aluminium and glass, which constitute 88% of the total weight (Latunussa et al., 2016a). In addition, the landfill will lead to the depletion of valuable and essential metals, such as silicon metal, as well as precious metals like silver, which is renowned for its conductivity, albeit in limited amounts. The WEEE directive, which is based on Extended Producer Responsibility (EPR), promotes resource efficiency by advocating for the reuse, recycling, and reduction of waste disposal in landfills (Farrell et al., 2020).

2.6.3 United Kingdom

The PV market and waste prediction in the UK is currently in its early stages, particularly in terms of PV and end-of-life (EoL) panels. The deployment of PV solar waste has shown a significant and swift growth, going from less than 1 GW in 2011 to over 9 GW in 2015. Currently, there are more over 750,000 installations (IRENA, 2016b). The installation of three quarters of the current PV capacity in the UK occurred after the implementation of the WEEE Directive in early 2014 (UK WEEE Directive, 2013).

The United Kingdom has established precise regulations for waste management, particularly in terms of defining a photovoltaic (PV) producer and implementing the extended producer responsibility principle while incorporating the WEEE Directive into domestic legislation. A photovoltaic (PV) producer operating within the framework of the UK Waste Electrical and Electronic Equipment (WEEE) legislation, such as a UK-based company that sells PV panels under its own brand. A UK based firm that specialises in importing photovoltaic (PV) panels into the UK market. The company sells PV panels that are either made by another entity or imported from another source, but are marketed under its own brand. In addition, all manufacturers of photovoltaic solar panels must be enrolled in a compliance programme and provide necessary information on the products they create for both residential and non-residential sectors. The criteria stipulate that PV solar companies must finance the collection of household PV panels based on their market share. For instance, if a producer introduces 10% (by weight) of new panels into the UK market in a specific year, they are responsible for funding the collection and treatment of 10% of the old panels gathered in the subsequent year. The year of their initial market introduction is disregarded. In addition, the PV solar panel manufacturers are required to fund the retrieval and disposal of both non-residential panels marked with a recycling symbol and those without it, provided that these panels are being replaced with new ones at the same time (WEEE Directive of 2013).

2.7 SUMMARY OF LITERATURE

To summarise, as the world sets high goals for solar installation, it is inevitable that solar waste will also expand globally. According to the predicted scenario, the forecast of waste indicates that the amount of PV waste might potentially reach 6.64 million tonnes. However, the utilisation of frameworks will have a pivotal function in bolstering sustainable end-of-life practises for photovoltaic (PV) systems. Early collaboration between public sector institutions and the business sector is crucial for establishing these. An integrated strategy to managing the EoL of photovoltaic (PV) systems can improve the collaboration between many stakeholders, such as PV providers and users, waste sector education and training, and the provision of necessary data and analysis to enable solar PV EoL management. It is imperative to encourage investment and implement creative financing schemes for the management of end-of-life

photovoltaic (PV) systems in order to overcome financial obstacles and secure the backing of all parties involved.

2.8 KNOWLEDGE GAP ANALYSIS

Table 2.1 1: Knowledge gap analysis

S/n	Author/Year	Article	Finding	Gap
1	Chowdhury et al. 2020	An overview of solar photovoltaic panels' end-of-life material recycling. Energy Strategy Reviews, 27, 100431–. doi:10.1016/j.esr.2019.100431	There is a lack of sufficient guidelines for policies to address issues regarding the recycling of solar panels and other components, as there are no regulations, especially in China..	Studies conducted in Zambia have emphasised the advantages of adopting solar photovoltaic energy. However, there is currently no known existing research on the assessment of the challenges associated with the sustainable development of the photovoltaic (PV) industry with focus being the city of Lusaka.
2	Oteng et al. 2022	Environmental emissions influencing solar photovoltaic waste management in Australia: An optimised system network of waste collection facilities. https://doi.org/10.1016/j.jenvman.2022.115007	The findings validate the substantial quantity of photovoltaic waste that will be generated in the upcoming years. The government should prioritise the implementation of legislation and regulations in the upcoming years to effectively recycle and recover solar panels in an environmentally sustainable manner.	There is a subsequent need to assess the extent of solar PP energy adoption in Lusaka to understand the projected amount of waste from solar system expected in the future.

3	<p>Xu, Y., et al. 2018</p> <p>Global status of recycling waste solar panels: A review. <i>Waste Management</i> (2018), https://doi.org/10.1016/j.wasman.2018.01.036</p>	<p>The direct disposal of obsolete solar panels is a severe problem since recoverable resources are being squandered because there is lack of designated infrastructure for recycling crystalline silicon solar panels.</p>	<p>This is the case to Zambia as the direct disposal of decommissioned solar panels is a significant concern due to increased accumulation of EoL solar PV panels. However, there has been no local study conducted to determine the preparedness of Zambia, with a specific focus on the city of Lusaka.</p>
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2.9 CHAPTER SUMMARY

This literature review aimed to thoroughly examine the less investigated aspect of solar system adoption by analysing its potential adverse effects. Although solar energy is well recognised for its multiple environmental and economic advantages, a careful examination of the literature reveals a complex situation that requires consideration of unexpected repercussions. In order to shed light on the possible negative effects of switching to solar PV systems globally and locally in Lusaka, Zambia. The research takes into account studies conducted in a variety of geographical and contextual contexts. It conducts a thorough assessment of the approaches used in the literature, identifying areas where research is lacking and needs to be further explored. The summary of findings emphasises the significance of taking a comprehensive approach when examining the downsides of solar system adoption, recognising that although these worries are real, they can be addressed and their negative effects can be minimised by strategic mitigation measures and legislative changes. This review seeks to enhance the understanding of the intricate factors involved in the adoption of solar energy. It intends to establish a basis for policymaking that guarantees the sustainable and fair deployment of solar energy in Lusaka, Zambia. In the preceding chapter, the researcher will examine and elucidate the theoretical frameworks, as well as establish the conceptual framework for the study.

CHAPTER THREE

THEORETICAL AND CONCEPTUAL FRAMEWORK

3.1 INTRODUCTION

The Theoretical framework for assessing the implications of transitioning to solar PV energy on waste management in Lusaka, Zambia was based on the key three theories namely; circular economy (CE), extended producer responsibility (EPR) and sustainability theory

3.2 THEORIES

3.2.1 Circular economy theory

Waste that has reached the end of its useful life can be used as a useful source of supplementary resources, and this is the core of a circular economy. The Ellen MacArthur Foundation (2013) states that these materials can be used similarly to basic natural resources and in the past ten years, the circular economy has grown in acceptance as a potent paradigm for directing humankind for sustainable development (Geissdoerfer et al., 2018). A circular economy (CE), according to Arruda et al. (2021), is a structural revolution in society that gets rid of waste and pollution, maintains goods and resources in circulation for the economy, and recovers ecological systems.

The resource-intensive linear economy of "take, make, dispose" that underpins the current global economy has put the environment under increasing strain, limited the amount of natural restoration, and jeopardised the prospects for future generations to flourish (Esposito, et al. 2018). To ensure the integrity of materials, mitigate depletion of current reserves, and prevent environmental pollution, economies should prioritise reducing extraction of resources from the Earth's crust and instead prioritise the use of renewable methods for resource production and disposal. One of CE's primary objectives is to achieve this. According to Arruda et al. (2021) the other is for economics to reduce material loss and dispersion. To accomplish this, one must maintain resources inside closed loops in both biological and technical cycles, minimise waste and pollution, and restore natural systems (Ellen MacArthur Foundation, 2018). Building long-lasting systems is linked to the idea of CE. This approach therefore suggests a set of linked

regenerative actions with the goal of reducing waste generation and creating systems for secondary raw material recovery (EMF, 2013; Kirchherr et al., 2017; Paulik, 2018). The adoption of clean technology and a decrease in the use of virgin materials are key components of CE's ecologically responsible approach (Andersen 1997, 1999; Sariatli, 2017). Figure 3.1 illustrates an example CE by Ellen MacArthur Foundation. The framework prioritises the reduction, reuse, repair, remanufacture, and recycling of products in order to prevent the extraction of new resources and the disposal of waste in landfills (Ellen MacArthur Foundation, 2014).

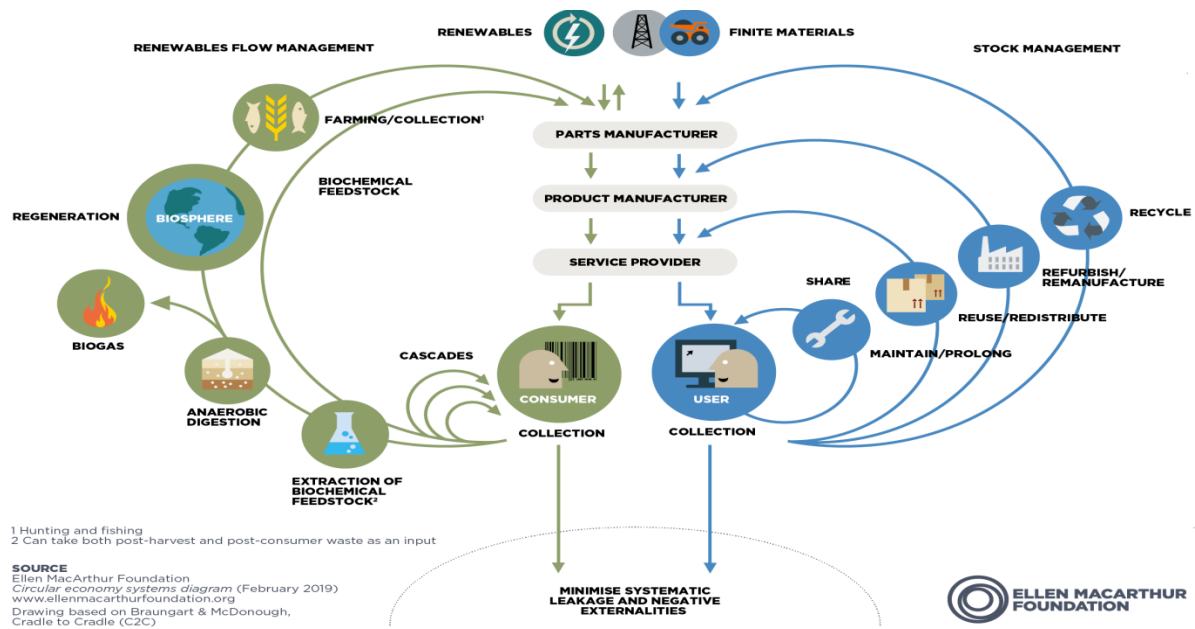


Figure 3.1 1: Circular Economy (Ellen Macarthur Foundation (3), 2019)

Circular economy as strategy for addressing the management of EoL solar panel waste

The implementation of the circular economy (CE) is still in its infancy worldwide, with a primary focus on recycling as opposed to reuse, despite the fact that recycling is the least profitable and resource-efficient CE activity (Stahel, 2014). Despite this, a number of EPR programmes have been implemented, and in some countries, significant progress has been made in waste management and recycling over the past few decades (Cialani et al., 2016). By encouraging the use of clean technologies and minimising the use of virgin materials, CE offers an environmentally friendly paradigm (Andersen 1997, 1999; Sariatli, 2017). A number of

nations, including China, Germany, and Japan, have regulations pertaining to the circular economy that include setting recycling and material recovery rates. According to Ignatuschtschenko (2017), Japan's recycling system collects and processes 50–60% of the country's e-waste annually, with an estimated 30% of the material arriving illegally. In Germany, CE was begun by a legislative act in 2012. The Extended Producer Responsibility (EPR) principle, which is the third principle, upheld by the German method, encompasses three key tenets: cooperation, polluter-pays, and precautionary principles. Similar regulations are currently being developed in South American and African nations.

PV panels can also be treated under the circular economy framework (cradle-to-cradle opportunities) and according to the traditional waste reduction guidelines of the 3Rs (reduce, reuse, and recycle) (IRENA, 2016). Solar PV systems can also be used to apply the 9R framework refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover for the circular economy (Potting, et al., 2017). As part of the 9R framework, recycling, refurbishing, and remanufacturing are the preferred methods for handling EoL solar PV waste worldwide and in certain regions of Africa, according to Gautum et al. (2022). The most favoured option is to use less material in PV panels, which will lead to an increase in high-efficiency technology and effective mass production. These factors, along with a robust market expansion, a shortage of raw materials, and downward pressure on PV panel prices, are what are causing this shift (IRENA, 2016). Refurbishment or remanufacturing is the second most favourable choice after reduction, with recycling being the least favoured alternative (excluding landfilling). Recycling is only considered when the first two options have been fully utilised (Potting, et al., 2017).

3.2.2 Theoretical Conceptualization of Extended Producer Responsibility (EPR)

Waste management, as noted by Schubeler (1996), is a challenging undertaking that requires coordination and cooperation between private businesses, public agencies, and households in addition to the appropriate choice and use of technological approaches for collecting waste, transfer, recycling, and disposal. Because of this, it's imperative to create a strategic framework for the management of solar photovoltaic (PV) waste that links all parties involved in the project's lifecycle and gives them specific responsibilities. It is widely understood that there are

many opportunities to establish these connections and assign accountability for waste management through the Extended Producer Responsibility (EPR) concept.

The notion Extended Producer Responsibility (EPR) is an environmental policy that operates on the premise of making the polluting party bear the costs associated with their pollution (Walls, 2006). It aims to establish the financial incentives necessary for producers to adopt recycling and waste reduction strategies, either independently or in conjunction with other producers. Extended Producer Responsibility (EPR) is an environmental policy strategy that holds producers accountable for their products across the whole life cycle, including the post-consumer stage (Nicol and Thompson, 2007). Two related aspects of EPR policy are acknowledged by the Organisation for Economic Cooperation and Development (OECD) (2001). These include the transfer of responsibility from municipalities to producers, either fully or partially, either physically or economically, and by offering incentives to producers to integrate environmental factors into the production process of their products. Producers must cover all associated post-product consumption, disposal, and recycling costs as a result of producers being given more financial responsibility for waste management. The producer is implied to handle a disposable product both directly and indirectly, including taking it back for recycling, when physical waste management is transferred to them (Nicol and Thompson, 2007). This relieves local governments of a significant financial and logistical burden associated with managing waste. Research by Hoornweg and Bhada-Tata (2012) shows that in developing nations, waste management is frequently the single biggest expense item for local governments.

Enforcing manufacturers to bear the environmental cost of their products throughout their lives offers financial motivation for adopting sustainable production and disposal methods. Producers may therefore be focused on enhancing product design in order to minimise material and energy consumption as well as pollution at the product design phase. Aside from waste reduction, recycling or reuse, conserving materials, lowering pollution, reduced poisoning, and "ecological design," additional environmental factors are taken into account during the product design phase (Walls, 2006). It is possible to summarise the producers' efforts as a result of EPR by saying that they are focused on guaranteeing materials are used effectively to meet human requirements as well as minimising the environmental impact of waste disposal.

Several legislative tools are being used to transfer accountability for wasteful product production from taxpayers and the government to manufacturers and consumers. These include economic tools like advance disposal fees and deposit/refund systems, as well as regulatory tools like mandatory take-back programmes, minimum recycled content standards, bans and restrictions on solar panels made of less recyclable materials. All of these are pertinent to the goals of this study. The implementation of Extended Producer Responsibility (EPR) differs among countries, as evidenced by several policy tools. The adoption of this initiative has been predominantly effective, particularly in OECD countries and inside the European Union (EU) (Packaging Recovery Organisation Europe, 2011). That However, the concept continues to be a subject of controversy. If individual manufacturers take on the responsibility of overseeing the entire waste management process for their products, it will be challenging to determine whether a given practise is both economically and environmentally efficient (Hanisch, 2000). In order to maximise their economies of scale, certain producers who participate in extended producer relationships (EPR) typically pay a portion of the expenses associated with having product recycling and reclamation handled on their behalf. The widely used Green Dot system in the European Union is one such instance.

In keeping with the EPR principle, it should be noted that manufacturers are not the only ones responsible for managing solar panels after EoL cycle. As per the OECD (2001), the notion inherently involves sharing responsibility along the product chain. For maximum effectiveness, all stakeholders, such as players in the form of manufacturers, consumers, distributors, disposers, importers, local authorities, and the community, must actively engage in EPR policy initiatives. Product stewardship, as defined by the US Environmental Protection Agency (2012), is the collective duty of all individuals involved in a product's lifespan to minimise its environmental, health, and safety effects.

3.2.2.1 EPR as an effective strategy for addressing the management of solar panel waste in Lusaka

Offering a comprehensive plan to address the intricate and challenging waste management scenario in Lusaka, Zambia, would be both impractical and presumptuous. There are, however, options that, when carefully considered, could lessen the amount of garbage that ends up in the environment and in local communities. Utilising the phrase "cautious" is crucial since these

substitutes shouldn't be implemented as models from rich nations; while successful in the developed world, they cannot be transplanted straight to developing nations such as Zambia (Adebayo et al 2011). The Extended Producer Responsibility (EPR) strategy could be investigated as a tool to improve solid waste management in developing nations including Lusaka, Zambia in light of this logic and the many ways outlined in the literature. Extended Producer Responsibility (EPR) primarily seeks to enhance the management of products at the end of their life cycle and promote more environmentally friendly production methods. This theory suggests that in order to treat waste in a way that is desirable, product features and designs should be altered in addition to waste treatment practises (Lindhqvist, 2000). This transfers some of the waste management duties from consumers and local governments to the companies that make the products. It also represents the drive to internalise the social and environmental costs associated with manufacturing operations (such as the depletion of natural resources and the need to dispose of landfills).

Beyond being merely a tool for policymaking, extended producer responsibility (EPR) is a concept that is put into practise through various means, including informational, regulatory, and economic measures like product taxes, take-back programmes, and environmental labelling. These measures should be employed in concert to accomplish particular objectives and minimise costs (Walls, 2006; Nahman, 2010). It is noteworthy to acknowledge that these instruments may entail mandatory or optional tasks that provide positive outcomes upon thorough context investigation. Moreover, the implementation of EPR might take various forms, including voluntary industry initiatives or required rules enforced by the authorities (Widmer et al., 2005; Walls, 2006; Nnorom and Osibanjo, 2008).

3.2.3 Theoretical Conceptualization of sustainability

Sustainability can be defined in several ways, but it generally encompasses a consideration of human needs and values, with a particular emphasis on future oriented perspectives (e.g. Brundtland Report, 1987). The aforementioned report outlined the three fundamental aspects of sustainability, namely environmental, social, and economic, which are commonly referred to as ESG (Environmental, Social, and Governance). A number of international agreements and objectives serve as the main foundation for the shift to sustainable development, which is then carried out at the local and state levels by the various states and communities concerned. The

most renowned agreements in this category include the United Nations Framework Convention on Climate Change and its protocols, which establish obligations to decrease greenhouse gas emissions; the Convention on Biological Diversity (CBD), which advocates for the preservation of biodiversity; and notably, the UN Sustainable Development Goals (SDGs), which encompass a broad spectrum of sustainability concerns. The UN 2030 Agenda, enacted by the UN General Assembly on September 25, 2015, is a comprehensive plan that prioritises the well-being of people, the sustainability of the planet, and the promotion of wealth. The Agenda encompasses 17 universally applicable goals that are structured around the three pillars of sustainable development: economic, social, and environmental. In this context, sustainability is once more defined as the ability to maintain three key goals: social progress, environmental protection, and economic growth. Although they recognise the value of adding a social component, they question whose responsibility it is for defining sustainable development in the context of sustainability. They expand upon a set of indicators created in 1996 that were largely focused on the economic-environmental interaction. The application of sustainability theory to the management of waste from solar PV systems in Lusaka, Zambia is based on the three pillars of sustainability, which were introduced during this period (Bradley Guy and Kibert 1998; Fricker 1998; Stirling 1999; Azapagic and Perdan 2000; Valentin and Spangenberg 2000).

The urgent imperative to advance sustainability has catalysed the emergence of a novel and developing subject known as sustainability science. This field is primarily concerned with resolving issues and addressing obstacles, rather than adhering to conventional academic disciplines (Spangenberg, 2011). This emerging area of study aims to investigate the interdependencies between human actions and the natural surroundings (Rapport, 2007). An explicit challenge confronting sustainability science is the worldwide surge in urbanisation and technological progress in the energy industry, resulting in a widespread shift towards solar energy as a renewable source. Emerging urban centres, such as Lusaka City in Zambia, pose both obstacles and prospects for achieving sustainability (Weinstein, 2010). Urban centres across the globe are confronted with a multitude of obstacles, such as rapidly growing populations that have led to heightened energy requirements, as well as disturbances to the economy and the environment. Hence, comprehending sustainability and enhancing the capacity of policymakers to attain sustainable management are urgent imperatives of the 21st century (Birch & Wachter, 2008; Naess, 2001; Register, 2006).

In order to comprehensively and effectively address the management of solar waste in Lusaka, the sustainability theory was employed. The objective is to develop a sustainable relationship by including social, environmental, and economic responses. During the 2005 World Summit on Social Development, it was observed that achieving sustainability necessitates the harmonisation of three fundamental aspects: environmental preservation, social fairness, and economic requirements. In order to attain equilibrium among the economy, the environment, and society as a whole it is imperative to implement strategic and discerning sustainable designs (McLennan, 2005). This perspective has been conveyed through the depiction of three ellipses that overlap with each other.

