

Exploring the perceptions on the effectiveness of solid waste management of end-of-life photovoltaic installations in Gauteng

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PREFACE AND ACKNOWLEDGMENTS

Preface

As the world increasingly employs renewable energy, such as solar photovoltaic installations, to reduce greenhouse gas emissions and achieve the Kyoto Protocol target of net zero by 2050 (United Nations, 2024), the resultant consequence of this is the increasing rate of generation of End of Life (EoL) PV installations. With an approximated 25-year lifespan, an increasingly large number of solar panels are expected to reach the end of their lifespan by 2050 (Chowdhury *et al.*, 2020). The effective management of the waste stream presents a serious concern that urgently needs to be addressed for fear of negating the gains achieved towards the reduction of greenhouse gas emissions. The appeal of renewable energy, and more specifically, solar, is its net reductive effect on greenhouse gases. As the world races to resolve this challenge, another threat has emerged, the pollution of soil and water through the ineffective management of end-of-life (EoL) photovoltaic (PV) installations.

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A dream deferred is never a dream denied, Isaiah 40:31: *“they who wait for the Lord shall renew their strength; they shall mount up with wings like eagles; they shall run and not be weary; they shall walk and not faint”*. Thank You, Abba Father.

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ABSTRACT

As the world strives to achieve the Sustainable Development Goal of clean energy, halving the greenhouse gas emissions by 2030 and net-zero greenhouse gas emissions by 2050 (United Nations, 2024), the use of solar photovoltaic (PV) energy has gained widespread adoption. The popularity of solar PV in South Africa is partly due to the sustainability goals, but mostly due to the intermittent energy supply from South Africa's current power provider. The most populous province in South Africa, Gauteng, has embraced PV energy developments. PV installations in the province include small-scale urban solar farms, concentrated solar panels on high-rise corporate buildings and shopping malls, as well as individual installations for emerging enterprises, small businesses, and households. However, as Gauteng addresses one crisis, it faces another: the effective management of end-of-life (EoL) PV installations.

The aim of this research is to explore of perceptions regarding effectiveness of solid waste management related to EoL PV installations and provide recommendations for their effective management, with a focus on Gauteng as a case study area. To achieve this, the study firstly conducted a literature review to explore global practices for EoL PV installation management and secondly interviewed sixteen (16) stakeholders who were either involved in the field of energy management and development or waste management to understand their perceptions of EoL PV management in Gauteng.

The literature review revealed a global shift towards sustainability, not only in renewable energy use but also in the sustainable and circular management of waste generated by EoL PV installations. The interviews highlighted the current state of waste management in Gauteng and its connection to EoL PV installations in the province. The general perceptions amongst respondents were that they were concerned about the state of preparedness of the waste management services of Gauteng for the management of EoL PV.

Respondents highlighted several significant concerns in the management of (EoL) PV solar waste. These concerns included challenges in infrastructure management, insufficient enforcement of landfill prohibitions, a lack of viable recycling alternatives and implementation strategies, issues with the existing legal framework, a widespread lack of compliance among the public, and limited enforcement. Additionally, the government's capacity to enforce EoL PV solar waste management was deemed inadequate. This lack of enforcement was often attributed to poor understanding of the legal framework and the capacity of enforcers in the public sector. These concerns underscore the complexities and challenges surrounding the management of EoL PV solar waste. Finally, the dissertation provides recommendations towards more sustainable management of EoL PV solar waste.

Keywords: *Solid waste management; end-of-life photovoltaic installations; perceptions; Gauteng; South Africa*

ABBREVIATIONS AND ACRONYMS

AA:	Agreement Approach
BESS:	Battery Energy Storage System
BRICS:	Brazil Russia India China South Africa
CA:	Civil Approach
CaC:	Command and Control
COP:	Conference of the Parties to the United Nations
DFFE:	Department of Forestry, Fisheries and Environment
DLA:	Department of Legal Affairs
DPWI:	Department of Public Works and Infrastructure
DTIC:	Department of Trade, Industry and Competition
EI:	Economic Instrument
EAF:	Energy Availability Factor
EAP:	Environmental Assessment Practitioner
ECA:	Environment Conservation Act
EIA:	Environmental Impact Assessments
EM:	Electricity Ministry
EoL:	End-of-Life
EPR:	Extended Producer Responsibility
ESG:	Environment Sustainability and Governance
e-WASA:	e-Waste Association of South Africa
E-Waste:	Electronic Waste
FA:	Fiscal Approach

GDP:	Gross Domestic Product
IM:	Intelligence Ministries
IndWMP:	Industry Waste Management Plans
IWMP:	Integrated Waste Management Plans
ISO:	International Standardisation Organisation
LCA:	Life Cycle Assessment
MA:	Mutual Approach
NEMA:	National Environmental Management Act 108 of 1998
NEM:WA:	National Environmental Management Waste Act 59 of 2008
NEMWAA:	National Environmental Management Waste Amendment Act 26 of 2014
NGO:	Non-Governmental Organisation
NWMS:	National Waste Management Strategy
PA:	Participatory Approach
PCB:	Polychlorinated biphenyls
PV:	Photovoltaic
REDZ:	Renewable Energy Development Zones
REI4P:	Renewable Energy Independent Power Producers Procurement Programme
SDG:	Sustainable Development Goals
SECO:	Swiss State Secretariat for Economic Affairs
SONA:	State of the Nation Address
SoWR:	State of Waste Report
STEM:	Science Technology Engineering Mathematics
TCT:	Total Concentration Threshold

TLT: Threshold for Leachable Concentration

UN: United Nations

WEEE: Waste from electronic and electrical equipment

KEY DEFINITIONS

“**Airspace**” means an area of land where large amounts of waste material are buried under the earth (Oxford Advanced Learner's Dictionary, 2023).

“**Anthropogenic**” means of, relating to, or resulting from the influence of human beings on nature (Merriam-Webster Dictionary, 2023).

“**Command-and-Control**” means the setting of standards to protect or improve environmental quality (Philippine Institute of Development Studies, 2002).

“**Circular economy**” means

- a) To transition out of a ‘take, make, dispose’ linear model;
- b) Creating a system that allows for longevity, optimal use, refurbishment, remanufacturing and recycling of products and materials while maintaining a continuation of quality of products for the users, which can be achieved without loss of revenue or extra costs. (Said Business School University of Oxford , 2023).

“**Circularity**” means using plastics (or any resource) more efficiently by keeping the material in use for as long as possible, getting the most we can from the material during its use, and then recovering it to make new products. (America's Plastic Makers, 2023).

“**Constitution**” means the Constitution of the Republic of South Africa. 1996 (Act No. 108 of 1996).

“**Disposal**” means the burial, deposit, discharge, abandoning, dumping, placing or release of any waste into, or onto, any land (National Environmental Management: Waste Act 59 of 2008).

“**Economic Instruments**” are financial tools used to achieve a specific environmental objective, also known as fiscal instruments (Croner-i, 2023).

“**Electrolyte**” means a liquid that allows an electric current to pass through, especially in an electric cell or battery (Oxford Advanced Learner's Dictionary, 2023).

“**End of life**” in the context of manufacturing and product lifecycles, is the final stages of a product’s existence (Kirvan, 2023).

“**Energy Availability Factor**” of an Eskom power plant is the difference between the maximum availability and all unavailability expressed as a percentage. This excludes renewables, IPPs and international imports. (Eskom, 2023).

“Environment” means the surroundings within which humans exist and that are made up of—

- (i) the land, water and atmosphere of the earth;
- (ii) micro-organisms, plant and animal life;
- (iii) any part or combination of (i) and (ii) and the interrelationships among and between them; and
- (iv) the physical, chemical, aesthetic and cultural properties and conditions of the foregoing that influence human health and well-being (National Environmental Management Act 107 of 1998).

“Extended Producer Responsibility measures” means measures that extend a person’s financial or physical responsibility for a product to the post-consumer stage of the product, and includes –

- (a) waste minimisation programmes;
- (b) financial arrangements for any fund that has been established to promote the reduction, re-use, recycling and recovery of waste;
- (c) awareness programmes to inform the public of the impacts of waste emanating from the product on health and the environment; and
- (d) any other measures to reduce the potential impact of the product on health and the environment; (National Environmental Management: Waste Act 59 of 2008).

“Fiscal Approach” are financial tools used to achieve a specific environmental objective, also known as economic instruments (Croner-i, 2023).

“General waste” means waste that does not pose an immediate hazard or threat to health or to the environment, and includes— (a) domestic waste;

(b) building and demolition waste;

(c) business waste;

(d) inert waste

(e) any waste classified as non-hazardous waste in terms of the regulations made under section 69, and includes non-hazardous substances, materials or objects within business, domestic, inert, building and demolition wastes (National Environmental Management: Waste Amendment Act 26 of 2014).

“Hazardous waste” means any waste that contains organic or inorganic elements or compounds that may, owing to the inherent physical, chemical, or toxicological characteristics of that waste, have a detrimental impact on health and the environment (National Environmental Management: Waste Amendment Act, 2014 Act No 26 of 2014).

“Import” means any entry into the Republic other than entry for transit (National Environmental Management: Waste Act 59 of 2008).

“NEMA” means the National Environmental Management Act 107 of 1998 (National Environmental Management Act 107 of 1998).

“NEM:WA” means the National Environmental Management: Waste Act 59 of 2008 (National Environmental Management: Waste Act 59 of 2008).

“Life cycle assessment” is the calculation and evaluation of the environmentally relevant inputs and outputs and the potential environmental impacts of the life cycle of a product, material or service (The Department of Environmental Affairs and Tourism, 2004).

“Mutual Agreement” means multi-lateral private agreements supported by governments as a means of governance over environmental issues, similarly participatory approach (Bouwma *et al.*, 2015).

“Participatory Approach” means multi-lateral private agreements supported by governments as a means of governance over environmental issues, similarly participatory approach (Bouwma *et al.*, 2015).

“Photovoltaic (PV)” relates to the production of electricity at the meeting point of two substances that have been exposed to light (Oxford Advanced Learner's Dictionary, 2023).

“Pollution” means any change in the environment caused by—

- (i) substances;
- (ii) radioactive or other waves; or
- (iii) noise, odours, dust or heat,

emitted from any activity, including the storage or treatment of waste or substances, construction and the provision of services, whether engaged in by any person or an organ of state, where that change has an adverse effect on human health or wellbeing or on the composition, resilience and productivity of natural or managed ecosystems, or on materials useful to people, or will have such an effect in the future (National Environmental Management Act 107 of 1998).

“Rare-earth elements” means any of a series of metallic elements of which the oxides are classed as rare earths and which include the elements of the lanthanide series and sometimes yttrium and scandium (Merriam-Webster Dictionary, 2023).

“Recovery” means the controlled extraction or retrieval of any substance, material or object from waste to produce a product (National Environmental Management: Waste Act 59 of 2008).

“Recycle” means a process where waste is reclaimed for further use, which process involves the separation of waste from a waste stream for further use and the processing of that separated material as a product or raw material (National Environmental Management: Waste Act 59 of 2008).

“Renewable energy” means any naturally occurring, theoretically inexhaustible source of energy, such as biomass, solar, wind, tidal, wave, and hydroelectric power, that is not derived from fossil or nuclear fuel (Energy Information Administration, 2023).

“Respondent” means a person who gives a response or answer to a question that is asked especially as part of a survey (The Britannica Dictionary, 2023).

“Re-use” means to utilise the whole, a portion of or a specific part of any substance, material or object from the waste stream for a similar or different purpose without changing the form or properties of such substance, material or object (National Environmental Management: Waste Amendment Act, 2014 Act No 26 of 2014).

“Solid waste management” means the collecting, treating, and disposing of solid material that is discarded because it has served its purpose or is no longer useful (Nathanson, 2023).

“Sustainability” means the ability to continue economic, social, cultural, and environmental aspects of human society and the nonhuman environment (Oxford Reference, 2023).

“Sustainable development” means the integration of social, economic and environmental factors into planning, implementation and decision-making so as to ensure that development serves present and future generations (National Environmental Management Act 107 of 1998).

“Total Concentration Threshold” means the total concentration thresholds limits for particular elements or chemical substances in a waste, expressed as mg/kg (National Norms and Standards For The Assessment Of Waste Landfill Disposal, 2013).

“Threshold for Leachable Concentration” means the leachable concentration threshold limits for particular elements and chemical substances in a waste, expressed as **mg/l** (National Norms and Standards For The Assessment Of Waste For Landfill Disposal, 2013).

“Urban mining” means recovering and reusing cities’ waste materials, such as concrete, bricks, steel reinforcements, roofing materials, copper pipes or aluminium (Holcim, 2023).

“Waste” means –

- a) Any substance, material or object, that is unwanted, rejected, abandoned, discarded or disposed of, or that is intended or required to be discarded or disposed of, by the holder of that substance, or the holder of that substance, material or object, whether or not such substance, material or object, whether or not such substance, material or object can be re-used, recycled, or recovered and includes all waste as defined in Schedule 3 to this Act; or
- b) Any other substance, material or object that is not included Schedule 3 that may be defined as waste by the Minister by notice in the Gazette.

But any waste or portion of waste, referred to in paragraphs (a) and (b), cease to be waste –

- (i) Once an application for its re-use, recycling or recovery has been approved, or after such approval, once it is, or has been re-used, recycled or recovered;
- (ii) Where approval is not required, once a waste is, or has been re-used, recycled or recovered;
- (iii) Where the Minister has, in terms of Section 74, exempted any waste, or a portion of waste generated by a particular process from the definition of waste; or
- (iv) Where the Minister has, in the prescribed manner, excluded any waste stream or a portion of a waste stream from the definition of waste (National Environmental Management: Waste Amendment Act 26 of 2014).

“Waste classification” means establishing –

- a) Whether a waste is hazardous based on the nature of its physical, health and environmental hazardous properties (hazard classes); and
- b) The degree or severity of hazard posed (hazard categories) (Waste Classification and Management Regulations, 2008).

“Waste management activity” means any activity listed in Schedule 1 or published by notice in the Gazette under section 19, and includes –

- a) the importation and exportation of waste;
- b) the generation of waste, including the undertaking of any activity or process that is likely to result in the generation of waste;
- c) the accumulation and storage of waste;

- d) the collection and handling of waste;
- e) the reduction, re-use, recycling and recovery of waste;
- f) the trading in waste;
- g) the transportation of waste;
- h) the transfer of waste;
- i) the treatment of waste; and
- j) the disposal of waste (National Environmental Management: Waste Act 59 of 2008).

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CHAPTER 1 INTRODUCTION

1.1 Background

The world is becoming increasingly aware of the need for sustainable, clean energy. This awareness has prompted the innovation of technology that enables renewable energy. Renewable energy is defined as “*energy that is generated from a source such as wind, solar, hydropower, biomass and geothermal, that is replenished naturally, but have a limited amount of energy per unit of time*” (Energy Information Administration, 2023).

As sustainability and measures to address climate change continue to gain momentum throughout the world, renewable energy has taken centre-stage in achieving these aspirations (Dincer, 2000). Many countries now view solar photovoltaic (PV) energy as a technically feasible, economically viable and environmentally sustainable energy source (Pearce, 2002). The world at large has experienced an increase in the use of PV installations for the generation of renewable energy (Bojek, 2022). Similarly, the use of solar PV installations in South Africa has seen a dramatic increase over the past decade, mainly due to the inconsistent supply of energy in the country.

As the sole electricity generator and supplier, Eskom has increasingly struggled to meet the country’s energy demand, with an Energy Availability Factor (EAF) of only 52.56% as reported for the first nineteen (19) weeks of 2023 (Daily Investor, 2023). In instances where electricity is available, it is inconsistent and unreliable, as the country experiences regular bouts of load shedding that last anything from two hours to the entire day and longer (CSIR, 2021), depending on the area you live in and the extent of the constraint of the energy demand on the South African grid (Zubair *et al.*, 2021). The country’s struggle with intermittent power supply is a major business and investment detractor (Lenoke, 2017). As citizens resolve to take matters into their own hands, the risks of fire due to illegal electricity connections has seen an increase, which would subsequently cause an increase in air pollution (Selokela & Langerman, 2019). The potential for air pollution is aggravated because of the use of energy sources such as paraffin for cooking and waste for heating purposes in informal settlements, while industry burns diesel in generators to supplement their energy requirements (Burkhardt, 2023), which contributes towards the country’s already high greenhouse gas emissions with a status of the fifteenth highest emitter in the world (Akinbami *et al.*, 2021; Tomaschek *et al.*, 2016; Tiseo, 2023).

The South African government is under pressure to find solutions to the country’s energy crisis in the form of a consistent base load of energy that can be supplemented by renewable energy (Mapulane, 2016; Pan & Dinter, 2017), particularly in consideration of the country’s commitment to reduce carbon emissions and transform to a less coal dependent energy mix (Walker &

Jourdan, 2003) as well as the environment, sustainability and governance (ESG) commitments found on various corporate websites. As people adapt to the norm of intermittent power supply in South Africa, industrial and small scale as well as household PV installations have become increasingly popular (Green Cape, 2020).

According to the International Energy Association (IEA), installed solar global capacity has increased by ten-fold between 2010 and 2017 (Wanner, 2019). In 2020, the South African total estimated installed capacity reached nearly 2.5 GW, up from approximately 230 MW in 2010. The Energy Sector Report of 2021 reports that in 2018 South Africa's primary energy mix was made up of 65% coal, 18% crude oil, 11% renewable energy and energy derived from waste, 3% natural gas, 2% nuclear energy and 1% geothermal energy (Ratshomo, 2022; National Planning Commission in the Department of the Presidency of the Republic of South Africa, 2020).

As recorded in the National Development Plan (NDP), South Africa aims to transition to a low carbon economy and to achieve an integrated energy sector with adequate investment in infrastructure by 2030 (National Planning Commission in the Department of the Presidency of the Republic of South Africa, 2020). According to the Integrated Resources Plan (IRP), South Africa plans to add 6400 megawatts of embedded energy generation to its grid by 2030 (Department of Mineral Resources and Energy of the Republic of South Africa, 2020). As a means of effecting these plans and reducing the country's reliance on Eskom for the generation of electricity, the South African government announced the increase in the independent energy generation without a license threshold from one megawatt to 100 megawatts in August 2021, effectively exempting embedded electricity generating companies from licensing obligations with the National Energy Regulator (International Energy Agency, 2023). This announcement was published as an amendment to the Electricity Regulation Act 4 of 2006 (Department of Mineral Resources and Energy of the Republic of South Africa, 2021).

In an effort to address and reduce South Africa's energy deficit, the amendment was enacted with limited consideration for the consequent waste to be generated because of the increase in independent electricity producers that use PV as an energy source.

1.2 Problem statement and rationale for the study

As the world transitions from fossil fuels to renewable energy sources, partly in response to the oil embargo of the 1970s, but mostly in the global quest for sustainability as laid out in the Brundtland Commission (Kammen, 2006; Johnston *et al.*, 2007), countries have joined this quest as the use of solar PV has risen from a global capacity of 141,417 Megawatts (MW) in 2013 to unprecedented levels of 1,061,632MW in 2022, while locally, South Africa has also seen an increase in their PV installation capacity from in 262 MW in 2013 to 6 326 MW in 2022

(International Renewable Energy Agency, 2023). The positive trajectory illustrated in these statistics have been corroborated by recent news articles stating that there has been an increase in solar panel imports in the first half of the 2023 of a monetary value of R12 billion in comparison to R5.6 billion for the entire 2022 (Daily Investor, 2023).