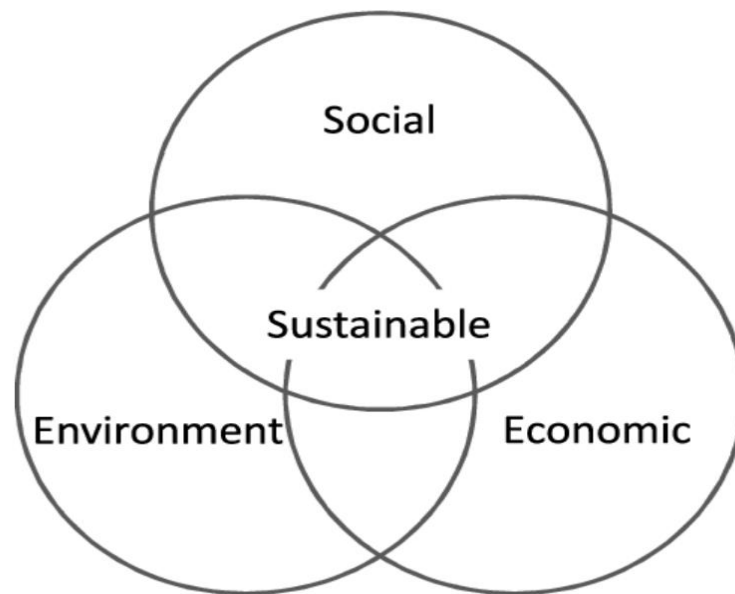


Figure 3.2 1: Typical illustration of sustainability with three circles intersecting (Purvis, 2019)

3.2.3.1 Economic Model

According to sustainability theory, an economic model aims to preserve both natural and financial capital. The management of solar panel waste relies on the essential framework of environmental and financial capital. The social and environmental effects of economic activities

serve as a bridge between sustainability and economics. Sustainable economics is a comprehensive view of ecological economics that emphasises environmental and ecological variables and challenges as fundamental components of a multifaceted picture. Mebratu (1998) and Clinton (1977) both emphasise the need to incorporate social, cultural, health-related, and financial factors into the study. The economic model is crucial for this project as it plays a vital role in supporting technological improvements in the manufacturing of solar panels. Its primary objective is to ensure that the production of solar panels results in little pollution and utilises recyclable materials. In this regard, the right treatment of solar panel waste, which contains hazardous materials and is typically released after improper disposal that degrades the environment, requires financial resources.

Efforts to enforce crucial environmental policies, which are designed to save the environment, necessitate substantial financial backing. Regulatory bodies like ZEMA, who are responsible for overseeing and enforcing sector regulations, also require substantial financial support to facilitate the smooth implementation of their enforcement efforts. Sustainable waste management from solar panels in Lusaka, Zambia, will be ensured by the comprehensive cooperation of these economic players.

3.2.3.2 Environmental Model

An environmental model examines the physical and biological elements, as well as their chemical interactions, that impact an organism. It also examines the constructed environment, which refers to the physical structures and surroundings, as well as the natural environment that includes all living and non-living elements. Additionally, it considers the social environment, which encompasses the cultural context in which an individual resides, as well as the individuals and institutions they engage with. In order to ensure the preservation of the environment and the well-being of human and other forms of life, it is necessary to implement protective measures such as policies and laws. This is particularly important in the case of solar PV waste disposal, as improper handling of solar pv waste can result in environmental degradation. Solar PV waste contains toxic substances that can have negative effects on the social aspect of sustainability (Raskin, 1993).

Essentially, sustainability theory has successfully elucidated a comprehensive strategy for managing solar panel waste. It highlights the role of many system players, such as social, economic, and environmental models, in promoting sustainability. In this regard, the advancements in traditional waste management systems for solar panels can be explained by the application of sustainability theory. There are a few drawbacks, though. In order to improve system performance, information interchange and learning are essential, and the theory first fails to account for actor-actor interactions among the heterogeneous parts. Secondly, with respect to the goal of this research, sustainability theory falls short in offering a structure for examining paradigm shifts in systems.

3.2.3.3 Social Model

When systems, interactions, structures, and formal and informal processes actively enhance the ability of present and future generations to build livable and healthy communities, this is known as a social model in sustainable development. Communities that are socially sustainable offer a high standard of living and are democratic, varied, equitable, and linked. The model examines various aspects of human existence, including the legal framework that governs human and environmental interactions, the interplay between human rights and human progress, as well as the influence of corporate authority on environmental fairness. To attain sustainability in solar pv waste management, it is necessary to consider and safeguard all elements of the social model (International Union, 1989).

3.3 CONCEPTUAL FRAMEWORK

The Circular Economy Waste Management Conceptual Framework serves as the foundation for assessment of the implications of Lusaka, Zambia's transition to solar PV energy on waste management. To ensure economic and environmental sustainability, as well as the principles of the circular economy (CE) in municipalities, Figure 3.3 presents the conceptual framework for sustainable waste management. This framework can be applied to the management of solar PV panels and spur action towards a sustainable solar PV waste management system in Lusaka, Zambia. This framework aims to facilitate the implementation of sustainable practises in managing solar photovoltaic (PV) waste in Lusaka. It will achieve this by ensuring that waste generation is effectively managed through the establishment of a 100% waste segregation

objective. In a circular economy, sustainable waste management is achieved when waste is recovered, reused, repaired, and reintroduced into the consuming mainstream, resulting in a reduction of environmental pollution and deterioration. The conceptual framework for CE sustainable waste management, shown in Fig. 3.3, has several distinctive features, including awareness, education, and training. For this reason, it is recommended that educational training and awareness campaigns be started in support of these programmes, as locals are not socially acclimated to waste segregation at the source. Public awareness campaigns can effectively shape the social attitude of residents, who have a significant role in determining the waste management systems implemented by local authorities. According to Elsaid and Aghezzaf (2015), residents who have knowledge about the benefits and consequences of recycling and reusing, as well as other sustainable practises, are more likely to follow environmentally responsible waste disposal methods.

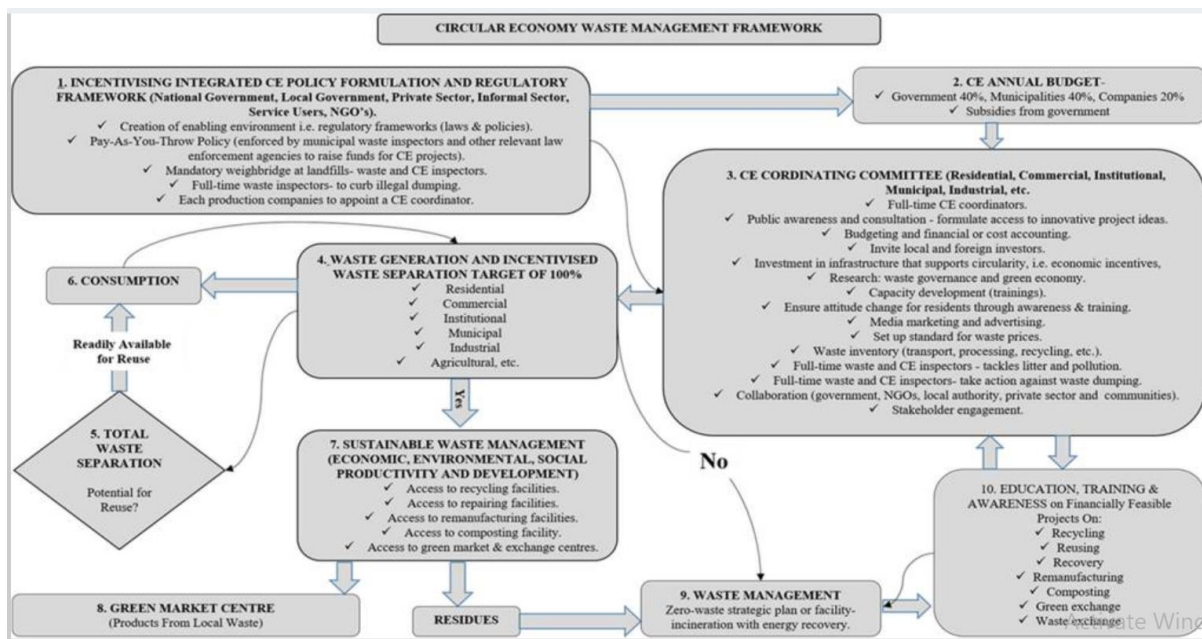


Figure 3.3 1: Conceptual framework for sustainable waste management based on circular economy (Kadhila et al, 2023)

Encouraging policies that support circularity and investments in circular economy infrastructure are among the regulatory frameworks that help create an enabling environment for circularity. Other strategies include educating all stakeholders and changing attitudes, as well as fostering collaboration amongst government agencies, non-governmental organisations, small businesses,

and communities. Cost is a significant obstacle to implementing circular economy. To ensure the proper operation of the framework, it is necessary to establish an annual budget that is supported by the government (40%), the local government (40%), and stakeholders (20%). To ensure that CE operations are carried out at waste generating sources (4), the circular economy coordinating committees (3) are established by means of the budget. An essential stage in this ecosystem is waste segregation (5). Reusable waste is recovered and put back into the food chain (6). Before being put back into the production cycle (7), waste that can be reused is recycled, repaired, and refurbished into useful items. Locally produced goods made from waste are then offered for sale to the community at green market centres (8) at reasonable costs. Finally, only little amounts of remains that might not be recycled are burned in order to create energy (9) and power some of the most impoverished communities. This idea serves as the foundation for economic development, with a focus on raising local community awareness, education, and training levels (10). The central concept revolves around the efficient utilisation of material resources, the proper collection of waste, and the implementation of recycling and reuse practises within the manufacturing process (Drljača 2015; Upadhayay and Alqassimi 2018). This conceptual framework (Figure. 3.3) makes sure that the sustainable waste management goal is fulfilled in terms of waste management.

3.3.1 The conceptual framework for the study

Effective management of solar photovoltaic (PV) waste is a crucial element of achieving a sustainable energy transition. This requires a comprehensive conceptual framework that takes into account the whole lifecycle of PV systems. During the production process, it is crucial to strictly follow eco-design principles in order to assist the future disassembly and recovery of materials (Kadhila et al 2023, Walls, 2006). During the whole operational lifespan, it is crucial to prioritise optimisation and efficiency, as well as perform routine maintenance and consider technology upgrades to prolong the useful life of the PV system. Upon reaching the conclusion of the PV system's lifespan, it is essential to have a comprehensive framework that includes multiple crucial stages. First and foremost, product design should include features that facilitate disassembly and improve the ability to recover materials throughout the decommissioning process. Following stages entail the implementation of efficient collecting and transportation systems to guarantee that retired PV modules are delivered to suitable recycling facilities (Choi

& Fthenakis, 2010). These facilities should include state-of-the-art recycling infrastructure that can effectively process PV modules and extract valuable materials, in line with the concepts of the circular economy (Cucchiella et al., 2015). Prudent attention must be given to the handling of dangerous substances in order to adhere to environmental laws, particularly focusing on proper disposal and the possibility of reusing and repurposing specific elements.

The regulatory and policy environment is a critical component of the conceptual framework, and it is of utmost importance to comply with established national and international standards. By implementing Extended Producer Responsibility (EPR) programmes, PV manufacturers are held accountable for managing the disposal of their products once they reach the end of their life cycle. This helps to encourage sustainable practises within the sector (Nicol and Thompson, 2007). The framework incorporates economic and financial factors, and decision-making on waste management solutions is guided by a thorough cost-benefit analysis. Another essential component of the conceptual framework is the promotion of public awareness and education. Stakeholder interaction is of utmost importance, encompassing manufacturers, installers, policymakers, and the general public. Efforts to increase knowledge and understanding of the environmental consequences of photovoltaic (PV) waste and the significance of proper disposal methods are essential for gaining support and cultivating a shared feeling of obligation (Kadhila et al 2023). Moreover, training programmes designed for industry professionals help augment comprehension and execution of sustainable practises in photovoltaic waste management.

The conceptual framework for assessing the implications of transitioning to solar PV energy on waste management in Lusaka, Zambia consisted of three main components: (1) Solar PV Energy Transition Factors, (2) Waste Management Implications, and (3) Sustainable Waste Management Strategies. Figure 8 depicts the proposed conceptual framework.

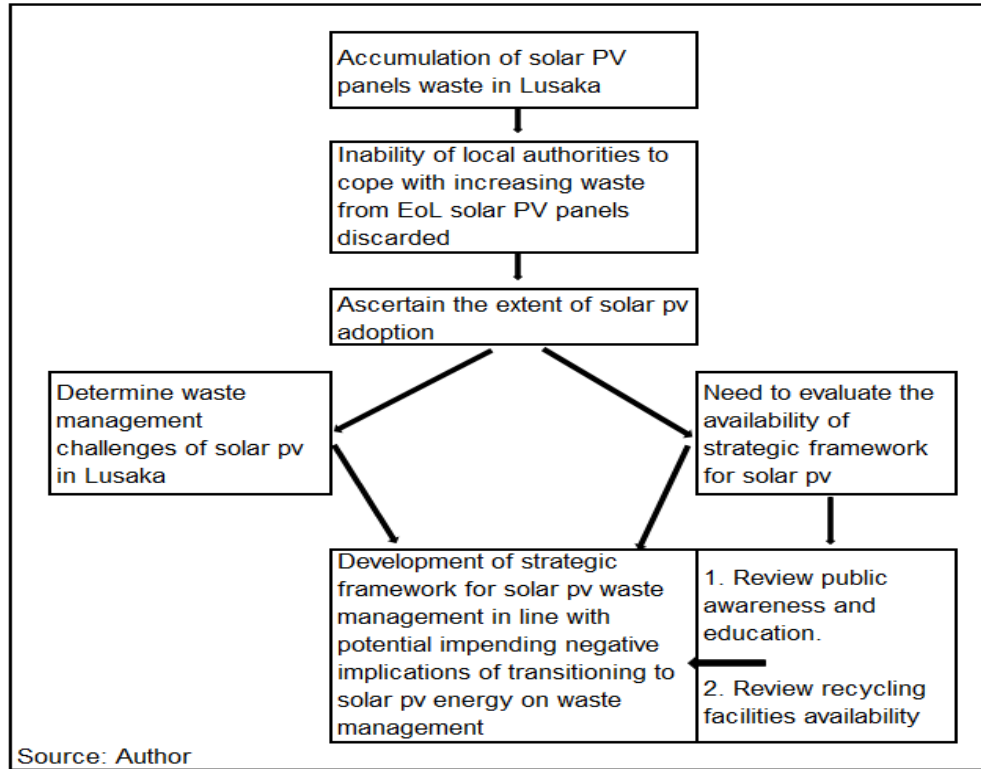


Figure 3.4 1: Independent, Moderating and Dependent Variables
(Author, 2023)

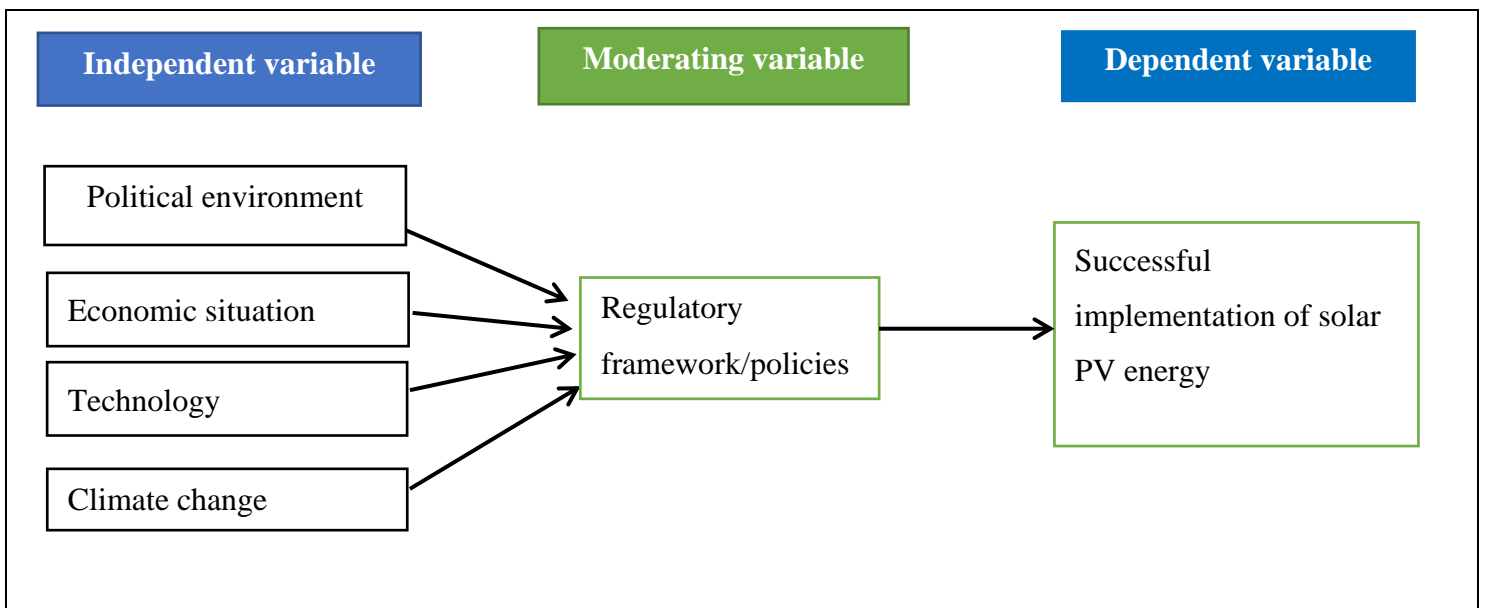


Figure 3.5 1: Independent, Moderating and Dependent Variables

3.3.2 Variables explanations

3.3.2.1 Overview

This component of the framework focuses on the factors influencing the transition to solar PV energy in Lusaka. It includes variables such as government policies and regulations, financial incentives, technological feasibility, public awareness and acceptance, and institutional support. These factors will be analysed to understand their impact on the adoption and implementation of solar PV energy, which, in turn, affects waste management practices (Okedu, Barghash and Nadabi, 2022).

3.3.2.2 Successful implementation of solar PV energy

Managing waste during the solar panel lifecycle is a crucial aspect of successfully implementing solar photovoltaic (PV) energy, in addition to utilising renewable power. This literature study explores the relationship between the adoption of solar photovoltaic (PV) energy systems and waste management strategies, based on a variety of academic sources. Various studies, notably Qu's research in 2015, emphasise the importance of regulatory frameworks and regulations in directing effective waste management practises in the solar industry. Extended producer responsibility (EPR) guidelines have a crucial role in guaranteeing the proper disposal and recycling of solar panels, as highlighted by many studies (Weckend et al., 2016; Lindhqvist, 2000; OECD, 2001; IRENA (1), 2016). The study conducted by Weckend et al., (2016) underscores the importance of including waste management considerations into renewable energy regulations. This shows the necessity of implementing comprehensive regulatory frameworks that cover the whole lifespan of solar panels, from their production to their decommissioning.

Technological progress also has a crucial role in reducing the environmental consequences of solar waste. Researchers such as Cucchiella et al.,(2015), Bio Intelligence Service, (2011), and McDonald and Pearce, (2010) explore advancements in recycling technology that can extract useful elements from retired solar panels, thereby promoting a more sustainable approach to waste management.

3.3.2.3 Regulatory framework/policies

The effective adoption of solar energy is significantly influenced by regulatory frameworks and regulations, particularly in relation to the management of waste connected with solar technology, as demonstrated in several studies. The study conducted by Weckend et al. (2016) emphasises the crucial significance of extended producer responsibility (EPR) regulations in dealing with the management of solar panels at the end of their lifespan. The research underscores the relevance of regulatory measures to ensure effective recycling and disposal practises. In addition, research conducted by Eberspacher and Fthenaki (1997), Frisson et al. (1998), Fthenakis (2000), and Fthenakis et al. (2008) explores the importance of including waste management measures in renewable energy policies. These studies highlight the necessity of comprehensive frameworks that regulate the entire lifespan of solar panels. Moreover, studies conducted by Miao (2015) and Gan et al. (2007) emphasise the significance of regulatory supervision in reducing potential environmental consequences arising from insufficient waste management methods in the solar sector. The purpose of this literature review is to combine these data in order to develop a thorough comprehension of how regulatory frameworks and policies influence the effective incorporation of solar energy and its techniques for managing waste.

3.3.2.4 Political environment

The effective integration of solar energy and waste management is closely tied to the political landscape, as governmental policies and regulatory frameworks play a pivotal role. This variable utilises a range of scholarly sources to clarify the impact of the political environment on these particular elements. The successful implementation of solar energy programmes relies heavily on the presence of strong political determination and stability. The study conducted by Omri et al (2015) highlights the crucial significance of government policies that provide support in promoting the adoption of solar energy. Feed-in tariffs, renewable energy regulations, and tax incentives have shown to foster a favourable climate for the expansion of solar plants. Even so, the political environment might provide difficulties, as alterations in governance or changes in political objectives may affect the consistency and durability of solar programmes (Lean & Smyth, 2013).

Political influence can also impact waste management practises associated with solar systems. According to Weckend et al (2016), Extended Producer Responsibility (EPR) policies play a vital role in setting up rules for the proper disposal and recycling of solar panels. Waste management initiatives related to solar energy can be greatly influenced by political decisions made about environmental regulations and sustainability objectives. Furthermore, the significance of international collaboration and treaties is growing in order to tackle global issues pertaining to solar energy and waste management. The International Renewable Energy Agency (IRENA, 2016) emphasises the necessity of cooperative political endeavours to advance sustainable practises and transnational solutions.