One of the unintended consequences of increased use of solar PV is the waste generated as a result of the End-of Life (EoL) of the installations, which includes the battery energy storage systems (BESS), the glass components and the metal or mineral content of the PV cells that contain silica covered in boron, phosphorus that is laced with silver, cadmium and lead. All the latter are toxic elements while the mounting or installation infrastructure such as the metal frames that are made of tin, copper and aluminium have been proven to be harmful to living organisms (Motta *et al.*, 2016).

Furthermore, in acknowledgement and recognition of the imperfections of PV installations, the components of the installations may not necessarily last for the entire projected lifespan of twenty to 30 years. Challenges such as premature failure of the panels due to environmental factors, such as the recent (13 November 2023) hailstorms in Johannesburg, adversely affecting the panels and causing the degradation of the panel components (Mlambo, 2023), the use of sub-standard material, improper mounting and construction defects can cause failures before the predicted lifespan. These inadvertently result in the increased volumes of a new waste stream from EoL PV installations sooner than anticipated (Weckend *et al.*, 2016), that would only cause further strain on what is regarded as the limited resources and capacity of the waste management sector of South Africa (Weckend *et al.*, 2016).

Responsible waste management encourages the evolution of the economy away from a linear economy of extraction, production, consumption and disposal, towards an economy that is resource efficient and cyclical. A proponent of sustainable development, the waste hierarchy, though with a debatable level of efficiency, proposes the reduction or prevention of waste altogether, through re-use, or recycling of material, or through heat recovery from material through incineration (Price & Joseph, 2000). Only when all else has failed, is the least preferred option of waste management, landfilling, engaged (Nilsen, 2020). This process of waste management has been described by Lansink's ladder, which was developed in the late 1970s. The ladder has subsequently evolved into the waste hierarchy (Zhang *et al.*, 2022), further corroborating the sustainable and efficient management of the earth's finite resources and the waste generated as a result of production (Lansink, 2018).

As the global use of renewable energy responds to the calls of the Kyoto Protocol, ratified in 1997, that advocates for the reduction of greenhouse gas (GHG) emissions (Breidenich *et al.*, 1998), further opportunities for advancement of the global Sustainable Development Goals (SDGs)

(United Nations Department of Economic and Social Affairs, 2023) exist through the effective management of the EoL PV installations. Through an understanding of the composition of the various components of the PV installations, the generated waste can be classified and the appropriate legislative framework for the management of the waste stream can be established and acted upon (Weckend *et al.*, 2016). In this sense, waste from solar PV installations may present both opportunities and challenges.

The National Waste Management Strategy (NWMS) (Department of Environment Forestry and Fisheries, Republic of South Africa, 2020) has identified the need for effective waste management. Determined to address this need, the strategy has resolved to increase its support for the circular economy by way of legislation, resources, infrastructure and directives (Patel, 2014), while acknowledging the limitations and challenges that are faced by the country's municipalities (Department of Environment Forestry and Fisheries, Republic of South Africa, 2020). These include the ageing and inadequate infrastructure, the limited or lack of support from the national departments, diminishing airspace availability, municipal landfill sites that have a heavy presence of landfill waste reclaimers that complicate compliance of the landfills as they work in accordance to their own needs, with minimal consideration of the health and safety concerns of the landfilling operation, the illegal dumping of both domestic and hazardous waste as well as the unlawful disposal of waste despite the specified classification and prescribed directives (Rasmeni & Madyira, 2019; Afrika *et al.*, 2010; Maeteletja *et al.*, 2019; Niyobuhungiro & Schenck, 2020).

Though the country has developed plans to transition from a linear to a circular economy through programmes such as the ineffective Operation Phakisa (Department of Planning, Monitoring and Evaluation, 2014; Pretorius, 2018) and the NWMS (Department of Forestry, Fisheries and the Environment, 2021), the plans have not been realised. The country's circular economy is not supported by the relevant infrastructure, citizenry participation, active enforcement, availability of funds for infrastructure maintenance and development or capacity of officials who would be tasked with effecting the plans (Department of Environment, Forestry and Fisheries of the Republic of South Africa, 2022; Muzenda, 2012:156-157). In recognition of extent of the challenge at hand, the government has been deliberate about the inclusion of the private sector within waste management. Through the extended producer principle programme (EPR), the government has roped in the private sector to invest into the waste management infrastructure and the development of employment opportunities and markets for the less privileged individuals of the communities of the country at large. The private sector has been granted the responsibility of creating value for waste items, thus effecting sustainable development and management through the circular economy.

In this context, this research aims to explore perceptions on the effectiveness of solid waste management of end-of-life photovoltaic (EoL PV) installations. The research specifically focused on Gauteng as a case study area. The province was chosen because of its status as an economic hub of South Africa, as well as its high potential for the use of PV in the country (Mulaudzi *et al.*, 2022). In addition to this, South Africa's most populous province (Dlamini *et al.*, 2020), is also faced with a myriad of challenges that need to be addressed to sustainably develop the province (Ben-Eli, 2018) and effectively and inclusively manage its waste. Amongst its various priorities, the province (Dlamini *et al.*, 2020) has competing land use requirements such as housing and schools, and budgetary constraints affecting electricity and infrastructural maintenance and development. This results in limited resources for the upgrade and maintenance of infrastructure such as waste management facilities and landfill sites (Bikam & Chakwizira, 2021; The City of Johannesburg, 2020). These challenges are further exacerbated by legacy spatial planning that hinder accessibility to service delivery, ailing infrastructure and a population that is becoming increasingly agitated by challenges, such as poverty, unemployment and inequality (Mushongera *et al.*, 2015).

1.3 Research aim and objectives

The aim of this research is to explore the perceptions on the effectiveness of solid waste management of EoL PV installations, with the view of making recommendations towards the effective management of EoL PV installations. For this purpose, Gauteng was selected as a case study area.

To achieve the above aim, the research objectives are set as follows:

1. To explore the global practices of managing end-of-life photovoltaic installations; and
2. To explore the perceptions of end-of-life management of photovoltaic installations in Gauteng.

1.4 Delineation of the research scope

This research explores *perceptions* of the effectiveness of solid waste management of EoL PV installations in Gauteng. This research is specifically focused on the perceptions of people within the waste management, energy management, renewable energy project proponents, or any other field that is involved in the renewable energy or waste management sectors on the effective management of EoL PV installations.

The geographical scope of the research was focused on the *Gauteng province* as a case study area. Gauteng was chosen because of the proliferation of solar PV installations in the province, and its current challenges with waste management. Although the findings of the research are

applicable to Gauteng. The findings or parts thereof may be generalizable to other provinces in South Africa, with similar characteristics.

Furthermore, the research specifically focuses on *end-of-life (EoL) waste from solar PV installations* only. No waste from any other forms of renewable energy, such as wind-, hydro-, tidal-, geothermal- or biomass energy was included. In this case, EoL waste from PV installations include the solar panels, metal mounting frames, and the battery energy storage systems (BESS) only. No other waste streams related to the manufacturing, installation and maintenance of solar PV installations were included.

1.5 Significance of this research

The South African government has committed to addressing the country's carbon footprint and excessive emissions through, in part, the procurement of renewable energy from independent producers through the Renewable Energy Independent Power Producers Procurement Programme (REI4P) (Department of Mineral Resources and Energy of the Republic of South Africa, 2020). The programme is committed to installing almost 18 Gigawatts of renewable energy generation capacity between 2012 and 2030 (Walwyn & Brent, 2015). This increase in the use of renewable energy sources such as PV installations will ultimately result in an increase in the generation of waste from EoL PV installations, a trend that has already been identified globally (Geyer & Dominguez, 2018). This is a waste stream of concern as the components of PV installations are constituted of hazardous material such as lead, silica and silver, which, when handled incorrectly could cause harm to humans, animals and the environment (Oteng *et al.*, 2022).

The management of EoL PV installations, or any other renewable energy component for that matter, is currently not sufficiently addressed in the South African policy framework related to renewable energy (Department of Minerals and Energy of the Republic of South Africa, 2004). The Government Notice Number, GNR 1185 of 5 November 2020, of the National Environment Management: Waste Act (59 of 2008) regarding extended producer responsibility does not explicitly mention EoL PV installation, but rather makes inferences to these as the definition set out in the Schedule defines electric and electronic equipment as follows (The Department of Environment, Forestry and Fisheries, 2020): *means equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields designed for use with voltage rating not exceeding 1000 volts for alternating currents and 1500 volts for direct current;*

Equipment is further listed as (The Department of Environment, Forestry and Fisheries, 2020) (Department of Environment, Forestry and Fisheries, 2020):

- (a) *Large equipment (any external dimension more than 100 cm);*
- (b) *Medium equipment (any external dimension between 50 and 100 cm);*
- (c) *Small equipment (no external dimension more than 50 cm); and*
- (d) *Batteries.*

The ambiguity continues in the Regulation notices, GNR 1185 of 2020, as unlike the guidelines of the European Union, (European Commission, 2012; Chowdhury *et al.*, 2020), the EoL PV installations are not explicitly labelled and identified, and the framework leaves the inclusion of this waste stream to the interpretation of the producer of the product. This missed opportunity to directly regulate the waste stream is as much a pity as it is opportunity for the producers to contribute positively towards achieving South Africa's SDG by proactively engaging with the government while acting on the regulation for the management of EoL PV installations.

In line with the NWMS of 2020, the movement of waste up the waste management hierarchy is the preferred method of management waste management. However, we lag in South Africa as far as the implementation of the waste management hierarchy and the circular economy is concerned as 90% of the waste generated is still being disposed of in landfills (Department Of Environment, Forestry and Fisheries of South Africa, 2020). The significance of this research is to delve into the perceptions of EoL management of PV installations in Gauteng, and therefore highlight the state of readiness as perceived by various stakeholders for the management of the waste generated by EoL PV installations. It will also make recommendations towards the province's preparation, by addressing the current regulatory framework and capacity and availability of infrastructure, for the management of the increased volumes of the waste stream.

1.6 Structure and outline of the dissertation

This dissertation consists of five chapters, a bibliography and annexures.

The first chapter of the research introduces the topic of discussion, detailing the purpose of the research. It provides the background of the topic and rationale for the research, and the research aims and objectives. The chapter further delineates the scope of the research and discusses the significance of the research.

The second chapter is a literature review of the global state of solid waste management and the strategies and practices involved in managing waste, and more specifically, EoL PV installations. Taking the global commitment to sustainability into account, this chapter discusses the legal framework developed to manage solar PV EoL waste, the environmental management principles employed within the legal framework and the effectiveness thereof.

The third chapter outlines the research methodology and the steps taken to conduct the empirical research.

The fourth chapter is a discussion of the results obtained from the empirical research. The chapter provides a discussion of the research findings in line with what other authors have found.

The fifth chapter presents the conclusions and recommendations related to the research objectives.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter provides a review of literature related to solid waste management of end-of-life photovoltaic (EoL PV) installations. The purpose of the literature review is to provide context to the research, and to specifically address *Research Objective 1: To explore the global practices of managing end-of-life photovoltaic installations.*

Literature was sourced from Google Scholar, as well as from the North-West University Library Repository which gives access to databases of journals such as Sage, and Springerlink and journal and article platforms such as Science Direct. Added to this, reports, and published plans from the various governmental departments, including the Department of Forestry, Fisheries and the Environment as well as the Department of Planning, Monitoring and Evaluation within the Presidency were sourced. Information was also sourced from past dissertations of South African students that have conducted research that explores South Africa's challenges such as intermittent power supply and service delivery levels in the country's municipalities. Lastly, due to the contemporary nature of the topic, technical publications such as Engineering News and ReSource, and websites such as National Renewable Energy Laboratory (NREL) and Council for Scientific and Industrial Research (CSIR) discussing solar photovoltaic components and their recyclability as well as the implications of renewable energy of South Africa were also sourced for information. A concerted effort was made to maintain the search of literature to publications within the last five years, but there were areas of discussions, such as policy discussions and the sustainable management of waste that warranted use of literary sources that were older than five years, to help bring context, by showing where we come from as a people.

To extract information that is relevant to this research, the following keywords in different combinations were used: *"PV solar waste", "solar waste management", "End-of-life PV waste", "waste management", "Global management of end-of-life photovoltaic installations", "E-waste circularity", "E-waste recycling", "WEEE", "WEEE management legislation", "End-of-life photovoltaic installation components", "Circularity of PV installations", "EPR for WEEE"*.

There was a lot of information researched globally, including countries outside of Europe such as China, India, and the United States of America (USA), who are currently leading the charge for the uptake of renewable energy (International Energy Agency, 2022; Jaeger, 2021). Within the African context, South Africa is leading the continent with its renewable energy investment, despite Sub-Saharan Africa having the slowest electrification rate of emerging markets between the years 2010 and 2020 (Bloomberg Philanthropies, 2022). Considering this, literature pertaining to the management of End of Life (EoL) photovoltaic (PV) installations was mostly in the global

context, with a fair amount of literature referring to countries such as Germany, China and the USA. Locally, in South Africa, though we do have recent legislation, that was promulgated in 2020 and amended in 2021, that incorporates and infers to the effective and circular management of waste from PV installations. There was limited literature referring to the circular economy and renewable energy in Africa. One such article is by RG Charles and others, with the specific aim to research the sustainable management of this new waste stream in rural Sub-Sahara Africa (Charles *et al.*, 2021).

This chapter will begin by reviewing the global concerted effort to reduce greenhouse gas emissions and advance the global sustainable development goals through the use of renewable energy, particularly solar PV, placing particular emphasis on Gauteng, South Africa. It will then review the unintended consequences of renewable energy, the generation of the resultant waste stream through the photovoltaic installation value chain, sustainably managing the waste streams generated along the chain, the legal framework for the management of waste and its applicability to EoL PV installations, and the challenges of managing waste in Gauteng. The chapter will then close by discussing the global practices of managing waste generated from EoL PV installations.

2.2 Global increase in renewable energy installations

Founded in the anthropogenic need to develop in a sustainable manner according to five sustainable development principles, the list to follow describes the principles for sustainability. The first of these principles is the social principle. This is about the social interaction between humanity, humans and the environment, and humans and the animals on earth. The second principle, the spiritual principle, describes the human attitude and value system towards the earth and all its inhabitants. The third principle, material, is the regulation of the flow of raw material from the cradle that supports the existence of people on this earth. The fourth principle, economic, is the guiding framework for the creation and management of the wealth that is generated from the extraction of the earth's resources. The fifth and final principle, domain of life, is the management of this anthropogenic behaviour on the earth (Ben-Eli, 2018). These principles have also influenced the local legislative framework as the NWMS stipulates that global best practices were taken into account in developing the South African strategy and ultimately legislation (Department of Environment, Forestry, and Fisheries of the Republic of South Africa, 2020).

Through these principles, sustainability is affected as circularity gains popularity in waste and resource management (Isenhour *et al.*, 2016). The use of resource intensive primary energy or fossil fuels is scrutinised, while a transition to the use of renewable energy takes centre stage (Yang *et al.*, 2022). Renewable energy is defined as energy that is generated from a source such as wind, solar, hydropower, biomass and geothermal, that is replenished naturally, but has a limited amount of energy per unit of time (Energy Information Administration, 2023).

Through the global drive to net carbon zero status initiated by treaties such as the United Framework Convention on Climate Change that was ratified in 1992, was the foundation for international climate discussions such as the Kyoto Protocol (United Nations Climate Change, 2024) that advocate for the reduction of greenhouse gas (GHG) emissions through renewable energy sources have gained popularity throughout the world. Ratified in 1997, the Kyoto Protocol established the legally binding greenhouse gas emission targets for 37 industrialised countries (Breidenich *et al.*, 1998; United Nations Climate Change, 2024). Post the Kyoto Protocol was the Copenhagen Accord which endorsed the Kyoto Protocol through the provision of explicit emission pledges (Centre for Climate and Energy Solutions, 2024), while the Paris Agreement, that was a legally binding treaty on the mitigation of global warming (United Nations Climate Change, 2024).

Through the constant activity of transformative economic development, increased urbanisation and the improvement of economic circumstances of the population of the mostly developed nations, there has been a global increase in the level of waste generated (Singh *et al.*, 2014). The world's consumption patterns have come under scrutiny as researchers have explored the earth's capacity to sustain linear economic activity that derived its capacity to produce from the use of finite resources. Though deliberations pertaining to the sustainability of the rate of consumption of the world have been a long time coming, taking from early discussions on the subject through treaties being signed in Stockholm in 1972 (Sand, 2015), Brundtland Commission of 1987 (Meyer-Naimi & Vaez-Zadeh, 2012), change has been gradual and slow.

In an effort to speed up the adoption and enactment of sustainability, The United Nations Sustainable Development Conference in 2012, in Rio de Janeiro, introduced the collaborative Sustainable Development Goals (SDGs) to the world. These are a set of universal goals that were developed to meet the world's political, environmental and economic challenges (The United Nations, 2015). The subsequent Paris Climate Agreement, of which South Africa is a signatory, has become a legally binding international treaty on climate change that gives effect to the SDGs by placing a limit on the rise in global temperatures to '*well below*' two degrees Celsius through greenhouse gas reduction targets (United Nations Climate Change, 2015; Powell *et al.*, 2018). It also commits to the provision of financial support to developing nations to assist in achieving the world's net zero carbon target by 2050 (Doelle, 2016), of which effective waste management is one of the avenues of implementation of this commitment.

Motivated by the realisation of finite nature of the earth's resources (Drolet, 2015), stewardship towards the environment in the face of economic development (Elsheekh *et al.*, 2021), as well as the increasing cost of fossil fuels (Kreps, 2020), the world is in a process of actively transitioning towards the use of renewable energy sources (Chen *et al.*, 2019; Dincer, 2000).

2.2.1 Renewable energy installations in South Africa

As a country that has a bleeding economy and a frustrated population because of the load shedding that is imposed by the state-owned monopoly, Eskom, (Lenoke, 2017; Mabugu & Inglesi-Lotz, 2022) both households and industries have gravitated towards seeking out ways to mitigate the effects of load shedding in an environmentally friendly and sustainable manner. This is evident in the increase in the use of solar photovoltaic systems by households and industries (Thango & Bokoro, 2022), while the government has committed to addressing the country's carbon footprint and excessive emissions through the procurement of renewable energy from independent producers through the Renewable Energy Independent Power Producers Procurement Programme (REI4P). The programme is committed to installing almost eighteen gigawatts of renewable energy generation capacity between 2012 and 2030 (Walwyn & Brent, 2015).

In addition to REI4P, the South African government has identified key geographical areas where renewable energy, solar and wind energy, could be developed in concentrated zones, Renewable Energy Development Zones (REDZs). Through the published government notices, Government Notice Number 114 in Government Gazette Number 41445 of the 16th of February 2018, Minister Edna Molewa identified eight renewable energy development zones for the development of large-scale solar PV and wind energy generation facilities. An additional three zones were identified by Minister Barbara Dallas Creecy and were published in Government Notice Number 142, 144 and 145 in Government Gazette Number 44191 of the 26th of February 2021 (Department of Forestry, Fisheries and the Environment, 2023). Gauteng forms part of the Central Transmission Corridor proposed in the second phase of REDZs. The zones are depicted in Figure 2-1 to follow.