3.3.2.5 Economic situation

A significant consideration in deciding how well solar energy projects work is how much the society can afford to adopt solar energy. The study conducted by Salim et al (2012) highlights the significance of economic incentives and subsidies in encouraging the use of solar energy. It demonstrates a direct relationship between financial assistance and the effective execution of solar projects. In addition, research undertaken by Yamashita et al. (2003) and Wambach (2004) examines the effects of economic downturns on the funding and sustainability of solar efforts, emphasising the susceptibility of these projects during periods of economic instability. The economic environment also impacts waste management strategies related to solar technologies. The economic conditions are crucial for the financial sustainability of recycling programmes and the advancement of efficient disposal technologies. Recycling technologies in the solar sector must be economically viable to ensure their widespread adoption and implementation. Furthermore, the economic viability of waste management solutions, such as recycling and disposal, is essential given the limitations of available resources. Sustainable waste management practises may encounter obstacles during periods of economic decline, requiring a delicate equilibrium between environmental goals and economic viability.

3.3.2.6 Technology

The improvement of solar energy systems' efficiency and economic viability is largely dependent on technological innovation. The United Nations Commission on Science and Technology for Development (2017) highlights the continuous advancements in solar panel materials and

designs, together with enhancements in energy storage technologies, which are leading to higher overall performance and dependability. Furthermore, the study conducted by REN21 (2017) emphasises the importance of pioneering manufacturing methods in reducing the environmental impact of solar panel production, hence promoting sustainable waste management strategies. Technology plays a crucial role in promoting sustainability in waste management. Deploying sophisticated recycling technologies is essential for managing old solar panels. The advancements in recycling techniques enable the retrieval of precious materials and reduce the negative effects on the environment, thereby promoting a circular and sustainable method of managing solar PV waste. In addition, solar energy systems are incorporating smart technology and data analytics to provide real-time monitoring and predictive maintenance. These technologies improve the efficiency of solar installations and facilitate effective waste management through the monitoring and management of defunct panels.

3.3.2.7 Climate change

The development of solar energy systems is hindered by the problems posed by climate change. Research undertaken by Carley (2009), Gan et al. (2007), Johnstone et al. (2010), and Marques and Fuinhas (2012) highlights the significance of including climate variability into the planning and functioning of solar arrays. The efficiency and dependability of solar panels can be affected by extreme weather events, altered sunshine patterns, and changing temperatures. This requires the implementation of adaptive strategies in the planning and management of solar energy infrastructure. On the other hand, solar energy plays a vital role in reducing the impact of climate change. The study conducted by Xu et al (2018) emphasises the capacity of solar power to serve as an environmentally friendly and sustainable energy source, hence aiding in the mitigation of greenhouse gas emissions. The shift towards solar energy is in accordance with worldwide climate objectives, highlighting the interdependence between efforts to combat climate change and the implementation of renewable energy sources.

Climate change can worsen specific difficulties related to waste management in the context of solar systems. The increase in temperatures and alterations in precipitation patterns could impact the process of leaching elements from retired solar panels. This necessitates careful deliberation in waste management procedures (Carley, 2009, Gan et al., 2007, Johnstone et al., 2010, Marques and Fuinhas, 2012).

3.4 CHAPTER SUMMARY

This chapter looked at the development of a comprehensive conceptual framework for managing solar PV waste which is necessary to successfully navigate the challenges of a sustainable energy future. This framework seeks to encompass the entire lifecycle of PV systems by incorporating eco-design principles, regulatory compliance, economic factors, public involvement, and technological advancements. Its objective is to promote responsible practises and contribute to the broader objectives of a circular economy and environmental sustainability.

CHAPTER FOUR

RESEARCH METHODOLOGY

4.1 INTRODUCTION

This research methodology chapter introduction lays out the methodical framework that is used to answer the research questions and highlights how important it is to the validity and reliability of the study. It outlines the selected research approach, research design, and how they are connected to the primary research questions and underlying philosophical assumptions. The section provides a comprehensive description of the study population, sample size, sampling techniques, tools for data collecting, and data analysis techniques. It also includes a justification for each option made in the study. Ethical considerations, including as participant privacy and wellbeing, are discussed together with validity and reliability. This detailed summary seeks to

inspire trust in the study's robustness and integrity, ensuring that the findings make a relevant contribution to the broader research field.

4.2 RESEARCH APPROACH

Kombo & Tromp (2006) have defined a research approach as a systematic and strategic plan for obtaining answers to research inquiries. Mugenda (2003) further asserts that it serves as a strategic and comprehensive method for tackling a set of research inquiries or concerns. In addition, Mohajan (2017) has described a research methodology as a strategic plan that provides guidance for conducting research in a methodical and effective manner. Creswell (2014) further states that research encompasses a wide range of tactics and methodologies, spanning from overarching assumptions to specific methods of collecting, analysing, and interpreting data.

The research approach employed in this study is the Mixed Methods Approach, which combines both quantitative and qualitative methods to gain a comprehensive understanding of the potential negative implications of transitioning to solar PV energy on waste management in Lusaka. According to M. S. Rahman (2016), a mixed-methods approach to research involves gathering, evaluating, and combining qualitative and quantitative research methods in a single study to better understand a research problem. The utilisation of a mixed method approach is in accordance with the three primary categories of research technique, namely Qualitative, Quantitative, and Mixed Methods strategy, as delineated by Creswell (2014). This methodology recognises the complex character of the research inquiries and aims to integrate findings from multiple sources to improve the overall credibility and comprehensiveness of the study. In comparison to employing either approach alone, combining qualitative and quantitative data can lead to a greater understanding of a study problem (Creswell, 2003). According to Patton (2002) and Giddings & Grant (2006), mixed methods research is valuable in research, assessment, and field studies due to its comprehensive approach and capacity to collect more diverse information on a phenomenon compared to using a single method.

This approach aims to quantitatively measure phenomena using statistical methods and is characterised by objectivity (M. S. Rahman, 2016). Statistical studies are utilised to detect patterns, correlations, and trends, hence facilitating a quantitative evaluation of the issue. Concurrently, a qualitative aspect was incorporated by conducting comprehensive interviews

with relevant participants involved. The subjective goal of this qualitative technique is to capture the complex views, attitudes, and experiences of those who are either a part of the shift or are impacted by it (Kothari, 2006). These findings are helpful for comprehending the technological, political environment, economic situations and other contextual elements that can impact the connection between solar PV adoption and waste management practises. In addition, Rahi (2017) notes that a qualitative research approach is an interpretive strategy that permits the utilisation of several subjective points of view and the creation of understanding as opposed to the pursuit of its tangible realisation.

The integration of quantitative and qualitative approaches is consistent with the study's primary objective of offering a comprehensive and nuanced assessment of the research subject. By utilising triangulated data from many sources, this approach strengthens the reliability of the conclusions and enables a more thorough comprehension of the potential adverse implications of transitioning to solar PV energy on waste management in the distinctive setting of Lusaka.

4.3 RESEARCH DESIGN

According to Creswell et al. (2009), the main strategy for integrating the various research components into a logical and coherent whole gives the confidence that the research problem will be adequately addressed. The research design serves as the guide for the collection, measurement, and analysis of the collected data. In addition, Christensen (1994) describes research design, which is an outline, plan, or strategy that outlines the steps to be taken in order to find the answer to the research question. This definition contains details like data collection, analysis, and variation control. Based on a mixed methods research methodology, this study was conducted. In order to assess the potential impending adverse implications of solar PV waste management in Lusaka; the study used both qualitative and quantitative methods of research. The term "qualitative" in the context of this study, according to Denzin et al. (2005), refers to an emphasis on the qualities of study subjects as well as on processes and meanings that are not empirically studied or assessed. This research employed a hybrid (mixed) methodology, combining qualitative and quantitative techniques. Research questionnaires were developed as the primary method for gathering data from key individuals with knowledge and expertise in the sectors of solar PV energy and waste management.

4.4 PHILOSOPHY OF THE STUDY

According to Creswell (2014), research philosophy is the set of assumptions and convictions that direct a researcher as they undertake research. Slife and Williams (1995) argue that it offers a structured approach for planning and executing research, influencing the methods used to gather, analyse, and interpret data. Creswell (2014) identifies four prevalent worldviews found in literature: constructivism, transformative, post positivism, and pragmatism.

- **Constructivism**

Although interpretivism and constructionism take many different forms, they are all concerned with common and subjective interpretations. These philosophical stances focus on the ways in which individuals or groups interpret and comprehend social events and environments. Interpretation plays a crucial role in analysing qualitative data, as much of this type of study centres around human activity and understanding. For instance, Alvesson and Willmott (2003) emphasise the significance of interpretation in qualitative analysis. The theoretical foundation of interpretive and constructionist study lies in the fields of hermeneutics and phenomenology, which significantly shape the concepts of the societal formation of actuality (Berger and Luckmann, 1967).

- **Transformative**

Mertens (2010) defines a transformative worldview as the act of examining the world through the lens of diverse and historically marginalised or subjugated groups of people, such as individuals with disabilities, those with non-traditional sexual orientations, ethnic minorities, and various genders. This perspective aims to connect these groups with political and social actions.

- **Post positivism**

Main criticism of positivism led to the development of post positivism, also called post empiricism. It contends that, contrary to positivism's claims, the knower and the knowing cannot be separated. Furthermore, it challenges the notion of a collective, singular reality. It implies that while humans may not fully comprehend reality, researchers can make progress in comprehending it through meticulous data gathering and analysis. Grounded theory, symbolic interactionism, scientific and critical realism, and other philosophical and methodological stances

that differ from these are all covered under post positivist thought, which has a significant impact on qualitative research (Glaser and Strauss, 1967). Additionally, Miles and Huberman's (1994) meticulous methods of evaluating qualitative data are frequently referred to be post positivist. However, Barbules (2000) advances the post-positivism school of thought, which emphasises the study of cause-and-effect scenarios and places a premium on empirical evidence, reasoned reasoning, and the validation of theories and hypotheses. Therefore, quantitative research embraces it due to its qualities.

- **Pragmatism**

Mixed methods research embraces the pragmatic worldview because it is not limited to any particular type of realism. This allows researchers to freely employ both qualitative and quantitative standards, methodologies, and approaches which are most appropriate for their study's objectives (Creswell, 2014). Furthermore, epistemological assumptions, ontological assumptions, and axiological assumptions the degree to which the researcher's values impact the research process are all included in the definition of philosophy, according to Saunders et al. (2015). Consequently, in order to give the research context and perspective, research philosophy primarily focuses on epistemology and ontology (Holden & Lynch, 2004).

In assessing the potential negative implications of transitioning to solar PV energy on waste management in Lusaka, Zambia, a pragmatic worldview was employed as the appropriate research philosophy. This involved adopting a mixed research study design, specifically a mixed approach, mixed strategy, and sequential explanatory research design.

4.4.1 Epistemology

In research, epistemology refers to the philosophical underpinnings that guide the techniques used to conceptualise, produce, and validate knowledge. Researchers might choose to adopt several epistemological perspectives, which subsequently influence their approach to designing, conducting, and assessing research studies. According to Richards (2003) and Snape & Spencer (2003), epistemology is the study of the fundamental presumptions we have about the nature of knowledge and the processes by which we might learn about the outside world. Epistemology, as defined by Crotty (1998), is a framework that allows for the comprehension and interpretation of the universe. It necessitates specialised knowledge and necessarily involves a specific

understanding of the form of knowledge at hand. According to his explanation, epistemology deals with the nature of knowledge itself, including its validity, scope, and practicality (i.e., what can be researched and what cannot). In Bryman's (2008) definition, epistemology refers to differing viewpoints regarding the appropriate methodology for studying the natural and social worlds. The current inquiry pertains to the determination of what knowledge should be deemed acceptable within a specific field of study.

In this study, a critical approach to epistemology was employed. This approach utilises a combination of qualitative and quantitative research approaches to tackle multifaceted challenges throughout a significant framework. It also acknowledges the socio-political boundaries of knowledge output. This approach recognises the complexity of reality and the need to include multiple perspectives in order to comprehend it. Therefore, it is an appropriate strategy for assessing the potential negative implications of transitioning to solar PV electricity on waste management in Lusaka, Zambia.

4.4.2 Ontology

Ontology, the concept of being, is a crucial and often overlooked term in philosophy (Dale Jacquette, 2002). Furthermore, according to Snape & Spencer (2003), it refers to the conclusions made about the nature of the topic being studied and the amount of knowledge that may be obtained about it. Ontology, as defined by Smith Barry (2003), is the field of study that examines the forms, structures, substance, processes, activities, and linkages in all domains of reality. Braun et al. (2005) categorise ontology into two fundamental types: relativism and realism. According to Llewellyn et al. (2008), realism posits the existence of an external world independent of our consciousness, where immutable rules of nature remain indefinitely. Moreover, realism is the belief that the existence of reality is independent of the researcher's thoughts and judgements, as stated by Maxwell (2012). Relativism, on the other hand, posits that reality is a subjective and relative phenomenon, and that there is no external existence outside our own cognitive processes (Baghramian et al., 2004).

Moreover, according to Grady (2002), relativism is synonymous with pluralism, which means that there is no single ultimate truth or validity of reality. This study adopted a realist ontological perspective, acknowledging the existence of fixed rules of nature that are independent of the

researcher's viewpoint. But according to this expert, perspective continues to be very important in determining how one perceives and reacts to the unchanging rules of nature.

4.5 STUDY POPULATION

According to Polit and Hungler (1999), a population refers to a set of all the items, entities, or group members that satisfy the criteria set by the researcher. Wegner (2002) defined a population as all possible observations of the random variable under study. Leedy (1997) emphasises this idea even further by stating that the population can be viewed as a group of people, an individual, or an object that would help the researcher by revealing characteristics they have in common. The research study population comprises a heterogeneous group of persons and stakeholders who are crucial to comprehending the implications of transitioning to solar photovoltaic energy on waste management practises in Lusaka, Zambia. The analysis is conducted in Lusaka city, which is experiencing rapid urbanisation and facing issues related to energy transitions and waste management (Smith et al., 2019). By including various stakeholders, the goal is to gather different viewpoints that provide light on the inherent complexity of this shift.

The study's target population is a representative sample of Lusaka locals, drawn from a range of socioeconomic backgrounds, neighbourhoods, and demographic types. The incorporation of this factor is essential for understanding the potential implications of implementing solar PV energy on daily schedules, patterns of waste production, and attitudes towards environmental responsibility within various societies (Johnson & Wang, 2018). The research population includes policymakers and government authorities who are specifically engaged in environmental regulation, and waste management policy formation at both the municipal and national levels. The input from these stakeholders will offer valuable viewpoints on the regulatory environment, possible hurdles, and policy measures required for a viable transition (Brown & Sovacool, 2020). The research population consists of renewable energy experts and waste management professionals, including municipal waste management authorities, environmental professionals and waste management service providers. Their knowledge and practical experiences are extremely important in assessing the practical implications and feasibility of using solar PV energy while properly handling waste streams (Ren et al., 2021).

The inclusion criteria pertain to individuals who have been living in Lusaka for a specific period of time, as well as policymakers or professionals who are directly involved in the energy or waste management sectors. To ensure diversity in the study population, a purposeful technique was used, taking into account age groups, educational backgrounds, income levels, and professional responsibilities (Creswell & Creswell, 2017). This research aims to provide a thorough and detailed understanding of the possible difficulties and advantages that may arise from the shift to solar PV energy in waste management practises in Lusaka. It does so by including a wide range of stakeholders, ensuring a comprehensive analysis.

Table 4.1 1: Study population

S/n	Stakeholder group	Institutions	Contacted
1	Government authorities	ZEMA	3
		LCC solid waste division	3
2	Renewable energy experts/handlers	Bangweulu Solar Farm	2
		Solar Industry Association Of Zambia	2
3	Environmental professionals		100
4	Waste management companies	Service providers	10
5	Environmental NGOs	Members	10
6	Waste experts		10
Total			140

Source: Author, (2023)

4.6 SAMPLE SIZE

Ligthelm and Van (2005) characterised the sample size as a smaller subset of the entire population. A study's sample size is a condensed version of the full population being examined, and it should normally represent or resemble the complete population in order to allow for

generalizable findings. Following the guidelines established by Cooper and Schindler (2014), this study carefully chose a sample that accurately and precisely reflected the population's viewpoints regarding the potential implications of shifting to solar photovoltaic (PV) energy on waste management in Lusaka. The sample size was determined using the Cooper and Schindler's technique, which considers the sample size (n), the margin error (e), and the population size (N). The analysis of the results was conducted with a 95% confidence level, allowing for a 5% acceptable error margin.

$$n=N/(1+Ne^2)$$

$$n=140/(1+140(0.05^2))$$

$$102.7 \approx \mathbf{103}$$

Table 4.2 1: Sample size

S/n	Stakeholder group	Institutions	Contacted	Percentage	Sample size
1	Government authorities	ZEMA	3	2	2
		LCC solid waste division	3	2	2
2	Renewable energy experts/handlers	Bangweulu Solar Farm	2	0.7	1
		Solar Industry Association Of Zambia	2	0.7	1
3	Environmental professionals		100	74	76
4	Waste management companies	Service providers	10	7	7
5	Environmental NGOs	Members	10	7	7
6	Waste experts		10	7	7
Total			140	100	103

Source: Author, (2023)

4.7 SAMPLING TECHNIQUES

Cavana et al. (2001) defined sampling as the act of selecting a subset of the population to serve as a representative sample of the full population. The study employed the purposive sampling technique to select participants who are directly and indirectly involved in environmental regulation and waste management policy formation, as well as those with expertise in the solar industry and waste management. These individuals constituted the target population. Purposive sampling, as defined by Cavana et al. (2001), encompasses a range of non-probability sample techniques commonly employed in qualitative research. It is referred to as judging, selective, or subjective sampling because the choice of units depends on the researcher's judgement.

4.8 DATA COLLECTION TOOLS

To perform this research, both primary and secondary data were utilised.

4.8.1 Primary Data

As stated by Hair et al. (2010), primary data refers to variables that have been collected and compiled expressly for the current research problem or opportunity circumstance. These data provide first-hand information. The main data source mostly included of research questionnaires and interviews with key informants.

4.8.2 Secondary Data

Secondary information was collected from the body of published work and utilized to frame the study problem and set its background in history.

4.8.3 Data Analysis

The statistical measurements of variability, such as standard deviation and variance, and central tendency, such as mean, median, and mode, were applied to quantitative data obtained from questionnaires. The data was then subjected to descriptive statistical analysis, such as regression or correlation, to identify patterns and relationships. Simultaneously, qualitative data obtained from interviews with environmental professionals, waste experts, environmental non-governmental organisations (NGOs), policymakers, and waste management service providers underwent thematic content analysis, enabling the identification of recurring themes and nuanced

opinions. The objective of this analysis, which combines both quantitative and qualitative methodologies, is to gain a thorough understanding of how the adoption of solar PV and waste management practises in Lusaka interact with each other. The analysis will examine both numerical patterns and subjective observations. The process of arranging and categorising data was performed using Microsoft Excel. Additionally, a descriptive analysis was performed to determine the link between variables.

4.9 VALIDITY AND RELIABILITY

The efficacy of the study's precision processes was being evaluated in the findings section. The terms validity and reliability are employed to indicate the degree of accuracy with which items are measured in the study. The connection between these two concepts lies in the fact that a measurement can only be considered dependable if it is deemed legitimate. Validity, as defined by Bryman and Bell (2003), pertains to the extent to which the findings accurately reflect the intended subject matter. Validity refers to the degree to which a variable accurately measures what it is designed to measure. The level of consistency in outcomes produced by data collection methods or analysis procedures is described by Saunders et al. (2009). Using a mixed methods approach, this study established validity through the methodological triangulation method. Hence, the study employed interviews, questionnaires, and field observations as data sources to mitigate bias and enhance the credibility of the findings.

Research dependability refers to the extent to which measures or conclusions in a study demonstrate consistency and stability (Kumar, 2010). The validity of research is a crucial element that ensures the dependability and trustworthiness of study results. The notion pertains to the assurance that when the instrument is employed in a comparable manner on homogeneous populations, it will constantly yield dependable outcomes (Rackwitz, 2001). This study employed the Cronbach's coefficient alpha test to assess the reliability of the research tools, specifically gauging their dependability at a level of 0.67. According to Nyakundi (2015), a Cronbach's alpha test coefficient between 0.6 and 0.7 is deemed acceptable, while a coefficient above 0.7 is considered good or exceptional, depending on the highest value. According to Agresti and Finley (2009), a measure should possess both validity and reliability. Validity means

that it truly reflects the concept it is intended to assess, while reliability means that it is consistent, with subjects responding in the same way when prompted again.

4.10 ETHICAL CONSIDERATION

The research adhered to the highest standards of research ethics, considering the participation of various stakeholders from whom the data was intended to be gathered. An overview of the study's objectives was given to the respondents prior to the instruments being given to them. Each respondent had to give their consent before the instrument could be given, indicating their willingness to participate in the research and their desire to have their names kept confidential. The University of Lusaka's ethical code of practise for research was scrupulously followed when conducting the study. In addition, during the study, the researcher made a conscious effort to comply with applicable laws, as well as institutional and governmental laws, while taking appropriate precautions to minimise any potential harm, discrimination, or risk to the participants and sources of information.

4.11 CHAPTER SUMMARY

To summarise, this chapter introduced the appropriate research methodology and research design employed to carry out the investigation. The chapter also emphasised the research philosophy, which included the epistemological and ontological assumptions of the investigation. It also provided details on the study's population and the suitable sampling strategies that were applied. The chapter subsequently provided the precise sample size of the investigation, which was determined using Cooper and Schindler's methodology. Ultimately, the chapter expounded upon the assessment of the data collecting tools' validity and reliability, elucidating the methods employed to ascertain these parameters for the study. Additionally, it delved into the ethical considerations that were taken into account during the research process.

CHAPTER FIVE

DATA PRESENTATION AND FINDINGS

5.1 INTRODUCTION

This chapter represents the study's findings and explains the findings of the study aiming at assessing the potential impending negative implications of transitioning to solar PV energy on waste management in Lusaka. The study targeted government authorities, renewable energy experts, environmental professionals, waste management experts, members of environmental non-governmental organisations (NGOs), and electronic waste experts.

5.2 RESPONSE RATE ANALYSIS

A total of 118 questionnaires were distributed as part of the study to relevant authorities, professionals in the field of renewable energy, environmental professionals, the experts in general waste management, members of environmental non-governmental organisations, and experts in electronic waste. The study focused on individuals who had direct or indirect involvement in the development of environmental regulations and waste management policies, as well as people with specialised knowledge in the solar industry and waste management in the city of Lusaka. Out of the 118 survey questionnaires that were issued, 105 were returned, resulting in a response rate of 89 percent. A summary of the questionnaire response rate is presented in Figure 5.1 below.

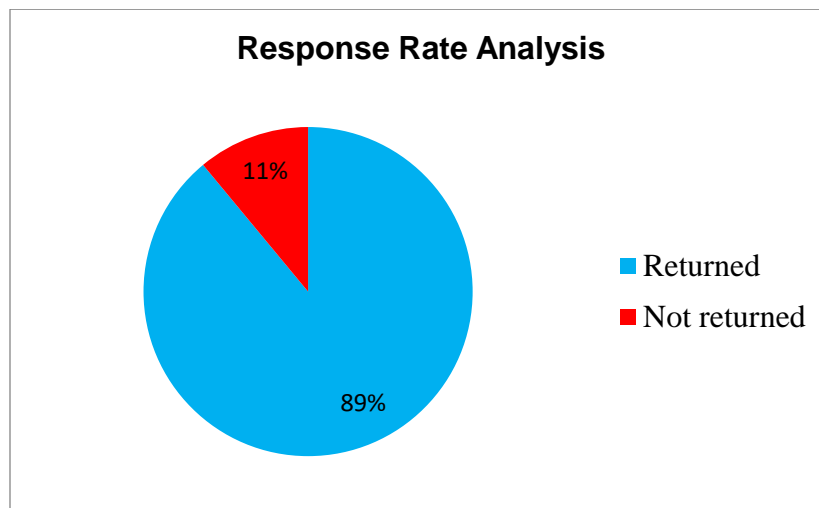


Figure 5.1 1: Questionnaire response rate- source:

Author, (2023)

In addition, the researcher gathered qualitative data by utilising an interview guide and conducting interviews with three (3) respondents. The interviewers consisted of an environmental inspector, a public health inspector, and a solar energy expert. The environmental inspector has extensive expertise in the electronic waste sector, while the public health inspector specialises in solid and municipal waste. The solar energy expert has a wealth of knowledge in the Zambia solar energy industry. Data collected through the questionnaires was supplemented with information obtained through interviews, which was reported in the narrative.

5.3 RESPONDENT'S GENERAL INFORMATION

The study aimed to ascertain the demographic attributes of the respondents based on their age range, Academic qualification, occupation, and monthly income.

5.3.1 Respondent's Age Range

Table 5.1 1: Distribution of respondents by age

Age range	Frequency	Percent	Valid percent	Accumulative percent
Below 30	21	20%	20%	20%
Between 30 and 40	69	66%	66%	86%
Between 40 and 50	12	11%	11%	97%
Above 50	3	3%	3%	100%
Total	105	100%	100%	

Source: Author, (2023)

According to the data presented in table 5.1, the majority of the respondents were in the age range of 30-40 years, accounting for 66% of the total. The second largest group consisted of individuals below 30 years old, making up 20% of the respondents. The percentage of individuals between the ages of 40 and 50 was 11%, while those above the age of 50 accounted for only 3%. Collectively, the participants were predominantly of advanced age.

5.3.2 Academic qualification for the respondents

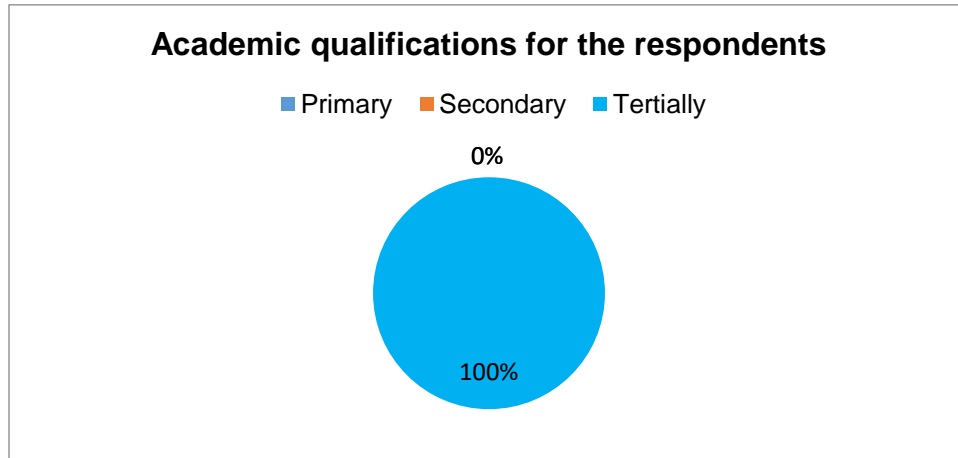


Figure 5.2 1: Distribution of respondents by academic qualifications

Source: Author, (2023)

All respondents had achieved a tertiary education level, according to the data. Consequently, the participants involved in the study possessed the necessary literacy and competence to comprehend and provide their perspectives on the offered research questions.

5.3.3 Respondent's occupation

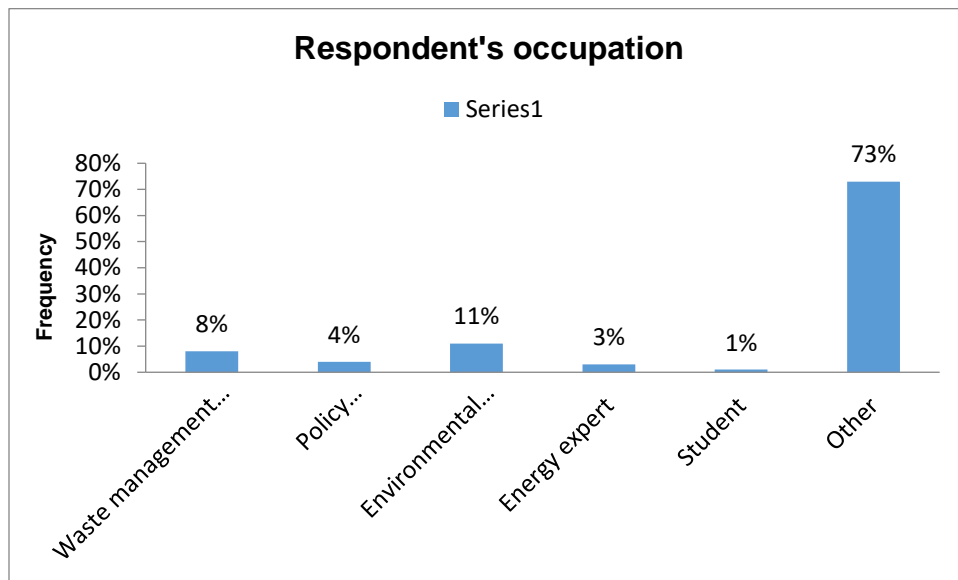


Figure 5.3 1: Distribution of respondents by occupational position

Source: Author, (2023)

The findings indicate that the majority of respondents fell into the "other" category, which included individuals such as environmentalists, SHEQ consultants, engineers, OHS practitioners, agricultural/environmental experts, and health and safety professionals, accounting for 73% of the total. Environmental inspectors accounted for 11%, waste management professionals for 8%, policymakers/government officials and energy experts for 3%. The student is lagging behind with a score of 1%. This demonstrates that a diverse group of specialists were purposefully contacted.

5.3.4 Respondent’s monthly income

Table 5.2 1: Distribution of respondents by monthly income

Income level (ZMK)	Frequency	Percent	Valid percent	Accumulative percent
Below 1000	3	3%	3%	3%
Between 1000 and 10000	30	29%	29%	32%
Above 10000	72	68%	68%	100%
Total	105	100%	100%	

Source: Author, (2023)

According to the data presented in table 5.2, the majority of the respondents were in the income level above ZMK 10,000, accounting for 68% of the total. The second group consisted of individuals with monthly income between ZMK1, 000 and 10,000, making up 29% of the respondents. The percentage of individuals with monthly income below ZMK1000 was 3%. Collectively, the participants were predominantly earning above ZMK10, 000.

5.4 Descriptive statistics data analysis for potential impending negative implications of transitioning to solar PV energy on waste management

The methods of organising, presenting, and analysing data that use numbers and graphics are known as descriptive statistics. Depending on the level of measurement utilised, a variable in a

sample may be described using one of several forms of descriptive statistics (Fisher & Marshall, 2009). According to Cresswell (2006), descriptive statistics analysis is thought to be the best method for gathering data that establishes links and illustrates phenomena as they actually occur. Therefore, this portion of the study focuses on the examination of the research variables using descriptive statistics. According to the questionnaire's design, respondents had to indicate which option, on a (5) point Likert scale, best represented their level of agreement or disagreement. The scale provided the following options: 1-Strongly Agree, 2-Agree, 3-Neutral, 4-Disagree, and 5-Strongly.

5.4.1 To ascertain the extent of adoption of solar PV in Lusaka

5.4.1.1 The rate of solar PV adoption in Lusaka in the recent past

The study aimed to determine the level of solar PV adoption in Lusaka. Among the 105 participants, 11% expressed strong agreement, 48% expressed agreement, 30% were neutral and/or indifferent, 10% expressed disagreement, and only 1% strongly disagreed. The specific information is displayed in table 5.3 presented below.

Table 5.3 1: The rate of solar PV adoption in Lusaka in the recent past

Adoption rate	Frequency	Percent	Valid percent	Accumulative percent
Strongly agree	11	11%	11%	11%
Agree	50	48%	48%	59%
Neutral	32	30%	30%	89%
Disagree	11	10%	10%	99%
Strongly disagree	1	1%	1%	100%
Total	105	100%	100%	

Source: Author, (2023)

5.4.1.2 Three (3) or more households have installed solar panels in my area

The research aimed to assess the extent to which households in various residential regions have utilised solar PV energy. The findings indicated that 10% of the participants expressed strong

agreement, 46% expressed agreement, 15% were neutral, 23% expressed disagreement, and just 6% strongly expressed disagreement. This data indicates that among the 105 participants, 56% of those living in residential areas, with 3 or more households have embraced solar PV energy as shown in table 5.4.

Table 5.4 1: Distribution of respondents residential areas with 3 or more household that have embraced solar PV energy

Adoption rate	Frequency	Percent	Valid percent	Accumulative percent
Strongly agree	11	10%	10%	10%
Agree	48	46%	46%	56%
Neutral	16	15%	15%	71%
Disagree	24	23%	23%	94%
Strongly disagree	6	6%	6%	100%
Total	105	100%	100%	

Source: Author, (2023)

5.4.1.3 Awareness of solar PV energy adoption in Lusaka

The researcher sought to determine the level of public awareness regarding the on-going transition to solar photovoltaic (PV) energy. The results indicated that among the 105 participants, 12% expressed a strong agreement with the general public's awareness of the on-going transition to solar PV energy. Additionally, 61% agreed, 17% were uncertain, 9% disagreed, and just 1% strongly disagreed as illustrated in table 5.5

Table 5.5 1: Level of public awareness regarding the on-going transition to solar (PV) energy

Solar PV energy adoption awareness	Frequency	Percent	Valid percent	Accumulative percent
Strongly agree	13	12%	12%	12%
Agree	64	61%	61%	73%
Neutral	18	17%	17%	90%

Disagree	9	9%	9%	99%
Strongly disagree	1	1%	1%	100%
Total	105	100%	100%	

Source: Author, (2023)

5.4.1.4 One's monthly income influence the adoption of solar PV energy

The researcher wanted to find out if ones income could influence ones decision to adopt solar PV energy in Lusaka with majority of the respondents strongly agreed with 55%, 20% agreeing, 12% were neither agreeing or disagreeing, 9% disagreeing while only 4% strongly disagreeing. Cumulatively, 75% of the respondents agreed and about 13% disagreed that one's monthly income could influence the adoption of solar PV energy.

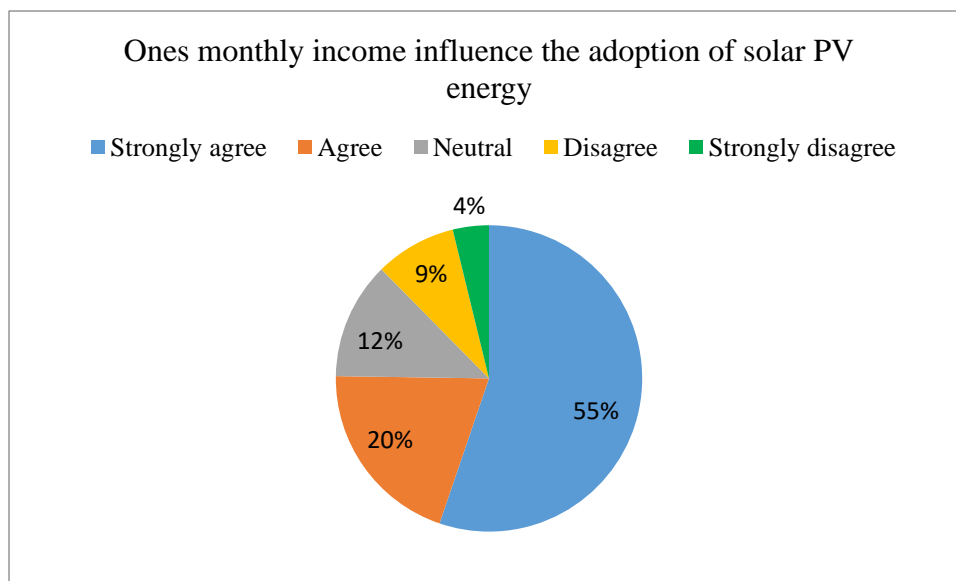


Figure 5.4 1: Distribution of monthly income influence on adoption of solar PV energy

Source: Author, (2023)

5.4.1.5 Factors that have influence on the adoption and successful implementation of solar PV energy in Lusaka

5.4.1.5.1 Political environmental factor

Regarding the impact of the political environment on the adoption and successful implementation of solar PV energy in Lusaka, a majority of the participants agreed with 56%, while a further 22% strongly agreed. 13% of the respondents had a neutral stance, whereas 7% disagreed and 2% strongly disagreed with. Collectively, 78% of the participants agreed while approximately 9% expressed disagreement regarding the impact of the political environment on the adoption and effective execution of solar PV energy as shown in Figure 5.5 below.

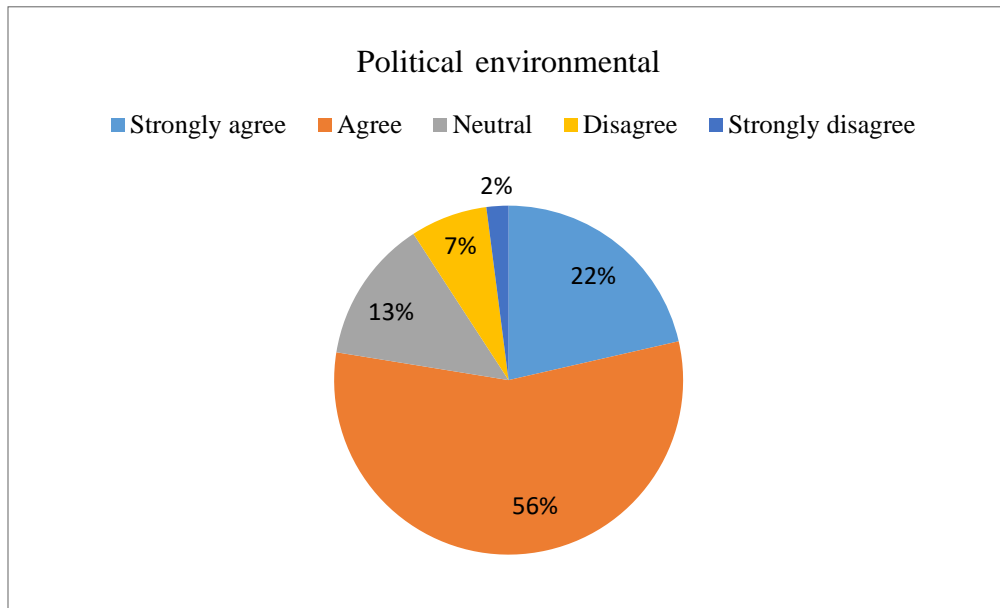


Figure 5.5 1: Influence of political environmental on the adoption and successful implementation of solar PV energy

Source: Author, (2023)

5.4.1.5.2 Economic situation factor

The study set out to determine whether Lusaka's economic circumstances had an impact on the uptake and effective use of solar PV electricity in Lusaka. 70% of the participants agreed, while an additional 20% strongly agreed. 9% of the participants expressed a neutral position, whereas 1% disagreed, and no one strongly disagreed. In Figure 5.6 below, it is evident that 90% of the

participants agreed, while around 1% expressed disagreement, regarding the influence of the economic situation on the adoption and successful implementation of solar PV energy.

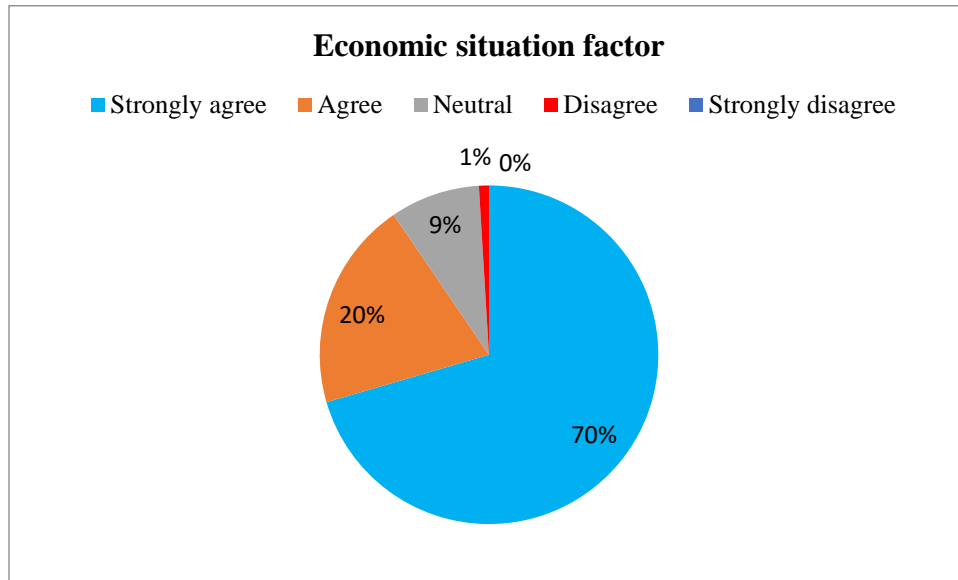


Figure 5.6 1: Influence of economic situation on the adoption and successful implementation of solar PV energy

Source: Author, (2023)

5.4.1.5.3 Technological advancement factor

The study set out to determine whether Lusaka's technological advancements had an impact on the city's adoption and effective use of solar photovoltaic electricity. 45% of the participants agreed, while an additional 33% strongly agreed. 17% of the participants expressed a neutral viewpoint, whereas 3% disagreed, and 2% strongly disagreed. Regarding the influence of technological advancement on the adoption and successful implementation of solar PV energy, as demonstrated in Figure 5.7 below, accumulatively 78% of participants agreed overall, with 5% disagreeing.

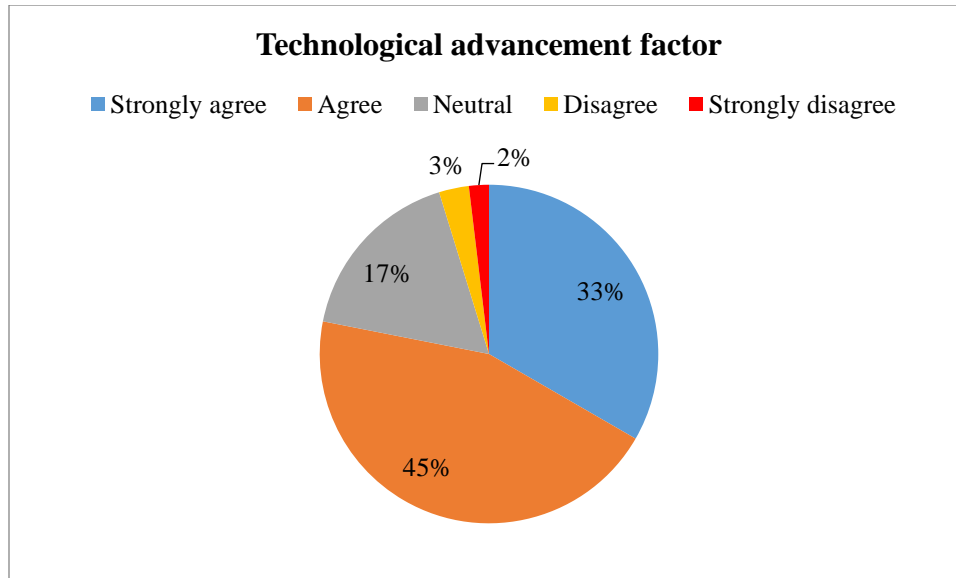


Figure 5.7 1: Influence of technological advancement on the adoption and successful implementation of solar PV energy

Source: Author, (2023)

5.4.1.5.4 Climate change factor

The respondents were asked for their views on whether there is a connection between climate change and the adoption and successful implementation of solar PV electricity in Lusaka. 31% of the participants agreed, while an additional 51% strongly agreed. 14% of the participants expressed a neutral position, whereas 3% disagreed, and 1% strongly disagreed. Cumulatively 82%, agreed with the notion that climate change has a significant influence on the adoption and successful implementation of solar PV energy. Conversely, only around 4% of participants disagreed as illustrated in figure 5.8 below.