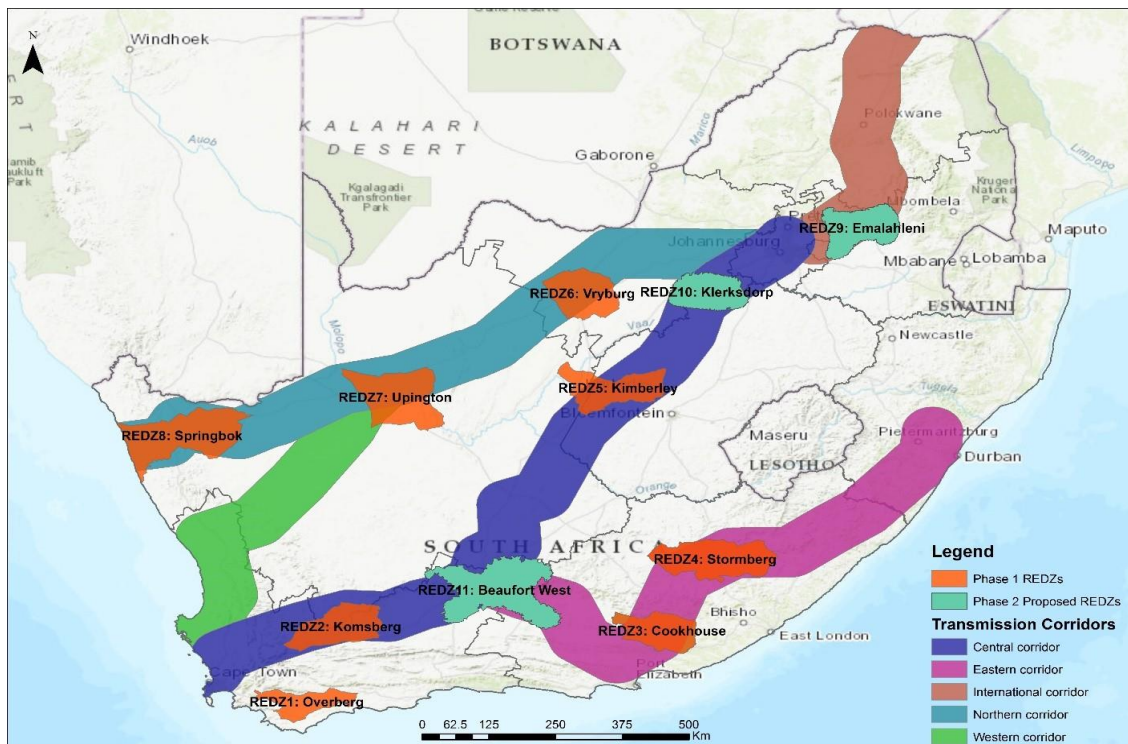


Figure 2-1: The eleven renewable energy development zones (Council for Scientific and Industrial Research, 2019).

While the *White Paper on Renewable and Clean Energy Development* of August 2002 bemoans South Africa’s heavy reliance on coal as a primary energy source and the resultant contribution of coal to the greenhouse gas emissions, and the government draws up policies and plans in a concerted effort to reduce emissions, the management of EoL PV installations, or any other renewable energy component for that matter, was not considered in the document (Department of Minerals and Energy of the Republic of South Africa, 2004). Particularly in light of the waste that would be generated throughout the utility scale renewable energy projects, as the generation of waste is not just limited to the end of its lifespan. The challenge with this approach is that the inclusion of renewable energy within South Africa’s energy mix is not just about greenhouse gas emissions reduction but is also about the contribution of renewable energy to the country’s sustainable development (Bugaje, 2006). The approach does not fully consider the carbon footprint of renewable energy, as it is only concentrated on greenhouse gas emissions at energy generation stage.

2.2.2 Solar PV installations in South Africa

In recent times, the country’s sole electricity generator and supplier, Eskom has struggled to meet South Africa’s energy demand with an Energy Availability Factor (EAF) of 52.56% as at the end of the first eleven weeks of 2023 (Daily Investor, 2023). In instances where electricity is available, particularly in the urban areas such as Gauteng, it is not consistently available, as load shedding has been employed as a form of grid protection from instabilities such as grid collapse (Zubair *et*

al., 2021). The country’s struggle with intermittent power supply is a major business and investment detractor (Lenoke, 2017) and a motivator for both corporate and private citizens to seek out alternatives (Engineering News, 2022).

As people adapt to the norm of intermittent power supply, PV installations have become increasingly popular in the South African industrial sector as well as with households (Green Cape, 2020). The turning point is succinctly expressed in Figure 2-2, towards the tail-end of 2022, after the Presidency announced the increase in the licencing threshold for embedded electricity generation from renewable energy from 1MW to 100MW in November 2021 (The Presidency of the Republic of South Africa, 2021).

While adoption was on the increase, in light of the intermittent energy supply from Eskom, the increase became exponential at the announcement of the tax incentive in February 2023 (The National Treasury of the Republic of South Africa, 2023) by the Minister of Finance during his budget speech. Figure 2-2 describes the increase in the number of imported solar panels into South Africa from China between September 2022 and January 2023 While Figure 2-3 describes the spike in solar capacity as a result of the imports over that same period (Hawkins, 2023).

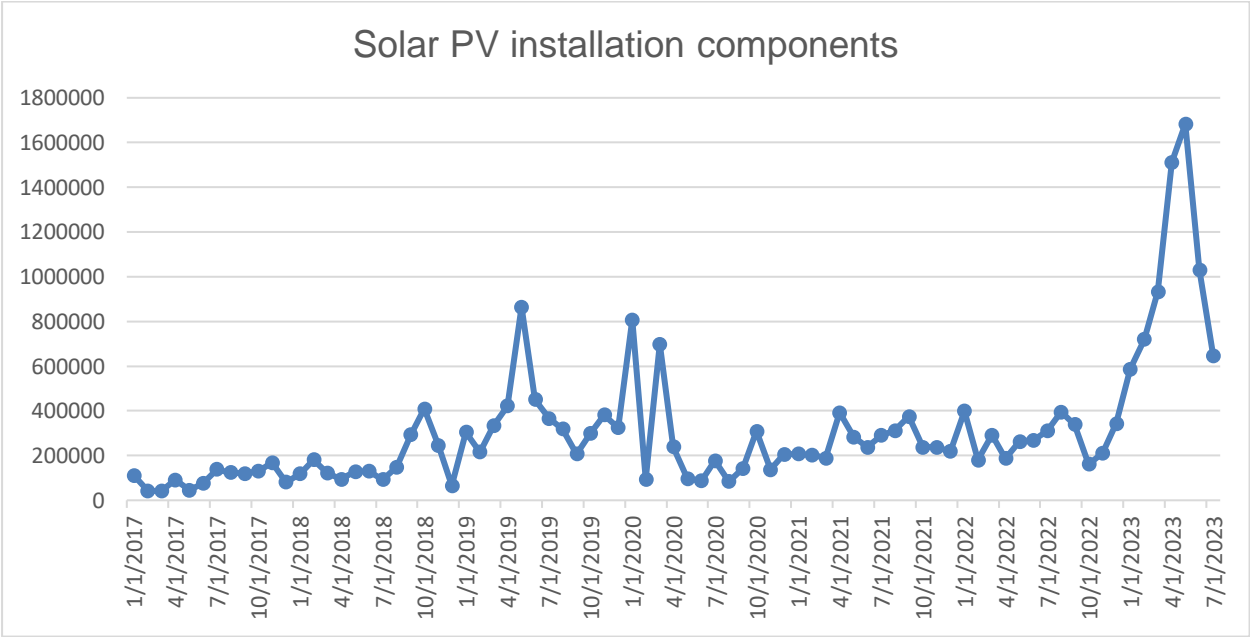


Figure 2-2: Number of solar PV installation components imported from China between January 2017 and July 2023 (Hawkins, 2023).

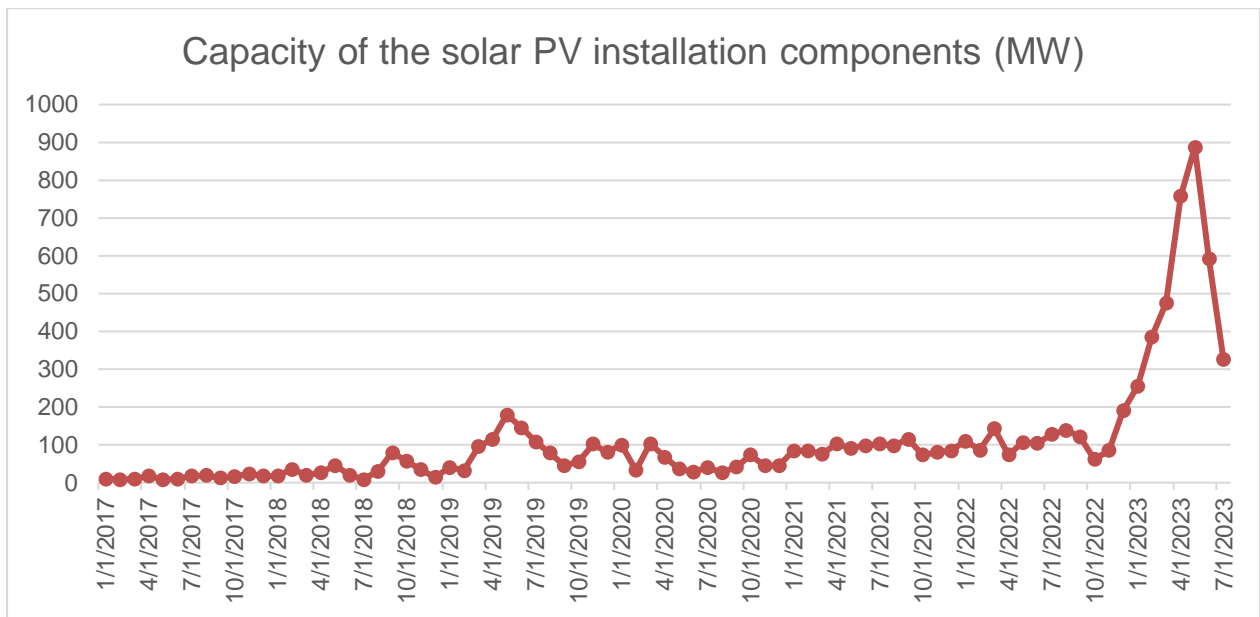


Figure 2-3: Capacity of the solar PV installation components imported from China between January 2017 and July 2023 (Hawkins, 2023).