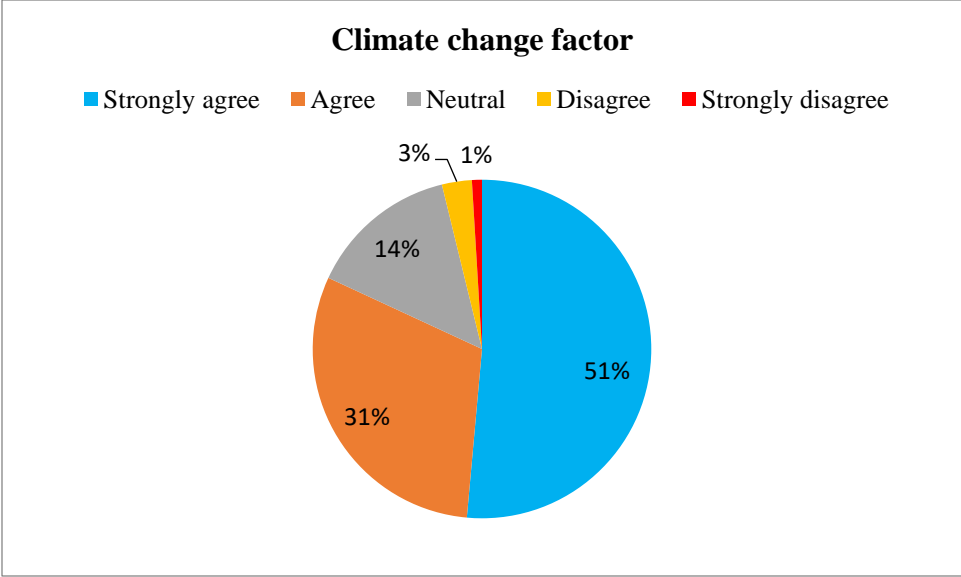


Figure 5.8 1: Influence of climate change on the adoption and successful implementation of solar PV energy

Source: Author, (2023)

5.4.1.5.5 Regulatory and legal framework / policies factor

Regarding the impact of the regulatory and legal framework / policies on the adoption and successful implementation of solar PV energy in Lusaka, a majority of the participants strongly agreed with 40%, while a further 29% agreed. 15% of the respondents had a neutral stance, whereas 14% disagreed and 2% strongly disagreed with. Collectively, 69% of the participants agreed while approximately 16% expressed disagreement regarding the impact of the regulatory and legal framework /policies on the adoption and effective execution of solar PV energy as shown in Figure 5.9 below.

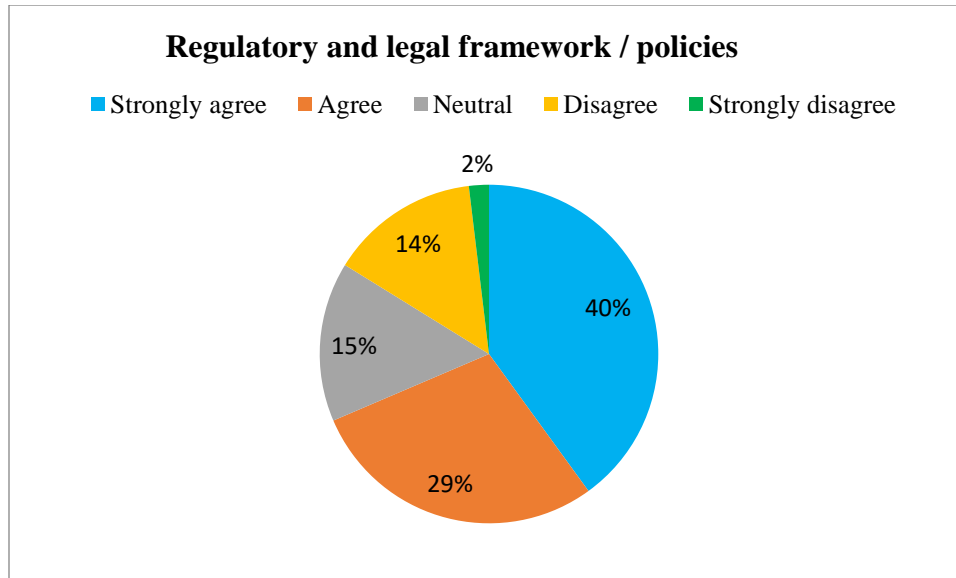


Figure 5.9 1: Influence of regulatory and legal framework / policies on the adoption and successful implementation of solar PV energy

Source: Author, (2023)

5.4.2 The relationship between political environment, economic situation, technological advancement, climate change factors and successful implementation of solar PV energy

Table 5.6 1: The relationship between political environment, economic situation, technological advancement, climate change factors and successful implementation of solar PV energy

S/n	Factor	Min	Max	Mean	S.d	Sample variance	Skewness	Mode	Median
1	Political environment	1	5	3.97	0.98	0.96	-0.75	4	4
2	Economic situation	2	5	4.42	0.79	0.63	-1.24	5	5
3	Technological advancement	1	5	4.03	0.96	0.92	-0.91	4	4
4	Climate change	1	5	4.24	0.92	0.85	-1.16	4	5

Source: Author, (2023)

5.4.2.1 Political environment

- **Mean (3.97):** The average score suggests that the respondents perceive political environment to have a moderate influence on the successful implementation of solar PV energy.
- **Standard Deviation (0.98):** The standard deviation, which measures the dispersion of data from the mean, indicates that the data was reliable with a probability value of 0.98. When rounded off, this result is close to 1, indicating that it is near the mean value of 3.97. This suggests a significant level of variability in the responses, indicating a wide range of viewpoints among the participants.
- **Skewness (-0.75):** The distribution is negatively skewed, indicating that there is a greater concentration of values on the right side (tail) of the graph. This suggests that respondents have a propensity to evaluate the political environment as having a substantial impact on the successful implementation of solar PV energy.

5.4.2.2 Economic situation

- **The mean score of 4.42** indicates that the respondents believe that economic situation has a substantial impact on the successful implementation of solar PV energy.
- **Standard deviation (0.79):** The standard deviation, a measure of the spread of data from the average, suggests that the data was dependable, with a likelihood value of 0.79. When approximated, this outcome is approximately 1, suggesting its proximity to the average value of 4.42. This implies a substantial degree of variability in the responses, signifying a broad spectrum of perspectives among the participants.
- **Skewness (-1.24):** The distribution exhibits negative Skewness, suggesting that there is a higher density of values towards the right side (tail) of the graph. This indicates that the respondents tend to assess the economic situation as having a significant influence on the effective implementation of solar PV energy.

5.4.2.3 Technological advancement

- **Mean (4.03):** The average score suggests that the respondents perceive Technological advancement to have a significant influence on the successful implementation of solar PV energy.
- **Standard Deviation (0.96):** The standard deviation, which measures the dispersion of data from the mean, indicates that the data was reliable with a probability value of 0.96. When rounded off, this result is close to 1, indicating that it is near the mean value of 4.03. This suggests a significant level of variability in the responses, indicating a wide range of viewpoints among the participants.
- **Skewness (-1.24):** The distribution is negatively skewed, indicating that there is a greater concentration of values on the right side (tail) of the graph. This suggests that respondents have a propensity to evaluate the Technological advancement as having a substantial impact on the successful implementation of solar PV energy.

5.4.2.4 Climate Change

- The respondents agree that climate change has a significant impact on a successful implementation of solar PV energy, as indicated by the mean score of 4.24.
- **Standard deviation (0.92):** The standard deviation, which quantifies the dispersion of data from the mean, indicates that the data was reliable, with a probability value of 0.92. When rounded, this result is roughly 1, indicating its closeness to the mean value of 4.24. This indicates a significant amount of variation in the responses, indicating a wide range of viewpoints among the participants.
- **The Skewness of the data is -1.16.** The distribution demonstrates a negative skew, indicating a greater concentration of values towards the right tail of the graph. This suggests that the participants are inclined to evaluate the climate change as having a substantial impact on the successful adoption of solar PV electricity.

5.4.3 Determine the waste management challenges of PV solar in Lusaka

5.4.3.1 Challenges or difficulties encountered in disposing of solar waste

The researcher sought out to determine the waste management challenges of PV solar in Lusaka. The findings indicated that among the 105 participants, 18% expressed a strong agreement with the general public's finding it difficult in disposing of EoL solar panels. Additionally, 12% agreed, 61% were uncertain, 6% disagreed, and just 3% strongly disagreed as illustrated in table 5.7 below.

Table 5.7 1: Distribution of respondent's perception with regards the challenges encountered in disposing of solar waste

Challenges or difficulties encountered in disposing of solar waste	Frequency	Percent	Valid percent	Accumulative percent
Strongly agree	19	18%	18%	18%
Agree	13	12%	12%	30%
Neutral	64	61%	61%	91%
Disagree	6	6%	6%	97%
Strongly disagree	3	3%	3%	100%
Total	105	100%	100%	

Source: Author, (2023)

5.4.3.2 Lack of knowledge about handling and disposal of end-of-life solar panels

The study aimed at finding out whether the general public's lack of knowledge about handling and disposal of EoL solar PV panels will have negative impact on the waste management of EoL solar PV panels. The findings revealed that among the 105 participants, 57% expressed a strong agreement with the general public's Lack of knowledge about handling and disposal of end-of-life solar panels. Additionally, 30% agreed, 9% were uncertain, 4% disagreed, and none strongly disagreed as illustrated in table 5.8 below.

Table 5.8 1: Lack of knowledge about handling and disposal of end-of-life solar panels by the general public

Knowledge	Frequency	Percent	Valid percent	Accumulative percent
Strongly agree	60	57%	57%	57%
Agree	32	30%	30%	87%
Neutral	9	9%	9%	96%
Disagree	4	4%	4%	100%
Strongly disagree	0	0%	0%	100%
Total	105	100%	100%	

Source: Author, (2023)

5.4.3.3 Waste management infrastructure

The research aimed to determine the extent of the general public's awareness regarding the existence of waste management infrastructure capable of handling the disposal of solar panel waste. Among the 105 participants, the data showed that 10% expressed a strong agreement. In addition, 16% of respondents agreed, 15% were undecided, 46% disagreed, and 13% strongly disagreed. A total of 59% expressed their disagreement regarding their awareness of any waste management system capable of handling the disposal of solar panels. In contrast, a mere 26% of participants agreed, as depicted in table 5.9.

Table 5.9 1: General public familiarity with waste management system capable of handling the disposal of solar panels

Waste management infrastructure	Frequency	Percent	Valid percent	Accumulative percent
Strongly agree	10	10%	10%	10%
Agree	17	16%	16%	26%
Neutral	16	15%	15%	41%
Disagree	48	46%	46%	87%
Strongly disagree	14	13%	13%	100%

Total	105	100%	100%
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Source: Author, (2023)

5.4.3.4 Recycling initiatives or programs specifically targeting waste from solar PV panels

The research sought to determine the level of public awareness of recycling initiatives or programmes specifically designed for waste from solar PV panels. Out of the 105 participants, the statistics revealed that 5% demonstrated a robust consensus. Furthermore, 13% of the participants agreed, whereas 50% remained uncertain, 19% expressed disagreement, and 13% strongly expressed disagreement. Collectively, 50% of the respondents neither agreed nor disagreed, while 18% expressed their agreement about the presence of recycling initiatives or programmes expressly aimed at managing waste from solar PV panels. Conversely, just 32% of the participants expressed disagreement, as illustrated in table 5.10.

Table 5.10 1: Recycling initiatives or programs specifically targeting waste from solar PV panels

Recycling initiatives targeting solar waste	Frequency	Percent	Valid percent	Accumulative percent
Strongly agree	5	5%	5%	5%
Agree	14	13%	13%	18%
Neutral	52	50%	50%	68%
Disagree	20	19%	19%	87%
Strongly disagree	14	13%	13%	100%
Total	105	100%	100%	

Source: Author, (2023)

5.4.3.5 Increase in EoL waste from solar PV energy in the recent past

The researcher sought to find out whether or not there has been an increase in the accumulation of EoL solar panel waste in the recent past. Out of the 105 participants, the statistics revealed that 9% demonstrated a robust consensus. Furthermore, 50% of the participants agreed, whereas 30% neither agreed nor disagreed, 9% expressed disagreement, and 3% strongly expressed

disagreement. Collectively, 59% of the respondents agreed, while 12% expressed their disagreement about having an increased in EoL waste from solar PV energy in the recent past as illustrated in table 5.11.

Table 5.11 1: increase in EoL waste from Solar PV energy in the recent past

Increase in EoL waste from Solar PV energy	Frequency	Percent	Valid percent	Accumulative percent
Strongly agree	9	9%	9%	9%
Agree	52	50%	50%	58%
Neutral	32	30%	30%	89%
Disagree	9	9%	9%	97%
Strongly disagree	3	3%	3%	100%
Total	105	100%	100%	

Source: Author, (2023)

5.4.4 To develop a Strategic Framework for Solar Photovoltaic (PV) waste management

5.4.4.1 Regulations and policies specifically targeting wastes from solar PV installations in Lusaka

The study sought to evaluate the existence of regulations and guidelines that particularly addressed waste from solar photovoltaic systems in Lusaka. The outcomes revealed that 10% of the participants strongly agreed, 17% agreed, 52% remained neutral, 12% disagreed, and only 8% severely disagreed. The data reveals that out of the 105 participants, 52% of the respondents expressed neither agreement nor disagreement, while 27% agreed and 20% disagreed, as depicted in table 5.12.

Table 5.12 1: Availability of regulations and policies specifically targeting wastes from solar PV

Regulations targeting solar waste	Frequency	Percent	Valid percent	Accumulative percent
Strongly agree	11	10%	10%	10%
Agree	18	17%	17%	28%

Neutral	55	52%	52%	80%
Disagree	13	12%	12%	92%
Strongly disagree	8	8%	8%	100%
Total	105	100%	100%	

Source: Author, (2023)

5.4.4.2 Mitigation measures for the potential negative implications identified in waste management during the transition to solar PV energy

5.4.4.2.1 Designate strategic for solar PV collection points

In order to formulate a Strategic Framework for Solar Photovoltaic (PV) waste management that would address the potential negative effects of waste management during the shift to solar energy, the study purposefully sought input from a variety of experts in Lusaka regarding the inclusion of strategic solar PV collection points in the framework. The results indicated that 40% of the participants expressed strong agreement, 54% expressed agreement, 6% stayed neutral, while no individuals expressed disagreement or strong disagreement. The data indicates that among the 105 participants, a total of 94% stated agreement, while just 6% neither agreed nor disagreed, as shown in table 5.13.

Table 5.13 1: Designate strategic for solar PV collection points

Designate strategies for Solar PV collection points	Frequency	Percent	Valid percent	Accumulative percent
Strongly agree	42	40%	40%	40%
Agree	57	54%	54%	94%
Neutral	6	6%	6%	100%
Disagree	0	0%	0%	100%
Strongly disagree	0	0%	0%	100%
Total	105	100%	100%	

Source: Author, (2023)

5.4.4.2.2 The producers and importers have to accept responsibility for the EoL treatment of their products or they are subjected to large fines.

With regards to establishing the mitigations measures for the potential negative implications identified in waste management during the transition to solar PV energy to include in the formulation of the Strategic Framework for Solar Photovoltaic (PV) waste management, the study sought to get the input from various experts identified purposively in Lusaka whether or not the framework should include producers and importers have to accept responsibility for the EoL treatment of their products or they are subjected to large fines. The outcomes revealed that 40% of the participants strongly agreed, 54% agreed, 6% remained neutral, while none disagreed or strongly disagreed. The data reveals that out of the 105 participants, cumulatively 94% of the respondents expressed their agreement while only 6% neither agreement nor disagreement as depicted in table 5.14.

Table 5.14 1: The producers and importers to accept responsibility for the EoL solar panels

Producers/Importers taking responsibility	Frequency	Percent	Valid percent	Accumulative percent
Strongly agree	56	53%	53%	53%
Agree	37	35%	35%	89%
Neutral	6	6%	6%	94%
Disagree	4	4%	4%	98%
Strongly disagree	2	2%	2%	100%
Total	105	100%	100%	

Source: Author, (2023)

5.4.4.2.3 Set up of solar panel waste recycling facilities

The study aimed to gather input from multiple experts specifically identified in Lusaka regarding the establishment of mitigation measures for potential negative impacts in waste management during the shift to solar PV energy. Specifically, the experts were asked if the framework should include the establishment of recycling facilities for solar panel waste under the jurisdiction of the Ministry of Environment and Green Economy. The results indicated that 58% of the participants

expressed strong agreement, 38% expressed agreement, and 2% had a neutral stance, while 1% expressed disagreement and severe disagreement, respectively. According to the statistics, 96% of the 105 participants agreed, 2% disagreed, and 2% neither agreed nor disagreed, as shown in table 5.15.

Table 5.15 1: Establishment of solar panel waste recycling facilities

Establishing waste recycling facilities	Frequency	Percent	Valid percent	Accumulative percent
Strongly agree	61	58%	58%	58%
Agree	40	38%	38%	96%
Neutral	2	2%	2%	98%
Disagree	1	1%	1%	99%
Strongly disagree	1	1%	1%	100%
Total	105	100%	100%	

Source: Author, (2023)

5.4.4.2.4 Develop public awareness strategy on handling and disposal of solar PV panels and impact on the environment

In order to incorporate appropriate measures for addressing the potential negative effects of waste management during the transition to solar PV energy into the Strategic Framework for Solar Photovoltaic (PV) waste management, the study aimed to gather input from selected experts in Lusaka. The study specifically sought to determine whether the framework should encompass the development of a public awareness strategy regarding the handling and disposal of solar PV panels and their environmental impact. The results indicated that 73% of the participants expressed strong agreement, 25% expressed agreement, 1% stayed neutral, and 1% strongly disagreed. According to the data, out of the 105 participants, a total of 98% expressed agreement, 1% disagreed, and only 1% neither agreed nor disagreed, as shown in table 5.16.

Table 5.16 1: Develop public awareness strategy on handling and disposal of solar PV panels

Developing public awareness	Frequency	Percent	Valid percent	Accumulative percent
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Strongly agree	77	73%	73%	73%
Agree	26	25%	25%	98%
Neutral	1	1%	1%	99%
Disagree	0	0%	0%	99%
Strongly disagree	1	1%	1%	100%
Total	105	100%	100%	

Source: Author, (2023)

5.5 QUALITATIVE DATA ANALYSIS

Semi-structured interview guides were used to get specific information from key informants about the potential negative implications of transitioning to solar PV energy on waste management in Lusaka. Table 5.17 below shows the characteristics of the respondents.

Table 5.17 1: Characteristics of the respondents

S/n	Institution	Designation	Code
1	Zambia Environmental Management Agency (ZEMA)	Senior Environmental Inspector	A1
2	Solar Energy Association of Zambia (SEAZ)	Senior Member	A2
3	Lusaka Integrated Solid Waste Management Company Limited (LISWMCL)	Environmental Health Inspector	A3

Source: Author, (2023)

5.5.1 Ascertain the extent of adoption of solar PV in Lusaka

The researcher aimed to identify the extent of solar PV energy adoption in the city of Lusaka and assess the level of public knowledge regarding the on-going shift to solar photovoltaic (PV) energy. Government officials and experienced solar sector professionals were consulted. All three experts acknowledged that the rate of adoption and integration of solar PV energy into the energy mix was fair.

The respondent stated that the uptake of solar energy has been quite equitable in the past few years, particularly among persons who have the financial means to purchase complete sets of solar photovoltaic (PV) systems for residential use.

“Many members of the general public would have desired to acquire and implement solar PV systems in their residences, particularly due to the occurrence of load shedding in Zambia. However, the economic conditions have prevented ordinary Zambians from doing so”. [A1]

Respondent response: *“From my perspective and based on my observations, the adoption rate of these devices has been minimal, and the number of persons who have installed them remains exceedingly low within our communities”.* [A3]

The Respondent stated in an interview that the use of solar energy has significantly increased since the start of frequent power outages in 2015.

“On average, the public purchases three pallets of 340W monocrystalline panels per month, which is equivalent to 90 panels. The growth was driven by the combination of increased energy demand and population growth. The government's implementation of policies to exempt taxes on the majority of solar equipment has significantly influenced the widespread adoption of solar energy, especially among the ordinary population”. [A2]

Additionally, he noted that private solar system installers have increased the quantity of solar panels they supply, as they cater to several households.

5.5.2 Waste management challenges of PV solar in Lusaka.

Further, the researcher sought out to determine the waste management challenges of PV solar in Lusaka. The initial reply,

The respondent confirmed that challenges indeed exist and attributed them to the absence of comprehensive guidelines and regulations to direct the general public.

He asserted that *“there is a lack of awareness among people on the proper procedures for handling and disposing of solar panels once they have reached the end of their lifespan.”* [A1]

On the other hand, the second respondent also mentioned the following difficulties with Lusaka's waste management from PV solar:

"It can be very expensive and difficult to dispose of hazardous and electronic waste within the country as one may need to transport it off-site, sometimes even outside, to South Africa, where it can be destroyed in high-temperature thermal incinerators and destroyed." [A3]

A lack of proper waste management presents a significant health hazard to both the environment and the general population.

Respondent *three*: Based on the third informant's reveal, one significant problem that has been emphasised is the absence of a framework for the proper disposal of end-of-life (EoL) solar panels.

"There is a substantial influx of solar panels into Zambia which is an as favourable development due to the growing demand for energy and the rising appeal of solar energy as a clean alternative. However, there will be challenges associated with disposing of these accumulations once they reach their operational end of life (EoL)." [A2]

Respondent **A2** emphasised the necessity of developing dedicated infrastructure in our country to effectively manage and recycle solar panel waste and that multiple stakeholders had engaged in discussions to address the issue, however.

5.5.3 Ways mitigate the potential negative implications identified in waste management during the transition to solar PV energy

The experts discussed several efforts that may be implemented to encourage the eco-friendly disposal of end-of-life (EoL) solar panels used in solar systems. Their replies were as stated:

The initial response suggests that *"the government should give priority to the creation of regulations and guidelines for electronic waste, specifically focusing on solar PV panels and other waste from solar systems. This would help to manage the entire life cycle of solar panels"*. [A1]

In addition, respondent **A1** proposed the establishment of recycling protocols for the solar panels. The informant suggested that the government should establish a favourable environment

for both domestic and international investors to invest in solar panel recycling plants within the country. Finally, he asserted that the worst-case situation would include establishing hazardous waste disposal sites specifically for the solar panel components that are not recyclable.

The Respondent **A3**, who was the second respondent emphasised;

“The importance of implementing community sensitization programmes about the proper management and disposal of solar waste. Such initiatives would benefit the general public and the entire nation”. [A3]

In addition, he emphasised the need for the government to establish recycling facilities in easily accessible locations.

The third respondent, Respondent **A2** stressed the importance of establishing End-of-Life (EoL) solar panel collection centres.

“Allocating dedicated sites for the collection and storage of decommissioned solar panels would significantly mitigate the improper disposal of these panels and facilitate local communities in identifying appropriate disposal methods after collection. The placement of these facilities should be strategic to ensure convenient drop-off locations for both residential and business users. In order to guarantee the recycling of the solar panels, he also expressed his hope for the government to build recycling facilities that would ensure the panels are handled in a suitable manner.” [A2]

Respondent **A2** also highlighted the importance of government and non-governmental organisations in promoting awareness and providing education to stakeholders.

“The government should initiate public awareness programmes aimed at educating solar panel owners, installers, and suppliers about the importance of appropriately disposing of them at the end of their lifespan. This entails teaching individuals on the benefits of recycling, as well as any potential environmental hazards associated with improper disposal.” [A2]

Respondent **A2** presented a compelling argument for the need to provide accurate guidance and resources for safe methods of disposing waste.

“One potential solution is the implementation of take-back programmes by solar panel manufacturers and/or importers. Upon reaching their operational End-of-Life (EoL) within these programmes, the responsibility of returning the solar panels lies with the providers or importers. This approach ensures that the panels are managed and disposed of appropriately by the entities possessing the most suitable resources and skills. Manufacturers and importers actively engage in the effective management of their products at the end of their life cycle by including take-back programmes into their operations. Government support in promoting recycling and recovery methods was emphasised as a crucial element of sustainable waste management initiatives.” [A2]

The response highlights the importance of establishing recycling facilities nationwide to offer specialised recycling methods for solar panels. These techniques are specifically designed to extract and reclaim valuable components that can be used to manufacture new panels or in various sectors, including silicon, glass, aluminium, and other elements. By implementing efficient recycling methods, EoL solar panels may significantly mitigate their adverse environmental impacts by maximising resource recovery.

Respondent **A2** emphasised the importance of collaborating with government entities and the solar industry association to review and incorporate the specific guidelines for solar panels into the extended producer responsibility programmes, despite the fact that these programmes already have clear guidelines for local producers.

“EPR programmes would enforce the proper disposal and recycling of end-of-life panels, holding foreign producers responsible for the whole lifespan of their goods. Engaging in global collaborations to establish uniform policies and procedures for the disposal and repurposing of solar panels could contribute to addressing this issue. These standards would streamline the implementation of uniform best practices worldwide and guarantee the formation of global recycling networks.” [A2]

5.5.4 Factors that have influence on the adoption and successful implementation of solar PV energy in Lusaka

The researcher aimed to gather insights from informants with expertise in the environmental and energy sectors to understand the relationship between political environment, economic situation,

technological advancement, and climate change, and their impact on the adoption and successful implementation of solar PV energy in Lusaka. The replies were as stated:

5.5.4.1 Political environment

The initial answer, **A1** asserted that the government's strong determination facilitated the creation of a favourable environment for the establishment of solar farms like the Bangweulu solar plant. This was achieved through the involvement of the industrial development corporation (IDC) as an alternative solution to meet the growing energy requirements of the country.

“The government's elimination of import tariffs on solar systems has incentivized suppliers to increase their importation of panels. Simultaneously, this measure has facilitated price regulation, ensuring that both ordinary citizens and farmers can afford these systems. However, in terms of waste management, the growing number of solar panels poses a challenge in terms of their disposal.” [A1]

The informant stated that the absence of clear guidelines and regulations has had a negative impact on waste management. This is mostly due to the growing importation of solar panels, which ultimately become waste after reaching the end of their lifespan. Furthermore, the country lacks the necessary recycling facilities to facilitate the proper disposal of these panels.

In an interview, the second respondent, **A3** expressed that political influence has had a fair and positive impact.

“The creation of the Ministry of Green Economy & Environment demonstrates the government's dedication to transitioning to clean energy, specifically through the adoption of solar PV energy. In regards to the influence on management of waste, the government has assigned the general people with the responsibility of submitting recommendations on waste recycling, with the intention of providing funding for the most exceptional plan. This is an endeavour aimed at establishing a long-lasting waste management system that is environmentally friendly and can be maintained throughout time.” [A3]

5.5.4.2 Economic situation

According to the first respondent, **A1** *“Lusaka's economic circumstances have had a negative effect on the uptake of solar PV energy since the average Zambian cannot afford to purchase solar systems, even if they so choose.”* [**A1**]

The second responder, **A3** indicated that the general population has not fully embraced solar energy due to financial constraints. The informant also mentioned that the economy has not been favourable for the average Zambian in recent times.

5.5.4.3 Technological advancement

The initial informant **A1** promptly asserted that the adoption of solar PV technology has had minimal impact on waste management in Lusaka due to its recent introduction to the market and the extended durability of solar panels. Nevertheless, the Respondent **A3** noted that no observable influence has been detected thus far. However, they acknowledged the possibility of future harm as the continuous influx of this technology persists.

5.5.4.4 Climate change

The researcher sought input from experts to establish the correlation between the adoption of solar PV energy and climate change. The objective was to determine if climate change impacts the transition to solar PV energy.

Respondent **A1** disclosed that, *“Solar PV energy is one of the most suitable alternatives to other energy sources and has been welcomed by the government and the general public as a clean energy.”* [**A1**]

The second respondent, **A3** said that, *“The public has realised that solar energy is the best clean energy choice to fight climate change because of the effects of climate change that have been observed in Zambia during load shedding.”* [**A3**]

5.5.5 To develop a Strategic Framework for Solar Photovoltaic (PV) waste management.

5.5.5.1 Waste management regulations and guidelines that could address potential volume of waste from solar PV in Zambia.

When asked whether Zambia has waste management regulations and guidelines that could handle the possible amount of waste from solar photovoltaic systems, the following were the answers.

In general, the informants noted that there is a lack of precise regulations and guidelines to deal with the possible amounts of waste generated by solar PV in Zambia. More precisely, Respondent **A3** stated, "*The solid waste regulation and management act no. 20 of 2018 does not include any provisions specifically addressing solar PV and electronic waste.*" [**A3**]

5.6 CHAPTER SUMMARY

In order to fulfil the three research objectives, surveys and interviews were undertaken. The results are presented and analysed in this chapter. The initial section provided a quantitative analysis of the findings, focusing on the assessment of the potential negative implications of converting to solar PV energy on waste management in Lusaka. The study primarily employed a five-point Likert scale to assess the respondents' level of agreement or disagreement. Furthermore, the relationship between the independent and dependent variables was established through the application of descriptive statistics.

The study utilised qualitative analysis to communicate the findings obtained from the interview guide by carefully examining the data gathered from the semi-structured interviews. The findings derived from this chapter were used as a model for developing a Strategic Framework to manage the disposal of photovoltaic (PV) waste produced by Solar PV systems in the Lusaka area

CHAPTER SIX

DISCUSSION AND ANALYSIS OF RESULTS

6.1 INTRODUCTION

This chapter outlines the primary findings of the study, which sought to assess the potential negative implications of transitioning to solar PV energy on waste management in Lusaka. The discussion will follow the particular research questions that are already laid out in the first chapter.

6.2 DISCUSSION OF FINDINGS

This section offers an in-depth discussion of the research findings through a comparison of the findings with the previously studied literature from the second chapter. The discussions of the main findings indicated below were presented following the order of the research objectives

6.2.1 The extent of adoption of solar PV energy

The study revealed that most individuals who were surveyed in Lusaka acknowledged that the rate of use of solar PV electricity has indeed increased in the recent past. Hence, a total of 59% (comprising 48% who agreed and 11% who strongly agreed) of the participants expressed their agreement with the fairness of the adoption rate of solar PV energy. The study revealed that 56% of the respondents, comprising 46% who agreed and 10% who strongly agreed, acknowledged that three or more out of ten households located in different residential parts utilised solar photovoltaic (PV) energy. The factors that significantly contributed to the widespread adoption of solar PV energy were acknowledged and appreciated. These factors include the political environment (78% agreement, mean=3.97, std=0.98), economic situation (90% agreement, mean=4.42, std=0.79), technological advancement (78% agreement, mean=4.03, std=0.96), and climate change (82% agreement, mean=4.24, std=0.92).

The results indicate a strong agreement that the adoption rate of solar PV energy has been satisfactory in recent years. This is supported by the widespread acceptance of solar PV energy among households in residential areas, including the use of solar rooftops, solar pumps, solar mini-grids, solar micro grids, solar parks, solar drinking water systems, and solar street lights.

These solar energy solutions have been widely appreciated in both urban and rural locations. Furthermore, the mean scores and standard deviations offered demonstrate that all the highlighted factors have had a major impact on a successful implementation of solar PV energy and the reliability of the data.

The study found that the political environment had a moderately beneficial influence on the successful adoption of photovoltaic (PV) energy. This conclusion was supported by both quantitative and qualitative data. The government's decision to eliminate import taxes on solar systems has encouraged merchants to increase their importation of panels. Simultaneously, this measure facilitated the implementation of price regulation on solar system kits, ensuring affordability for both ordinary citizens and farmers. Furthermore, the study revealed that the economic situation had a negative influence on the rate of adoption due the unfavourable economic conditions in the past year. Additionally, it was discovered that both technological advancement and climate change have a substantial and beneficial influence on the adoption and successful implementation of solar photovoltaic energy. Zambia's current increase of interest in solar photovoltaic (PV) technology can be attributed to the environmentally friendly, highly effective, dependable, and secure nature of solar energy.

The preceding findings about the level of adoption align with the research findings of Moreno-Garcia et al. (2016) and Osborne (2016), which indicated a significant global increase in the capacity of solar panels to 310 GW in 2016. According to Research (2016), it was projected that the capacity will increase significantly to 700 GW by 2020 and reaches a staggering 4500 GW by 2050 (IRENA: Stephanie Weckend, 2016). In addition, (Luo et al., 2008; Winneker, 2013; EPIA, 2016) predict that solar photovoltaic (PV) energy will surpass other ways of electricity generation and become the predominant source in the future.

Furthermore, the research revealed through both quantitative and qualitative data that the monthly income of an individual had a substantial influence on their decision to adopt solar PV energy, and that the general public did not completely embrace solar PV technology because of financial constraints. This is supported by Kachapulula et al. (2018), who stated that a considerable number of underprivileged individuals living in rural areas do not have access to energy since they cannot purchase the solar PV system kits. In addition, the study found a strong negative impact of the economic situation, as confirmed by Luiz and Muller (2011) and

Chirambo (2018). These researchers argue that the high cost of financing renewable energy projects has hindered the adoption of renewable energy technologies in Sub-Saharan Africa. A study conducted by Barry et al. (2011) supported this claim, revealing that the substantial initial costs associated with renewable energy projects can impede their expansion if there is a lack of financial management capabilities.

The research additionally determined that the adoption of solar PV energy has been positively influenced by both technology advancement and climate change. According to Xu et al. (2018), there has been a substantial rise in the use of solar photovoltaic (PV) panels. The cumulative capacity of these panels, which was approximately 1 gigawatt (GW) in 2004, has already reached around 470 GWs as of 2017. This represents an anticipated annual growth rate of over 20%. Studies conducted by Luo et al. (2008), Winneker (2013), and Xu et al. (2018) indicate that photovoltaic (PV) technology is projected to make a significant contribution to world energy consumption. This is because countries globally are making efforts to achieve clean energy. These findings are consistent with the findings of Bakhiyi et al. (2014) and Solar Power Europe, (2018), who asserted that solar energy, particularly photovoltaic technology, has gained worldwide interest in the past few years due to its eco-friendliness and ability to be scaled according to needed capacity. The desire for photovoltaic installation is evident in the current trend.

Lastly, the Author deduces that Zambia has seen a remarkable upsurge in the adoption of solar photovoltaic (PV) technology recently, based on the majority response. The Zambian government, faced with increasing demand for electricity, has significantly supported renewable energy efforts by fostering a positive political environment. This has led to the growing popularity of solar PV energy. Despite the country's poor economic performance in the recent past, its abundant sunshine resources and the falling cost of solar PV technology have made it an economically viable and alluring option for both urban and off-grid locations. Consequently, organisations and individuals have enthusiastically adopted solar PV systems, motivated not just by economic considerations but also in accordance with global endeavours to promote environmental sustainability and achieve climate change goals. Zambia's progress in adopting solar power demonstrates a promising path, representing a substantial advancement towards a more varied and environmentally friendly energy system for the country.

6.2.2 To determine the waste management challenges of PV solar in Lusaka

The research revealed that a significant proportion of participants in Lusaka admitted to being unaware of whether the general population has been struggling to dispose of EoL solar panels, while a minority of participants agreed that there is a difficulty in managing EoL solar photovoltaic (PV) waste. Therefore, a majority of 61% of the participants were uncertain, while just 30% (consisting of 12% who agreed and 18% who strongly agreed) expressed their agreement that managing EoL solar PV waste has posed a challenge. The study found that 87% of the respondents, with 57% strongly agreeing and 30% agreeing, recognised a lack of knowledge among the general public about how to handle and dispose of EoL solar panels. Additionally, 59% of the respondents acknowledged that they were unaware of any waste management infrastructure capable of handling the disposal of solar panel waste.

The research findings revealed that most residents of Lusaka have not yet encountered significant challenges related to the disposal of solar PV panels and demonstrated a lack of knowledge regarding any existing waste management facilities and recycling systems capable of handling solar PV panels. This is mostly owing to the relatively long lifespan of solar panels, which typically lasts between 25 and 30 years. However, a few individuals admitted to encountering difficulties that may have arisen from a limited number of defective panels and solar light fixtures. All the panels that have reached the end of their operational life are being disposed of in municipal dumpsites and natural environments.

These findings align with Yu's (2015) assertion that there is a shortage of sufficient collecting facilities for solar PV. Given the dispersion of PV systems over different geographic areas, it is imperative to build an efficient network for collecting and recycling them. In addition, the findings align with Bogacka et al., (2017) who emphasised the technical difficulties associated with recycling PV panels due to the diverse range of materials they contain. (Tao and Yu, 2015) emphasised the necessity of diverse recycling systems to accommodate the many types of PV panels and technologies (Das et al., 2016).

Additionally, these research findings align with Xu et al. (2018) who suggested that government agencies should actively promote the development of a recycling and safe disposal strategy for waste generated by photovoltaic (PV) panels. This has prompted numerous governments to formulate legislation aimed at addressing the solar PV waste management at the end of its

lifespan. Fthenakis et al. (2020) also said that strengthening the accountability of manufacturers is an effective strategy for managing solar PV waste, sometimes referred to as extended producer responsibility.

Ultimately, the Author deduces that the waste management complications linked to photovoltaic (PV) solar systems in Lusaka, Zambia, present a significant issue for the area's sustainable energy infrastructure. The upsurge in the adoption of solar PV technology has led to a corresponding increase in the build-up of electronic waste, which includes discarded solar panels and their associated components. The disposal and recycling methods for these materials are not keeping up with the rate at which they are being used, which can result in environmental risks and inefficiencies in resource utilisation. It is essential to address this deficiency in waste management to guarantee the enduring viability of solar energy initiatives in Lusaka. It is crucial for the government, industry stakeholders, and environmental organisations to work together in order to create successful policies, infrastructure, and awareness campaigns for the responsible management and recycling of PV solar waste. This will help reduce any adverse environmental implications and maximise the advantages of adopting renewable energy in the area.

6.2.3 To develop a Strategic Framework for Solar Photovoltaic (PV) waste management

The third and last objective of the research project was to provide a framework for managing waste from Solar Photovoltaic (PV) systems. This framework would specifically tackle the potential adverse impacts on waste management that may arise during the transition to solar energy. The objective is to support key stakeholders, including the government through the Ministry of Green Economy and Environment (MGEE), regulators (ZEMA), suppliers of solar PV systems, consumers, and the general public in the energy sector. The ultimate goal is to ensure the successful implementation of solar energy in the Lusaka District.

The study, employing quantitative statistics, determined that there were no clear regulations or guidelines addressing the management of waste generated by solar panels. The results of the research unequivocally demonstrate that, as time goes on, legislation and regulations pertaining to solar photovoltaic waste receive less focus. Nevertheless, recent studies have highlighted the importance of developing regulations and guidelines for the disposal of photovoltaic (PV) systems (Nain and Kumar, 2020; Shubbak, 2019). Although the long lifespan of solar PV panels, which typically lasts 25-30 years, currently masks the impact of the lack of guidelines and

regulations addressing waste management specifically for these panels, it is imperative to establish guidelines and regulations to tackle end-of-life (EoL) waste issues in the coming years.

6.2.3.1 Critical sustainable waste management measures for solar PV energy

The study revealed that the most crucial measures for effectively implementing solar PV and ensuring sustainable waste management are: raising awareness among people about the correct handling and disposal of solar PV panels (indicated by 27.37% of respondents), followed by the establishment of infrastructure and recycling facilities for solar panel waste (indicated by 26.80% of respondents). The establishment of strategic collection points for solar panels ranked third with 26.25% of respondents supporting it. Holding producers and importers responsible for the end-of-life treatment of their products, or imposing substantial fines, received support from 24.57% of respondents who expressed the need for regulations and guidelines to govern the life cycle of solar panels.

A holistic approach is necessary to effectively handle the sustainable handling and management of solar PV waste, as demonstrated by the study. Initially, it is imperative to build comprehensive regulatory frameworks to oversee the complete life cycle of solar panels. This involves implementing and enforcing eco-design regulations that incentivize manufacturers to integrate recyclable and ecologically sustainable components into the production process. The Zambian government, through the Ministry of Green Economy and Environment (MGEE), can have a significant impact by providing incentives for the adoption of certain techniques and imposing penalties for inappropriate disposal. Furthermore, the incorporation of EoL solar photovoltaic (PV) panels into extended producer responsibility (EPR) initiatives can ensure that manufacturers are held responsible for the removal and recycling of solar PV panels that have reached the end of their useful life. Hence, it is imperative to foster cooperation among industry stakeholders, government agencies, and environmental organisations to facilitate the formulation and execution of impactful policies.

Furthermore, it is crucial to build dedicated recycling facilities that are equipped with the requisite technologies to ensure the secure and effective processing of solar panels. The governments can facilitate the establishment of an advantageous environment for both domestic and foreign investors to allocate resources towards the development of solar recycling plants. Investing in research and development (R&D) is crucial for the advancement of recycling

technologies specifically designed for the distinctive composition of solar PV panels. This involves exploring techniques to effectively retrieve valuable substances like as silicon, glass, and metals while reducing the production of harmful waste. Collaboration among governments, commercial organisations, and research institutions is necessary to provide funding for research and development (R&D) projects focused on enhancing the sustainability of photovoltaic (PV) panel disposal. In addition, it is crucial to have public awareness campaigns that supplement these initiatives by providing education to consumers, businesses, and waste management authorities regarding the significance of appropriate disposal methods and the availability of recycling alternatives. Through the incorporation of these strategies, the sustainable handling of waste from solar PV panels can be accomplished, resulting in less harm to the environment and enhanced long-term advantages of solar energy. Moreover, it is crucial to construct strategic collecting centres in major urban and rural areas of Lusaka. These centres should function as handy locations where individuals, businesses, and solar installers may responsibly dispose of retired panels. Establishing a network of collecting locations guarantees the efficient acquisition of end-of-life panels, so preventing incorrect disposal and encouraging recycling. Engage in cooperation with local authorities, recycling corporations, and NGOs to construct and oversee these centres, promoting community involvement and consciousness. This strategic strategy enables the methodical and environmentally aware gathering of discarded solar PV panels, hence enhancing the overall sustainability of solar energy projects.