While this addresses the immediate challenge of intermittent power supply, it gives rise to a new challenge in the form of waste generated because of the end-of-life (EoL) and incapacitated PV installations (ultimately an earlier than anticipated EoL). It is under these circumstances that the research into the level of consideration by Gauteng, over the waste that would be generated because of the EoL PV installations is conducted. In view of the waste management practices of Gauteng, chapter one introduced the challenges of the advent of a new waste stream, the EoL PV installations, that is an unintended consequence of a solution to a different challenge, load shedding. The introduced challenges as well as others that were identified in the literature will be delved into in the remainder of this chapter.

2.3 Unintended consequences of PV solar installations

In an effort to manage greenhouse gas emissions, effecting global discussions such as the Brundtland Commission (Hopwood *et al.*, 2005), the Kyoto Protocol (United Nations Climate Change, 1997), the Rio Declaration (Tokuc, 2013) of Agenda 2030's SDGs (United Nations, 1992; Strong, 1995), the complex matter of sustainability presented with it other challenges that needed to be considered and addressed. The strategy of decarbonisation through renewable energy responds to a variety of challenges. These can be listed as the Paris Accord (Baruch-Mordo *et al.*, 2019), the effect of the increase in the mining of rare-earth elements, the transformative use of land for PV installations, its impact on biodiversity as well as the waste generated throughout the value chain and lifecycle of photovoltaics. These challenges have come to light as a result of the use of large-scale solar PV installations. On the other hand, much like the large scale installations, household installations also face challenges with the effective

management of waste generated as a result of installation components that have lost their efficacy in some way before the stipulated life expectancy expiration of 20 to 30 years. Ultimately, though renewable energy sources such as solar PV are praised for their positive contribution to sustainability and good environmental governance, the sources are not the perfect answer to the challenge of sustainability as they still impact the environment in a negative manner (Zhang *et al.*, 2023).

2.3.1 Increased mining of rare-earth elements

Despite renewable energy's prospects of decarbonisation and the reduction of GHG emissions, the rare earth element composition of renewable energy installation present with them a serious environmental challenge (Nayar, 2021). These detrimental effects include damages such as soil erosion, deforestation, destruction of the vegetation and land, and the loss of biodiversity because of the extractive process that takes away the current ecosystem of a space to make way for utility scale projects, whether big or small (Macknick *et al.*, 2013). Furthermore, are the detrimental environmental health effects that the manufactured products would have at the end of their lifespan including radioactive exposure, ground contamination, vegetation destruction and much of the similar effects of the extractive process of mining the rare earth metal components (Oladipo *et al.*, 2023; Ali, 2014).

2.3.2 Transformation of land-use for large scale installations

Taking the large scale REDZ into consideration, in the context of a complex past in relation to land in South Africa, transforming the land for large scale renewable projects had to take various environmental, social, agricultural, economic and political implications into account, hence the regulated requirement for Environmental Impact Assessment (EIA) (The Department of Environmental Affairs, 2005). Though there have been amendments that were published in 2023 that sought to make the requirements less onerous on the developers (Creamer, 2023), it remains imperative that all relevant and impacted stakeholders are considered in the transformation of the use of land from its current purpose to that of a large or utility scale renewable energy installation.

Though this research has focused on Gauteng as the area of study, the land-use challenges are not just limited to this province, though at varying degrees due to the country's landscape and human habitat distribution. As South Africa's most populous province (Dlamini *et al.*, 2020), Gauteng is no different to the rest of the country with its myriad of challenges that need to be effectively addressed to sustainably develop the province (Ben-Eli, 2018). The economic hub of the country (Dlamini *et al.*, 2020) has competing land use requirements such as housing and schools and budgetary constraints such as electricity and infrastructural maintenance and development, resulting in limited resources for the upgrade and maintenance of infrastructure such as airspace for waste disposal for the province (Bikam & Chakwizira, 2021; The City of

Johannesburg, 2020). These challenges are further exacerbated by legacy spatial planning, ailing infrastructure and a population that is becoming increasingly agitated by challenges, such as poverty, food security, inadequate housing, limited recreational infrastructure for the youth, unemployment, and inequality (Mushongera *et al.*, 2015; Alexander, 2010).

Evidently, the challenge is a complex concern of political-economic and social sustainability. Consensus is not an easily attainable status, taking multi-sectoral stakeholders such as farmers, traditionalists, municipalities, environmentalist and environmental activists must be into account (Calvert & Mabee, 2011), through EIAs, as required by Appendix 3 of the NEMA Amendments to the Environmental Impact Assessment Regulations, Government Gazette Number 985 of 2014 (The Department of Environmental Affairs, 2014). Impacts on biodiversity of large-scale installations.

In a diverse world of many complexities, solutions may be simple, but few can be applied in a simple manner. They require careful thought, and compromise. In addition to the earlier described competing land-use requirements, large-scale (or utility scale) PV installations have an impact on biodiversity as the installations impact the soil, vegetation, water in their area of installation and human health (Hernandez *et al.*, 2014).

The process of construction of utility scale solar PV projects involves the clearing of vegetation. This is an act that seems counter-productive amid the global move (Arbour Day) to plant trees to reduce the effects of greenhouse gas emissions and fight deforestation (Osman *et al.*, 2023). As such, the clearing of vegetation for solar plants must be carefully balanced with the resultant effects of constructing the plants (Moore-O'Leary *et al.*, 2017).

This balancing act, of managing the complex challenge (Clayton & Radcliffe, 2018) of sustainable development, must also consider the fact that the area being cleared is a habitat for both vegetation and animals, while also taking people's spiritual well-being, livelihood and agricultural use and people's affiliation to their land into consideration. Added to this, is the need to evaluate the material gain of the use of this land, the developmental considerations, and economic gains of the residents, against the ecological sensitivities of the area, that are not just limited to habitat challenges, but includes the destruction of migration pathways of migratory species such as birds and insects (Moore-O'Leary *et al.*, 2017).

2.3.3 Socio-economic impact of large-scale PV installations

The South African debate for land is rather emotive and the use of this land is highly contested (du Toit, 2019). While rural communities are sidelined and underdeveloped with limited opportunities for the improvement of the lives of citizens (Cousins, 2007), urban areas are over-populated, with rundown infrastructure and heavy competition for the use of land (Jenkins, 2006).

In addition to the technical feasibility, the socio-economic impacts of large-scale PV installations play a significant role within the EIA (Naicker & Thopil, 2019) in the form of public participation (Murombo, 2008).

These impacts would include the resettling of the population currently residing in the specified or chosen area for the implementation of the large scale energy project, the equitable management of water in light of the population's requirements and consumption levels, temporary and permanent employment opportunities for both skilled and unskilled labour, tourism from the influx of people as a result of the development of the utility project, and the improvement of the local infrastructure in line with the dawn of the new local activity (da Silva *et al.*, 2020).

2.3.4 A new target for criminals

The criminal activity in South Africa is at alarming proportions (Cameron, 2020). Unfortunately, solar installations have not remained unnoticed by the criminals of the country. This is laid bare by news website reports that describe the surge of theft of operational solar panels in the wake of an available market (Fraser, 2023; Brederode, 2023; Nyathi, 2023). The threat of criminal activity over the EoL components also exists, with the danger of poor management of the waste stream. The illicit trade of EoL components that should be sent for legitimate recycling but are rather illegally traded and sold off as new panels is also a threat to the unsuspecting citizens (Green Building Africa, 2020), adding to the complexities of managing Gauteng's municipal landfill sites.

2.3.5 Generation of waste

Considering the life cycle of PV installation components, the generation of waste from PV installations originates at the point of mining of the rare earth metals that make up the components of the PV installation. Similarly, the generation of electricity takes the environmental effects of coal mining into account. The life cycle analysis continues through the exploitation of the components, to the beneficiation process, manufacturing, packaging, transportation to the consumer, ultimately landing at the consumer's doorstep. It would be remiss not to mention the generation of this waste as it speaks to the carbon footprint, and ultimately the level of sustainability of PV installations (Zhang *et al.*, 2023).

The life cycle of utility scale solar PV installations can be summarised in three different phases, namely, the project phase, the exploitation phase and lastly, the end-of-life phase (Camarinha-Matos *et al.*, 2017). The project phase involves pre-planning, design and engineering and construction, with construction generating most of the waste, mainly builder's rubble and component packaging. The exploitation phase involves the actual operational phase of the utility plant, with waste being generated by the components that are either cracked or damaged due to

environmental or operational factors or have lost their efficiency and are no longer usable within the utility scale project as they effect the overall efficiency of the plant. This phase also includes the maintenance of the PV cells, which consists of washing to remove debris or dust that may affect the efficiency of the panels (Abu-Naser, 2017). Lastly, the EoL phase is self-explanatory. This is the phase of the project once the utility project has reached its end of life, predicted to be at twenty to 30 years from the point of commissioning.