These findings on EPR were supported by (Shiue and Lin, 2012, WEEE DIRECTIVE, 2014), who opined that manufacturers of PV panels usually work with stakeholders who are concerned about the environment and who are going to look for expert EoL management solutions. As a result, manufacturers and recycling companies may encourage the recycling and reusing of EoL photovoltaic panels. The research agreed with Bernard's (2008) findings regarding the consequences of inadequate sustainable management of end-of-life (EoL) photovoltaic (PV) panels. It highlighted the potential health risks associated with exposure to heavy metals present in Crystalline Silicon (containing lead), Cadmium Telluride (containing cadmium and lead), and Copper Indium Gallium Selenide (CIGS) (containing cadmium, lead, and selenide). In addition, several studies (Kampa and Castanas, 2008; IRENA, 2016; Bang et al., 2018; Podoan et al., 2019; Mahmoudi et al., 2021) have provided examples that demonstrate the association of cadmium with adverse effects on the lungs, kidneys, and bones when it is absorbed into the

body. Similarly, exposure to lead has been found cause harm to the central nervous system. The study conducted using the qualitative method also supported the findings of Besiou and Van Wassenhove (2016), who found that many newly industrialised countries will produce affordable photovoltaic products without giving the same consideration to environmental standards as well established global producers. Implementing a compulsory prerequisite for enrolment in a collective recycling programme could serve as a potential strategy to encourage the participation in collecting and recycling initiatives for EoL PV panels, as well as the development of environmentally friendly products

With regards establishment of specialized recycling facilities, the research findings were supported by the findings of McDonald and Pearce (2010), who noted that while certain recycling strategies may not be financially viable, some businesses, like First Solar and Solar World, go above and beyond the law by facilitating in-house recycling facilities for photovoltaic panels. These organisations typically prioritise achieving competitive advantages by enhancing their green reputation. Therefore, the study emphasises the importance of initiating plans for the establishment of photovoltaic solar panel waste recycling infrastructure, in collaboration with Luo et al. (2008) and Winneker (2013). This need arises due to the projected significant increase in the quantity of solar panels, driven by the worldwide demand for PV electricity. The demand for PV energy has surged from 1 GW in 2004 to 57 GWs in 2015, representing a yearly increase of over 20%. This growth rate surpasses that of any other sector, which includes other arising renewable energy sectors. PV power has been proposed as the predominant form of new energy production in the future. This however, is despite Yamashita et al. (2003) and Wambach (2004) argument that only a handful of countries beyond the European Union are implementing measures since there is a limited supply of discarded PV panels accessible for recycling. This scarcity is a result of the extended lifespan of solar panels. The expense associated with recycling the panels outweighs the potential economic benefits of the method.

Furthermore, the study results with regards a lack of awareness and expertise regarding the proper management and disposal of waste generated from solar panels by the residents of Lusaka was in line with Joseph's (2006) assertion that governments can enhance awareness among citizens using social marketing initiatives and assure active participation of producers and installers through official education programmes on end-of-life (EoL) practices. Additionally, it

is necessary to promote the interchange of information and enhance the openness of supply chains in order to support the efficient management of EoL solar PV panels (Xu et al., 2018). In order to facilitate the recycling process of photovoltaic panels, manufacturers ought to offer unambiguous labelling of the goods they manufacture, including detailed information on product characteristics and materials composition, as suggested by Besiou et al. (2012). This will assist recycling companies in determining the most suitable method for recycling. The research results were further supported by the findings of Yin et al. (2014), who emphasised the significance of customers' environmental consciousness in effectively handling EoL PV products. Recycling practice is more common in societies that have a substantial amount of knowledge about the environment. In an investigation on mobile phone recycling practices, for example, it was found that environmentally conscious individuals are more likely to be prepared to pay for recycling. Additionally, Jiménez-Parra et al. (2014) found that individual end users who have a substantial amount of knowledge about the environment also tend to be willing to buy refurbished goods. This will motivate enterprises to encourage the implementation of collecting and recycling initiatives in order to have a competitive edge in the market. Hence, it is crucial for governmental and private organisations to enlighten the general populace about the comprehensive ecological and human health consequences of entire systems.

The study also found that setting up of specific locations for collecting and keeping track of solar panels that have reached the end of their useful lives will greatly reduce the likelihood of these panels being disposed of improperly and make it easier for nearby towns to dispose of their EoL solar panels in a safe manner. To provide easy drop-off places for both residential and commercial users, these stations should be positioned strategically. This research analysis collaborated Yu's (2015) finding that there is a scarcity of sufficient collection centres for solar PV. Given the widespread distribution of PV systems, it is imperative to build an efficient network for collecting and recycling them. More research further indicated that the biggest obstacle to controlling EoL PV panels is the intricacy of the EoL management procedure. This intricacy encompasses a variety of factors, such as the unpredictable return of EoL PV panels (Besiou and Van Wassenhove, 2016) and EoL solar PV supplies distributed across different geographic regions (Fthenakis, 2000). Bogacka et al. (2017) also confirmed the findings, emphasising the presence of technical obstacles in recycling PV panels due to the diverse range of materials they contain. Tao and Yu (2015) stated that a range of recycling technologies is

necessary to handle the diverse types of PV panels. Similarly, Das et al. (2016) underlined the importance of adopting recycling technology. Choi and Fthenakis (2010b) opined that it is crucial to promptly create collection and recycling facilities to encourage sustainable management of end-of-life solar PV panel waste. To reduce the costs associated with the EoL management system, an approach for both centralised and decentralised collection points is essential. This is especially true in remote and geographically isolated regions where logistics expenses can be significantly higher than in urban areas. The research also collaborated with the findings of Choi (2017), who emphasised the importance of incorporating capital expenses for opening collection points, logistical expenses for reverse logistics, the distance between collecting stations and recycling plants, as well as the distance between photovoltaic systems and collection stations. Both sufficient collecting stations and strong models for business are crucial for the proper management of end of useful life PV panels, as stated by Besiou and Van Wassenhove in 2016.

Lastly, the Author deduces that, the implementation of comprehensive mitigation measures is imperative for the sustainable management of solar PV panel waste. Establishing stringent regulatory frameworks, promoting eco-design standards, and enforcing extended producer responsibility programs are essential steps in holding manufacturers accountable for the life cycle of their products. Concurrently, investing in research and development for advanced recycling technologies is crucial to efficiently recover valuable materials while minimizing environmental impact. The establishment of strategic collection centers, coupled with public awareness campaigns, ensures responsible disposal at the community level. Through collaborative efforts between government, industry, and environmental stakeholders, these measures collectively contribute to the long-term sustainability of solar energy, minimizing waste and maximizing the environmental benefits of renewable power generation.

6.2.3.2 Rationale for developing the framework

According to Farrell et al. (2020), a framework is necessary to effectively communicate with stakeholders engaged in managing waste from solar photovoltaic systems, with the goal of promoting efficient use of resources. The study employed data obtained from a review of the literature, theoretical and conceptual analysis, as well as both qualitative and quantitative analysis to develop a Strategic Framework for the management of waste produced by Solar PV

systems. This was undertaken in order to address the third research question regarding the effective implementation of solar PV energy in Lusaka through the sustainable handling and management of EoL solar PV waste. The suggested framework aims to optimise the implementation of solar PV energy by assuring sustainable handling and management of EoL solar PV waste, in compliance with specified international and local regulatory requirements.

The research's framework was based on the circular economy (CE) idea, which posits that waste that has reached the end of its useful life can be utilised as a valuable source of additional resources, forming the foundation of a circular economy. A circular economy (CE), as defined by Arruda et al. (2021), is a transformative societal shift that eliminates waste and pollution, while ensuring the continuous cycling of products and resources within the economy, and the restoration of ecological systems. Hence, this method proposes a series of interconnected regenerative measures aimed at diminishing waste production and establishing frameworks for the retrieval of secondary raw materials (EMF, 2013; Kirchherr et al., 2017; Paulik, 2018). CE's environmentally conscious strategy emphasises the implementation of clean technologies and the reduction of raw materials (Andersen 1997, 1999; Sariatli, 2017). Therefore, the developed framework (Figure 7.1) specifically examines the interrelationships and connections between the transition to solar PV energy as an alternative for the growing energy demand, the management of solar PV waste, and how these interactions contribute to the successful implementation of solar PV energy in Lusaka.

6.2.3.3 Framework Validation

According to (Misra et al., 2012; Taylor, 2013), the efficacy of a metric depends on its validation, user comprehension, and a strong correlation between the parameter and the trait it intends to assess. Validation is the process of confirming that the framework accurately represents the characteristics of the complete population and is not limited to the specific sample size used in estimation (Arafat et al., 2016; Al Shamsi, 2019). Heale (2015) and Banda (2019) posited that the purpose of validating a framework is to ascertain its appropriateness for the targeted measurement. Therefore, validity increases the degree of trustworthiness and assurance in the framework.

The validated Framework for Solar PV waste management was assessed through the distribution of questionnaires and conducting semi-structured interviews with three (3) experts in the fields

of environment and energy. These experts were purposefully selected their profound understanding and expertise in national regulatory and legal frameworks, as well as in the areas of environment, energy, and waste management. The utilisation of purposive sampling strategies enabled the researcher to intentionally choose individuals who possessed the necessary capacity to furnish crucial information pertinent to examining the research questions (Alotaibi, 2019). The study's author highlights the flexibility of the created framework for making alterations in study.

6.2.3.4 Validation feedback

Table 6.1 1: Key informant’s feedback on thematic areas

No.	Thematic area	Comments	Informant credentials	Years of experience
1	Regulation and Guidelines	The framework should include enacting and enforcement of regulations mandating solar PV suppliers and/or manufacturers to adhere to eco-design standards, ensuring products are recyclable and environmentally friendly. Only products that are recyclable should be allowed into the country	<i>Master of Engineering (MEng), Nuclearing Energy Engineering Bachelor of Engineering (BEng), Environmental Engineering Institution: ZEMA</i>	8 years
2	Waste Handling Guidelines	Clear guidelines for the proper handling, transport, and disposal of end-of-life (EoL) PV panels, emphasizing environmentally responsible practices needed to be highlighted in the framework	<i>Master of Engineering (MEng), Nuclearing Energy Engineering Bachelor of Engineering (BEng), Environmental Engineering Institution: ZEMA</i>	8 years
3	Extended Producer Responsibility (EPR)	<ul style="list-style-type: none"> • Include legislation implementation: To enforce EPR legislation, making PV 	<i>Bachelor’s Degree, Development studies and political science</i>	9 years

		<p>manufacturers and/suppliers responsible for the collection, recycling, or safe disposal of their products at the end of their life cycle.</p> <ul style="list-style-type: none"> Financial Assurance: it should be clear in the frame that there is need for manufacturers/suppliers to provide financial guarantees deposited to the environmental protection fund (EPF) to cover the costs of recycling and proper disposal, ensuring accountability. 	<p><i>Master of Science (MSc)</i> <i>Environmental Management</i> <i>Institution: the Mission to Improve Global Health Through Innovation (MIGHTi)</i></p>	
4	Waste Monitoring and Reporting	<ul style="list-style-type: none"> Tracking System: The framework needed to include the implementation of a comprehensive tracking system to monitor the movement of PV panels from production to end-of-life, ensuring compliance with waste management regulations. Annual Reporting: in order to account for the potential volume of EoL solar panels, suppliers and commercial solar companies should be submitting annual reports on their waste management activities to ZEMA, promoting transparency 	<p><i>Master of Science (MSc),</i> <i>Project Management</i> <i>Bachelor of Science (BSc),</i> <i>Wood Science & Technology</i> <i>Institutions: Solar Industry Association of Zambia,</i> <i>Astronergy Solar</i></p>	11 years

		and accountability.		
5	Public Awareness Programs	<ul style="list-style-type: none"> • Education Initiatives: Develop comprehensive public awareness campaigns to educate consumers, businesses, and solar installers about the environmental impact of improper disposal and the benefits of recycling PV panels. • Training Programs: Provide training for installers and maintenance personnel on proper handling and disposal procedures, emphasizing the importance of sustainable practices. 	<i>Master's degree, Sustainable land and environmental management</i> <i>Bachelor of Science (BSc), Environmental Health</i> <i>Institution: Lusaka Integrated Solid Waste Management Company Limited</i>	5 years
6	Strategic Collection Centres	Set up strategically located collection points in urban and rural areas, providing convenient and responsible disposal options for individuals, businesses, and solar industry professionals.	<i>Bachelor of Engineering (BEng), Environmental Engineering</i> <i>Institutions: EIZ, DICHEM Limited</i>	21 years
7	Recycling Facilities	Establish specialized recycling facilities equipped with advanced technologies for efficient recovery of valuable materials, meeting environmental standards.	<i>Master of Engineering (MEng), Nuclearing Energy Engineering</i> <i>Bachelor of Engineering (BEng), Environmental Engineering</i> <i>Institution: ZEMA</i>	8 years
8	Collaboration and	<ul style="list-style-type: none"> • Government-Industry 	<i>Master of Science (MSc),</i>	12 years

	<p>Stakeholder Engagement</p>	<p>Collaboration: Foster collaboration between government agencies, PV importer/suppliers, recycling firms, and environmental NGOs to align efforts and resources towards sustainable waste management practices. Also, Despite the Ministry of Environment & Green Economy not having been an informant, it needed to be included in the framework among the critical institutions.</p> <ul style="list-style-type: none"> Community Engagement: Establish solar PV waste management committees to encourage local communities to actively participate in waste management initiatives, creating a sense of responsibility and ownership. 	<p><i>Energy Policy</i> <i>Master of Business Administration (MBA),</i> <i>Business Administration and Management: General</i> <i>Bachelor of Science(BSc),</i> <i>Forestry</i> <i>Certified Expert in Climate and Renewable Energy</i> <i>Finance</i></p>	
9	<p>Incentive Mechanisms</p>	<ul style="list-style-type: none"> Tax Incentives: Introduce tax incentives for PV recyclers and/suppliers adopting sustainable practices and incorporating recyclable materials into their products. Recognition Programs: Develop recognition programs to acknowledge businesses and 	<p><i>Master of Science (MSc),</i> <i>Energy Policy</i> <i>Master of Business Administration (MBA),</i> <i>Business Administration and Management: General</i> <i>Bachelor of Science(BSc),</i> <i>Forestry</i> <i>Certified Expert in Climate</i></p>	<p>12 years</p>

		communities demonstrating excellence in PV waste management.	<i>and Renewable Energy Finance Institutions: GIZ, BIOFIN (Biodiversity Finance Initiative)</i>	
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Source: Author, (2023)

6.2.3.5 Analysis of feedback

The researcher examined the comments provided by the validators for each thematic area and embraced all the recommendations put out by experts. Nevertheless, the researcher did not concur with a few views, as indicated below:

- i. Incentive Mechanisms: The researcher disagreed with the introduction of tax incentives for PV manufacturers and/ or suppliers adopting sustainable practices and incorporating recyclable materials into their products. This is because the government's decision to abolish import tariffs on solar systems has incentivized merchants to ramp up their importing of panels.
- ii. Extended Producer Responsibility (EPR) and inclusion of legislation implementation: The researcher disagreed with the suggestion to implement EPR legislation, which would require PV manufacturers to assume responsibility for collecting, recycling, or safely disposing of their goods at the end of their life cycle. The researcher instead emphasized the need for the framework to prioritize suppliers in order to establish an agreement with manufacturers who are willing to accept the end-of-life (EoL) panels when they are no longer functional. It is imperative to incorporate this aspect into the process of formulating regulations and guidelines to guarantee that the letter of agreement is submitted to the regulatory authority prior to permitting importation.
- iii. Financial Assurance: In response to the expert's comment, which said it should be clear in the framework that there is need for manufacturers to provide financial guarantees deposited to the environmental protection fund (EPF) to cover the costs of recycling and proper disposal, ensuring accountability. The researcher appreciated the suggestion, but it

is important for the framework to prioritize the suppliers rather than the manufacturers, as the country does not have any solar PV manufacturers.

6.3 CHAPTER SUMMARY

The findings which were derived from the specific study objectives are discussed and analysed in this chapter. This chapter's content is consistent with the research findings presented in the fifth chapter. The following chapter provides the recommendations and conclusions that were drawn from the research findings. The chapter additionally presents a strategy framework for managing waste generated from Solar Photovoltaic (PV) systems.

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATIONS

7.1 INTRODUCTION

This chapter summarises the conclusion that was reached after the study findings were analysed and discussed. It also offers recommendations for how to solve the research problem. It aims to achieve the previously stated objectives by examining the research questions. The chapter additionally delineates the research's contribution to the existing body of knowledge and highlights the limits of the study.

7.2 CONCLUSION OF THE RESEARCH FINDINGS

The study was aimed to assessing the potential impending negative implications of transitioning to solar PV energy on waste management in Lusaka. The study purposefully and thoroughly analysed the level of solar PV adoption and revealed patterns of adoption in order to provide significant insights into the current state of solar PV energy integration. The study further investigated the waste management challenges related to PV solar in order to pinpoint important problems, including as the accumulation of solar PV waste and regulatory gaps, underscoring the pressing need for customised strategies. Finally, the development of a Strategic Framework for Solar PV waste management encompasses practical measures to tackle the identified challenges, providing a comprehensive roadmap for stakeholders to navigate the complexities of transitioning to solar PV energy and waste management integration. The research questions were addressed in accordance with the following specifications:

7.2.1 What is the extent of adoption of solar PV in Lusaka?

The extent of solar photovoltaic (PV) adoption in Lusaka demonstrates a positive trend towards the integration of renewable energy and current energy mix. The study concluded that there was a significant surge in the implementation of solar PV systems, spanning homes, businesses, and industrial uses in recent years. The study additionally established that the adoption of solar photovoltaic energy is driven by factors such as technological advancement and climate change, which contribute to an increasing recognition of the environmental advantages of such energy

sources. Furthermore, a favourable political environment has led to a reduction in the costs of solar technology. On the same objective, the study also concluded that the broad use of solar energy has been further facilitated by government initiatives, which encompass various incentives and regulations. The observed positive trend indicates a transition towards sustainable energy practices in Lusaka, in line with international endeavours to decrease dependence on conventional energy sources and address the impacts of climate change.

7.2.2 What are the existing waste management challenges of PV solar in Lusaka?

The Author sought out to determine the waste management challenges of PV solar in Lusaka. The study established that the waste management challenges linked to solar photovoltaic (PV) systems in Lusaka were complex, highlighting significant lack of infrastructure and solar panel recycling facilities, information sharing, and regulatory frameworks. The study concluded that a lack of awareness on the correct methods for managing and disposing of EoL solar panels had resulted in unintentional and incorrect disposal practices such as poor disposal of solar panels in conventional landfills, hence generating environmental risks and impeding the feasibility of efficient recycling.

Furthermore, the study established that there was lack of specialised infrastructure and recycling facilities for the potential volume of solar panel waste available. This was due to the complex structure of PV panels which necessitated specialised procedures for the safe disposal and recovery of materials. As a result of unavailability of suitable infrastructure, the city would encounter challenges in executing efficient recycling initiatives, resulting in a substantial environmental impact linked to PV solar panels. In addition, the research found that there were no strategically placed collection stations for solar PV waste which exacerbates the potential problem, since there were no places for the general public, institutions, and the private sector to dispose of their EoL solar panels. Therefore, it is crucial to set up easily accessible and evenly distributed collection stations in order to promote environmentally friendly disposal practices and avoid the improper dumping of photovoltaic (PV) waste.

The study further established that there were absence of clear regulations and guidelines to regulate the life cycle of solar PV panels that contribute to the challenges faced in Lusaka. That meant that a comprehensive regulatory framework is necessary to address issues such as EoL

management, recycling standards, and the responsibilities of various stakeholders in the solar industry and guidance for the general public. Lastly, the study concluded that there was lack of a system to track waste accumulating from solar panels which hampers the ability to monitor and manage the EoL solar panels effectively. The study further, established that implementing a tracking system was vital for maintaining transparency, ensuring compliance, and informing strategic decision-making in the sustainable handling and management of solar PV waste in Lusaka. The study lastly concluded that addressing these challenges requires collaborative efforts from stakeholders, including government bodies, the private sector, and the local community, to develop and implement effective waste management strategies aligned with the city's commitment to sustainable energy practices.

7.2.3 Develop a Strategic Framework for Solar Photovoltaic (PV) waste management

The framework was put together by the Author based on data obtained from a comprehensive analysis of existing literature, study outcomes, and expert validation. The purpose of the framework is to function as a tool for policy makers in the environment and solar energy sector, specifically to promote sustainable waste management in relation to the effective adoption of solar PV energy, not only in Lusaka but throughout the entire country. Figure 7.1 depicts a Strategic Framework for managing waste from Solar Photovoltaic (PV) systems.