This lifecycle, though, does not exist without considering the lifespan of the actual components and it is thus important to note that waste is not just generated by the PV installation components at the end of their lifespan, but true sustainability considers waste generated along the entire value chain, including the mining process for the rare earth metals that form part of the components, the process of manufacturing to the point of consumption by both the industrial and household scale user and ultimately, the end of the components lifespan (Fthenakis & Kim, 2011). The lifecycle analysis also entails the evaluation of the use of energy as well as the greenhouse gas (GHG) emissions or any other factors of the entire lifecycle of the photovoltaics that would impact the carbon footprint of the product (Kiger, 2016). Waste is generated throughout the entire value chain (Heath *et al.*, 2022). It is, however, important to note that the purpose of this research is to explore the perceptions on the effectiveness of solid waste management of end-of-life photovoltaic.

2.4 Waste from EoL solar PV installations

In light of the increasing popularity of solar PV (Abdelilah *et al.*, 2023), volumes of the resultant waste stream, EoL PV installations, could get to approximately 80 million metric tons in 2050, this is increasingly becoming a cause of concern as the sense of urgency at the effective management of EoL photovoltaic installations grow internationally (Komoto & Lee, 2018).

2.4.1 Considerations of the projections on EoL solar PV waste volumes

Even though volumes of EoL installations are on the rise there is still an element of uncertainty in the management of the waste stream. Though the research has taken the value chain for PV installations into account, the focus will now shift to EoL PV installations. While recycling is the preferred method of management of this waste stream, considering the European Union's Directives which were first introduced in February 2003 and have recently been amended as the global use of solar PV matures (European Commission, 2012; Zarcone, 2023), it is not a simple management method to apply. Firstly, the heterogenous nature of the waste steam warrants further research, (Chowdhury *et al.*, 2020). Similar to the variable composition of WEEE (Buekens & Yang, 2014), the lack of uniformity in the production of photovoltaic equipment or standardisation of the process of classification of the waste generated at the EoL justifies the

research into the determination of the best possible directive (Wang *et al.*, 2012) for this variable waste stream and the ensuing structure for this directive.

As EoL PV installations have been broadly included in the definition of WEEE in South Africa, once classified according to the Global Harmonised System (GHS) the waste stream is prohibited from landfill. The challenge with this is that in the event that households are not aware of this prohibition, outside of the involvement of the installers or insurance houses for components that reach the end of their lifespan, EoL PV installations are bound to form part of household hazardous waste. A classification that is reliant on the level of awareness of the household consumers, as well as their sense of responsibility towards the proper management of EoL PV installations. Based on the hazardous nature of the components as discussed in Section 2.4.2, the hazardous waste classification, therefore, implies that landfilling in a suitably built landfill or incineration is the default method of management for the EoL PV installations. A complicated method of management in light of the presently non-existent directive for the management of hazardous household waste. This default setting is further challenged by the components of the EoL PV installations that could release toxic and carcinogenic gases as a result of incineration (Farrell *et al.*, 2020) or the prohibitive cost of specialised landfilling, particularly in South Africa (Makgae, 2011).

In the South African context of reclaimers that pick through the domestic waste (Samson *et al.*, 2022), in addition to toxicity, the potential hazard of electrocution, however minute, does exist in the case of contact with EoL PV installations that have been discarded along with domestic waste (Moskowitz *et al.*, 1983; Moskowitz *et al.*, 1987), for lack of alternative hazardous waste collection infrastructure and services (Edokpayi *et al.*, 2017). This hazard is presented in light of the potential quantities of EoL PV installations that would be mismanaged considering the popularity of solar panels amongst Gauteng's households (Ormajee, 2023; South African Photovoltaic Industry Association, 2023). This challenge of disposal persists in spite of a recently drafted strategy, for the provision of a legislative framework to manage household hazardous waste (The South African Department of Forestry, Fisheries and the Environment, 2023) and the EPR directives of GNR 1184 and GNR 1185 as legislation is only effective if it enforced.

2.4.2 Composition of EoL solar PV waste

The two most common types of photovoltaic installation components addressed in literature thus far are the Silicon based photovoltaic systems and the Cadmium Telluride systems (Oteng *et al.*, 2022), but the panel compositions are not just limited to these elements. The difference in the two types of components is important to note as this affects the type of technology that can be used to drive this waste stream up the waste hierarchy (Maani *et al.*, 2020).

As the panels consist of other elements, such as copper and lead (Ongondo & Williams, 2011), the environmental management challenges linked to the panels of photovoltaic installations are as follows (Oteng *et al.*, 2022):

- leaching of lead;
- leaching of cadmium;
- loss of conventional resources such as aluminium and glass and the loss of rare earth metals such as, indium, gallium and germanium; and
- the PV panels' ability to produce electricity even though it is disconnected from a power source

Compacted together as depicted in Figure 2-4, this structure of the components makes separation difficult. The image depicts the compacted material in between the silicon covers. The material distribution of a typical photovoltaic component is illustrated by Figure 2-5. Further to this is Figure 2-6, which is a description of BESS and the accompanying list of cathode, electrode and anode materials or chemicals. The figures presented are a graphic representation of the conundrum that the world finds itself in, the photovoltaic components consist of valuable materials that are tightly compacted together, making separation an art.

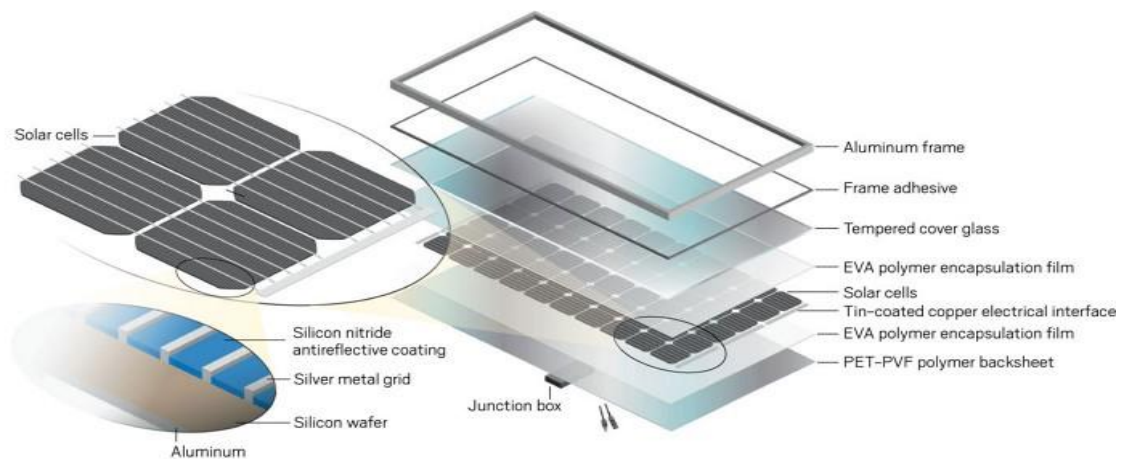
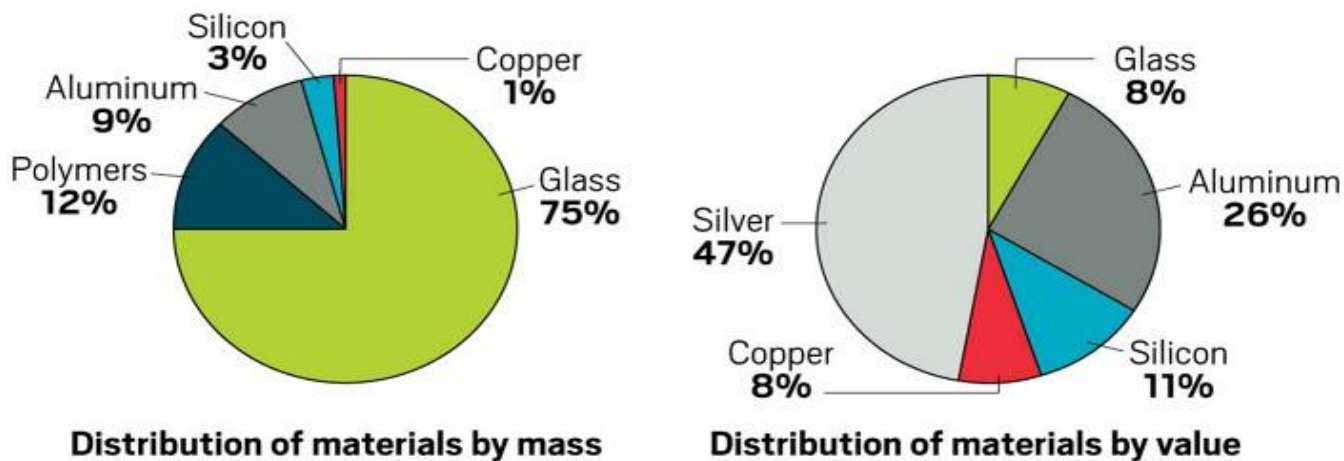


Figure 2-4: A solar photovoltaic module (Peplow, 2022)

In considering the compaction of the components, the management of the adhesives that hold the entire PV installation together are also a point of contention (Chowdhury *et al.*, 2020: 7-8). Particularly in light of the known challenges with the hazardous nature of the components, and ultimately, the recyclability of the adhesives (Thellen *et al.*, 2017).

Materials in a typical silicon photovoltaic cell



Source: Martin Bellman/Icarus. Note: Silver is less than 1% of the mass.

Figure 2-5: Distribution of material in a typical solar photovoltaic (Peplow, 2022).