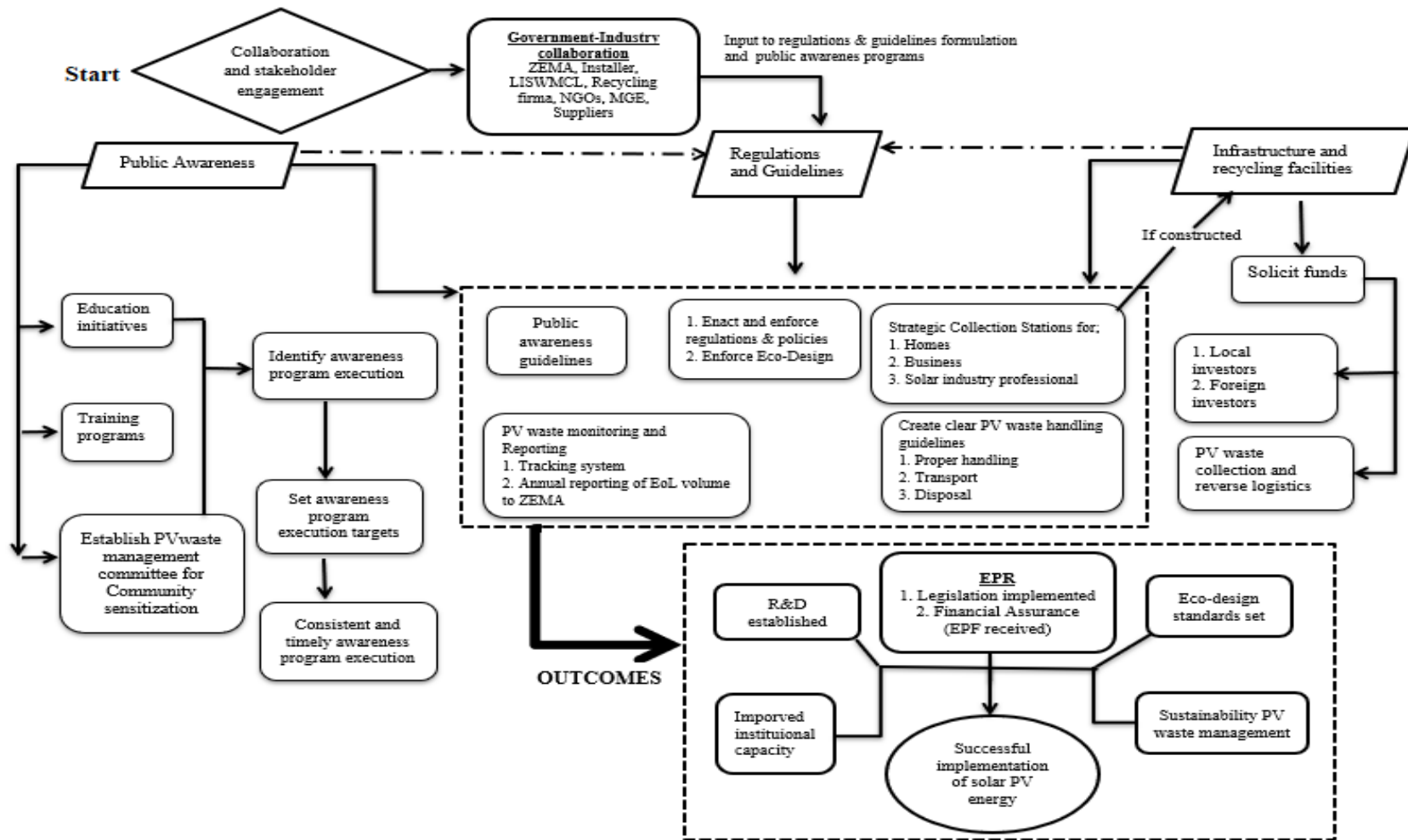


Figure 7.1 1: Proposed Strategic Framework for Solar Photovoltaic (PV) waste management

Source: Author, (2023)

7.3 RECOMMENDATIONS

This research study outlines the following recommendations:

i. **Strategic Framework for Solar Photovoltaic (PV) waste management**

The study recommends implementing the Proposed Strategic Framework for Solar Photovoltaic (PV) waste management in Lusaka, as it incorporates the key components necessary for a successful implementation of solar PV energy. The Proposed Strategic Framework is a comprehensive plan that aims to effectively tackle the developing challenges related to the disposal and recycling of EoL solar panels. The framework prioritises the implementation of strict and comprehensive regulatory procedures that regulate all stages of the solar panel life cycle. This involves applying Extended Producer Responsibility (EPR) programmes to make sure that manufacturers actively engage in the proper disposal and recycling of their products, as well as incorporating eco-design concepts into production processes. The essential guidance to reduce environmental risks related to inappropriate disposal of EoL PV panels will be provided by these regulations.

In addition, the Framework recommends the establishment of strategic collection stations that will have a crucial impact on the framework's effectiveness. These collection points will serve as convenient spots for consumers, businesses, and private companies to responsibly dispose of their end-of-life (EoL) solar panels. The collection locations will be carefully placed in both urban and rural regions of Lusaka to ensure convenience and promote wider participation in sustainable waste management practices. In addition, the framework emphasises the significance of public awareness programmes aimed at educating community members about the environmental consequences of photovoltaic (PV) waste and the advantages of recycling. Workshops, outreach programmes, and instructional materials will be utilised to cultivate a culture of accountability and engaged involvement in the appropriate disposal of EoL solar panels.

The suggested framework highlights collaboration as a central topic, underscoring the importance of forming relationships among government bodies, environmental organisations, and industry stakeholders. These partnerships will play a crucial role in implementing and improving the framework, promoting inventiveness, and guaranteeing that waste management

policies are adaptable and responsive to changing circumstances. The Strategic Framework aims to establish a durable and effective solar PV waste management system in Lusaka by integrating these components. This effort is in line with worldwide sustainability objectives and supports the city's dedication to a cleaner and more resilient future.

ii. **Institutional capacity**

The study also recommended that the Ministry of Green Economy and Environment, along with its implementing agency (ZEMA), should regularly educate rural communities about the negative environmental consequences of improper disposal of EoL solar PV waste and the advantages of recycling. This education should be conducted on a quarterly basis to ensure its effectiveness and consistency. These efforts should prioritise highlighting the necessity of adopting sustainable practices and increasing awareness about the value of solar PV recycling and its positive impact on environmental conservation. In order to achieve this, the study further recommended enhancing institutional capacity and ensuring efficient and prompt coordination among the Ministries in charge of Environment and Energy, implementing agencies such as ZEMA, Zambia Electricity Supply Corporation Limited, and Rural Electrification Authority, the Energy Regulation Board, and collaborating partners. The study saw this recommendation as crucial for fostering a mind-set of appreciation and recognition of the costs related to incorrect EoL disposal of solar PV waste. Finally, this would promote a state of equilibrium between socioeconomic progress and environmental sustainability.

7.4 FUTURE RESEARCH AREAS

The study proposed the following as possible areas of further/future research;

The study aimed to assess the potential impending negative implications of transitioning to solar PV energy on waste management. Hence, the study proposes conducting analyses of Circular Economy Approaches to PV Waste: Focus on circular economy models for managing EoL solar PV waste in Lusaka. The research could examine recycling technologies, resource recovery, and the development of secondary markets for recycled PV materials. The study further proposes assessing the economic viability and environmental benefits of circular approaches and its contribution to sustainable waste management strategies.

The study was limited to Lusaka city due to funding and time constraints. Therefore, it is recommended that similar research be undertaken in other locations to further examine and expand upon the findings.

7.5 CONTRIBUTIONS TO THE BODY OF KNOWLEDGE

The primary contribution of this research is the creation of a Strategic Framework for managing waste from Solar Photovoltaic (PV) systems. The study illuminates important environmental and regulatory factors by addressing the issues connected with end-of-life solar panels and their waste. This understanding is crucial for policymakers, industry stakeholders, and the general public as they navigate the shift to solar energy, guaranteeing a proactive and sustainable method for handling waste in the changing energy environment. Additionally, this study helps to fill the gaps in existing literature regarding the potential negative implications of shifting to solar PV energy.

7.6 LIMITATIONS OF THE STUDY

The limitations faced during the undertaking of the study were as outlined below:

- i. The researcher personally funded the collecting of quantitative data in the city of Lusaka. Consequently, it had a dual impact on the researcher, both in terms of financial and physical strain. In addition, there was a potential for misinterpretation by certain targeted organisations, encounters with aggressive canines or theft (since not all residences were accessible by vehicle and certain organisations denied the researcher entry). These risks posed significant obstacles to the data collection process. Nevertheless, a substantial and representative sample was attained.
- ii. Several respondents expressed the opinion that the questionnaire was excessively long, which prevented them from being able to complete it. As a result, this hindered the achievement of complete involvement from all participants.
- iii. Collecting qualitative data from the informants proved to be difficult as half of them refused to grant access to the desired experts for interviews due to misunderstandings and other obligations. Additionally, some informants would only delegate the task after persistent reminders. This posed an obstacle to acquiring more comprehensive data promptly.

7.7 CHAPTER SUMMARY

Zambia, like other countries, faces challenges in successfully implementing solar PV energy and managing solar PV waste while maintaining environmental sustainability. This study has highlighted the political environment, technological advancement, economic situation, and climate change as the primary factors influencing the adoption of solar PV energy in Lusaka, with the aim of achieving a successful energy shift. This study additionally revealed significant challenges linked to the disposal of products at the end of their lifespan. The findings emphasised the risks associated with improper waste disposal, the absence of a strategic framework for managing solar PV waste, and the potential negative environmental impacts of accumulating PV waste. In order to address these challenges and lessen the potential negative implications of the increasing use of solar PV technology, the research recommended that proactive strategies be developed as soon as possible.

The study proposed a strategic framework that included enacting stringent regulations and guidelines, increasing public awareness campaigns, and setting up collection stations for solar panels that have reached the end of their operational lives in strategic locations. The purpose of these measures is to promote environmentally friendly PV waste management practices, thereby guaranteeing the environmental sustainability to the solar PV energy shift. The findings obtained from this study provide significant information to the field, directing policymakers, industry stakeholders, and communities towards a more sustainable and responsible approach to PV waste management in the growing solar PV industry.

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APPENDIX I: Framework Instruction Manual

The framework presents a comprehensive 5-step instruction and approach for the implementation of the framework. This includes the formulation of solar PV waste management guidelines, implementation of Solar PV Energy Regulations and the establishment of strategic locations for PV waste collection centres. The framework incorporates the integration of solar PV waste management infrastructure and recycling facilities, as well as the development of educational programmes aimed at raising awareness and educating the public about the significance of appropriate PV waste disposal and recycling. By adhering to these steps, individuals with a vested interest can collectively establish a resilient solar photovoltaic waste management structure in Lusaka, Zambia, fostering sustainable processes and environmental guardianship.

Step 1: Conduct a consultative meeting to develop guidelines for managing photovoltaic (PV) waste. The objective is to create a complete policy that ensures the efficient management of waste from solar PV systems, using an inclusive and collaborative approach.

Instructions:

- i. Organize a stakeholder consultative gathering comprising delegates from governmental entities, environmental organisations, energy industry experts, waste management authorities, and community representatives.
- ii. Conduct discussions to determine the main factors, challenges, and areas of focus for the management of solar PV waste in the specific local setting.
- iii. Cooperatively develop criteria for managing waste from photovoltaic systems, including procedures for collecting, transporting, recycling, and disposing of the waste.

Step 2: Implement Solar PV Energy Regulations to establish a regulatory structure that requires responsible procedures in the manufacturing, installation, and disposal of solar PV systems.

Instructions:

- i. Coordinate with pertinent government departments to formulate and implement rules that expressly pertain to solar photovoltaic (PV) energy systems and their whole life cycle.

- ii. Implement regulatory enforcement measures, such as penalties for failure to comply, in order to guarantee adherence to the regulations.
- iii. Disseminate the regulations extensively among industry stakeholders, installers, and consumers via official channels.

Step 3: Recommend suitable sites for establishing strategic PV waste collecting centres to optimise PV waste retrieval and streamline recycling operations. The positioning of these facilities should be strategic to guarantee convenient drop-off points for both residential and business users.

Instructions:

- i. Perform a geographic study to determine regions with significant concentrations of solar photovoltaic (PV) systems and evaluate the ease of garbage collection in such areas.
- ii. Suggest precise sites for the establishment of photovoltaic (PV) trash collection centres, taking into account their close proximity to both urban and rural solar PV systems.
- iii. Engage in cooperation with local authorities to obtain the required permissions and approvals.

Step 4: Develop PV waste management infrastructure and recycling facilities to develop a system for the proper management, recycling, and disposal of PV waste.

Instructions:

- i. Create and execute plans for establishing and operating PV waste collecting centres, which will include specific zones for organizing and temporarily storing the trash.
- ii. Engage in partnerships with recycling facilities or build dedicated recycling units with the capacity to handle photovoltaic (PV) components.
- iii. Guarantee adherence to environmental regulations for waste management facilities.

Step 5: Develop strategies for public awareness campaigns aimed at increasing public knowledge and educating them about the significance of appropriate disposal and recycling of PV waste.

Instructions:

- i. Create educational resources and initiatives to educate the public about the ecological consequences of photovoltaic (PV) waste and the significance of responsible disposal.
- ii. Engage in partnerships with nearby educational institutions, community establishments, and media platforms to distribute information.
- iii. Conduct workshops, seminars, and outreach programs to actively involve communities and tackle their concerns.

APPENDIX II: Research Questionnaires



SCHOOL OF POSTGRADUATE STUDIES

RESEARCH QUESTIONNAIRE

My name is Valentine Mutale Palangwa, a postgraduate student pursuing a Master of Environmental Management at the University of Lusaka, conducting research on the potential impending negative implications of transitioning to solar photovoltaic (PV) energy on waste management in Lusaka, Zambia.

Lusaka, a bustling metropolis, is currently experiencing a significant transition towards solar photovoltaic (PV) energy. This transformation exhibits potential for sustainable energy, although it also prompts inquiries regarding its influence on waste management practises. This study aims to gain detailed insights into the potential downsides and challenges that may arise from this shift, based on your experiences.

The study aims to provide a thorough understanding of the level of solar PV adoption in Lusaka, as well as the waste management challenges that locals and stakeholders encountered during this transition. It will do this by examining a number of dimensions, including the political environment, the economic situation, technological advancements, and climate change factors. Subsequently, a Strategic Framework for managing waste from Solar Photovoltaic (PV) systems will be created to guide and inform policy makers in the energy and environmental sectors on the successful implementation of solar PV energy in Zambia.

This research questionnaire aims to explore your experiences, perceptions, and observations in order to gain a thorough understanding of the challenges related to this substantial energy transition. This research is exclusively intended for educational purposes, and you have been purposefully selected to participate in it. Rest assured that your responses will be treated with

utmost confidentiality and solely utilised for educational reasons. Your important perspectives are essential for comprehending the challenges and possible solutions associated with waste management in the context of solar PV energy adoption.

Kindly fill out the enclosed questionnaire by answering the questions as honestly and completely as possible.

For any queries or challenges observed, kindly do not hesitate to forward them to my email address, valentine.mutale93@gmail.com, or cell phone number, 0976770811.

Thank you in advance for your valuable support

PART A: PARTICIPANTS PERSONAL INFORMATION

A1. What is your gender?

Male () Female () Prefer not to say ()

A2. What is your age range?

Below 30 () Between 30 and 40 () Between 40 and 50 () Above 50 ()

A3. What is your highest academic qualification?

Primary () Secondary () Tertiary ()

A4. What is your occupation?

Waste Management Professional () Policymaker/Government Official ()

Environmental inspector () Energy expert () Student ()

Other.....

A5. How much is your monthly income?

Below 1000 () Between 1000 and 10000 () Above 10000 ()

PART B: GENERAL INFORMATION ON THE POTENTIAL NEGATIVE IMPLICATION OF TRANSITIONING TO SOLAR PV ENERGY ON WASTE MANAGEMENT

i. To ascertain the extent of adoption of solar PV in Lusaka.

Kindly provide feedback on the following statement by indicating (X) where appropriate.

1B. in your opinion, how has the solar PV adoption rate in Lusaka been in the recent past?

No.	Statement	Agree	Strongly agree	Neural	Strong disagree	Disagree
1B1	The solar PV adoption rate in Lusaka been very good in the recent past					
1B2	In my area on 3 or more households have installed solar panels					
1B3	I am very much aware of solar PV energy adoption in Lusaka					
1B4	Has ones monthly income influence the adoption of solar PV energy?					

2B. in your opinion, which factor do you think has more influence on the adoption and successful implementation of solar PV energy in Lusaka?

No.	Statement	Agree	Strongly agree	Neural	Strong disagree	Disagree
2B1	Political environment					
2B2	Climate change					
2B3	Economic situation					
2B4	Technological advancement					
2B5	Regulatory and legal framework/policies					

ii. To determine the waste management challenges of PV solar in Lusaka

3B. in your opinion, how has this transition negatively impacted waste management practises in Lusaka?

No.	Statement	Agree	Strongly agree	Neural	Strong disagree	Disagree
3B1	Have you encountered challenges or difficulties in disposing of solar waste					
3B2	Is there lack of knowledge about waste management practices for end-of-life solar panels					
3B3	Is there lack of knowledge about the proper handling and disposal of solar panels and related components at the end of their lifespan?					
3B4	Are you familiar with the waste management infrastructure in Lusaka, such as recycling facilities for electronic waste and EoL solar panels and/or local dumpsite?					
3B5	Do you believe that the existing waste management infrastructure in Lusaka is equipped to handle the increasing amount of waste generated from solar PV installations?					
3B6	Are there any recycling initiatives or programs specifically targeting waste from solar PV installations in Lusaka?					

3B7	Has there been an increase in EoL waste from solar PV energy in the recent past?					
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iii. To develop a Strategic Framework for Solar Photovoltaic (PV) waste management

4B. Are you aware of waste management regulations and policies that could address potential volume of waste from solar PV in Zambia?

No.	Statement	Agree	Strongly agree	Neural	Strong disagree	Disagree
4B1	There are regulations and policies specifically targeting wastes from solar PV installations in Lusaka?					

5B. in your view, what could be done to mitigate the potential negative implications identified in waste management during the transition to solar PV energy?

No.	Statement	Agree	Strongly agree	Neural	Strong disagree	Disagree
5B1	Designate strategic solar PV collection points across the city of Lusaka					
5B2	The producers and importers have to accept responsibility for the EoL treatment of their products or they are subjected to large fines.					
5B3	Establish solar panel waste recycling facilities under the control of the Ministry of environment and green economy.					
5B4	Develop public awareness strategy on					

	handling and disposal of solar PV panels and impact on the environment.					
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The end

APPENDIX III: Interview Guides



SCHOOL OF POSTGRADUATE STUDIES

INTERVIEW GUIDE

My name is Valentine Mutale Palangwa, a postgraduate student pursuing a Master of Environmental Management at the University of Lusaka, conducting research on the potential impending negative implications of transitioning to solar photovoltaic (PV) energy on waste management in Lusaka, Zambia.

Lusaka, a bustling metropolis, is currently experiencing a significant transition towards solar photovoltaic (PV) energy. This transformation exhibits potential for sustainable energy, although it also prompts inquiries regarding its influence on waste management practises. Our goal is to gain detailed insights into the potential downsides and challenges that may arise from this shift, based on your experiences.

The study aims to provide a thorough understanding of the level of solar PV adoption in Lusaka, as well as the waste management challenges that locals and stakeholders encountered during this transition. It will do this by examining a number of dimensions, including the political environment, the economic situation, technological advancements, and climate change factors. Subsequently, a Strategic Framework for managing waste from Solar Photovoltaic (PV) systems will be created to guide and inform policy makers in the energy and environmental sectors on the successful implementation of solar PV energy in Zambia.

This interview aims to explore your experiences, perceptions, and observations in order to gain a thorough understanding of the challenges related to this substantial energy transition. This research is exclusively intended for educational purposes, and you have been purposefully selected to participate in it. Rest assured that your responses will be treated with utmost confidentiality and solely utilised for educational reasons. Your important perspectives are

essential for comprehending the challenges and possible solutions associated with waste management in the context of solar PV energy adoption.

Recording the interview will only occur upon the interviewee's consent.

PART A: PARTICIPANT PERSONAL INFORMATION

Name.....

Position.....

Contact.....

Organisation.....

Time spent in the organisation.....

PART C: INTERVIEW QUESTIONS

1. In your opinion, generally how has the solar PV adoption rate in Lusaka been in the recent past?

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2. As the institution, have you encountered challenges or difficulties with regards to disposing of solar panels by the general public?

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3. How aware is the general public with regards proper handling and disposal of solar panels and related components at the end of their lifespan?

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4. Are there any waste management infrastructure/ facilities in Lusaka for recycling for electronic waste and EoL solar panels?

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5. Do you any recycling initiatives or programs specifically targeting waste from solar PV installations in Lusaka to guide the public with?

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6. Has there been an increase in EoL waste from solar PV energy in the recent past?

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7. How do you track solar panel waste year-on-year (YoY) accumulation for the city of Lusaka?

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8. Are there any regulations and policies specifically targeting wastes from solar PV installations?

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9. In your view, what could be done to mitigate the potential negative implications identified in waste management during the transition to solar PV energy?

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10. To what extent do you think the political environment has influenced waste management practices during the transition to solar PV energy? Please provide examples.

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11. In your view, how has the economic situation in Lusaka affected the adoption of solar PV systems and its waste management during this energy shift?

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12. How has the adoption of solar PV energy technology impacted waste management practices in Lusaka?

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13. Do you perceive a connection between the transition to solar PV energy and climate change in Lusaka?

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The interview has ended, thank you for your time and support.