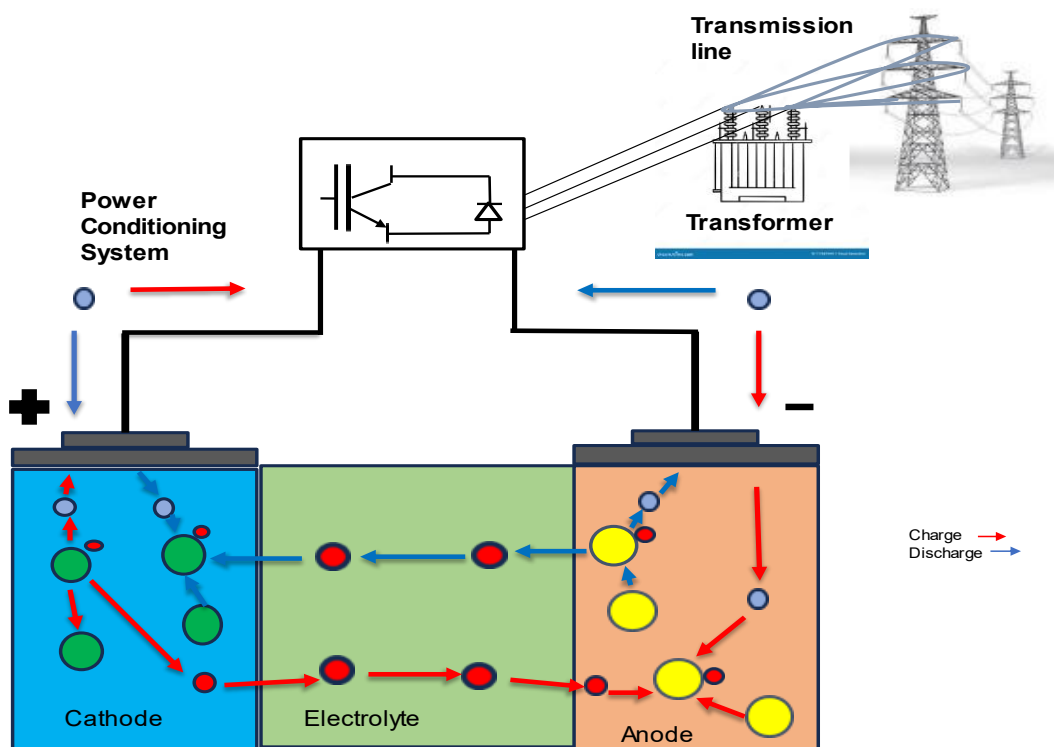


Figure 2-6: Typical components of a battery energy storage system (Nikolaidis & Poullikkas, 2017).

Table 2-1: Materials and chemical compositions that can be listed as possible cathodes, electrolytes and anodes (Nikolaidis & Poullikkas, 2017; Al Shaqsi *et al.*, 2020)

	Cathode	Electrolyte Solution	Anode
1	Lead oxide (PbO ₂) – lead acid	Sulphuric acid (H ₂ SO ₄)	Lead (Pb)
2	Nickel oxyhydroxide (NiOOH) – nickel cadmium	Potassium hydroxide (KOH.H ₂ O)	Cadmium (Cd)
3	Oxygen (O ₂) – Zinc – air	Alkaline	Zinc (Zn)
4	Sulphur (S) – Sodium sulphur	Beta Alumina	Sodium (Na)
5	Lithium Cobalt Oxide (LiCoO ₂) - Lithium ion	Lithium hexafluorophosphate (LiPF ₆)	Carbon (C)

The illustration of Figure 2-6 above is a depiction of the BESS. It is a representation that the battery consists of a cathode, the electrolyte solution, and the anode. Table 2-1 is a list of the possible BESS compositions, listed according to a particular cathode/electrolyte/anode combination. The BESS is connected to a power conditioning system, which is then connected to a transformer and finally the transmission lines (Nikolaidis & Poullikkas, 2017). Both the anode and cathode consist of various metals and rare earth elements, while the electrolyte solution is made up of a specific chemical composition which can have a detrimental effect on the environment and the health of people with which these can come into contact. As the solar PV system also consists of the battery energy storage systems (BESS), it is imperative that the EoL management of the solar PV installation also considers the management of BESS. Lithium-ion batteries are currently the most dominant technology at play. Though prohibited from landfill and further emphasised through the EPR legislation yet the EoL management of all the components of this waste stream has not been fully considered or understood (Pellow *et al.*, 2020). This is of particular importance in light of the nonspecific declaration of the lifespan of the EoL BESS (Stecca *et al.*, 2021), unlike the specified 25 – 30-year lifespan of the PV panels (Chowdhury *et al.*, 2020).

2.4.3 Considerations for sustainable waste management

Though challenged by the economies of scale of the cost of the recycling process versus the potential value of the recovered recyclable material, the geographical considerations of the collection point for the EoL installations, the value and amount of reclaimable material (Fthenakis, 2000), the continued research and development into improved recycling and the governmental commitment to sustainability contributes to the increase in efforts to ensure the recyclability of the EoL PV components (Farrell *et al.*, 2020; Cucchiella & D'Adamo, 2015). Particularly as the use and therefore, the need for the components grows, thus tipping the scales in favour of the circular

economy and aligning to overall sustainable waste management practice of the waste hierarchy (European Commission, 2012; Rathore & Panwar, 2021). The waste hierarchy is the management of waste through the four R's (4R's) of reduce, re-use, recycling and recovery with disposal the least preferred waste management option, while prevention of waste in the first place, being the prize option (Pires & Martinho, 2019).

2.5 Overview of the legal framework for PV solar waste management in South Africa

The sections below provide an overview of the legal framework for PV solar waste management in South Africa.

2.5.1 Summative overview of the legal framework

Waste has been defined, and classified, through the employment of the South African National Standard Globally Harmonised System of Classification and Labelling of Chemicals 10234 (SANS 10234). The overview provides a setting for the legal framework used to evaluate, classify, and ultimately manage waste through the regulations, classification process, norms and standards (Government of the Republic of South Africa, 2014). This is all illustrated in Figure 2-7 below.

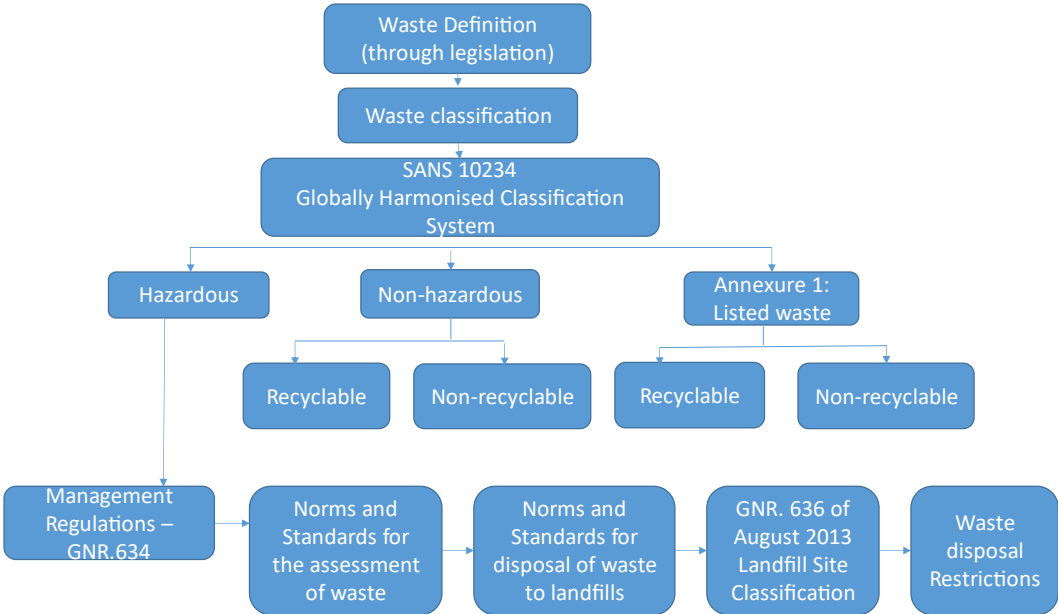


Figure 2-7: The legal framework governing waste management in South Africa

Waste generated from photovoltaics and ultimately from the EoL PV installations would be initially identified as hazardous or non-hazardous, by means of the waste definition from legislation or through the identification on the listed waste of Annexure 1. Through SANS 10234 described in the GNR 435 of 2011, the *Waste Classification and Management Regulation*, EoL PV installations are classified hazardous due to the intrinsic hazardous nature of its listed components or the

detrimental effects of these components on the environment (The South African Department of Environmental Affairs, 2011). These management regulations are applied on the waste stream. These regulations apply the Norms and Standards GNR 634 of 2013 (Department of Environmental Affairs of the Republic of South Africa, 2013) to classify, and once found to require landfilling the waste is to be assessed according to the Norms and Standards GNR 636 of 2013 (The Department of Environmental Affairs, 2013) to determine whether the waste stream can be landfilled or should rather, once classified as hazardous be prohibited from landfill and recycled.

2.5.2 Legal framework applicable to PV solar waste management in South Africa

The sub-sections below discuss the legal framework applicable to PV solar waste management in South Africa.

2.5.2.1 The Constitution of the Republic of South Africa

In agreement with the global realisation of the right to a clean environment, including clean air and water, that promotes good health in South Africa (Du Plessis, 2011), the governance of human interaction with the environment originates from Section 24 of South Africa's *Constitution Act 108* of 1996 (Constitution of South Africa, 1996), which states that,

“Everyone has the right to:

- *an environment which is not harmful to their health or well-being*
- *have the environment protected for the benefit of present and future generations through reasonable legislative and other measures that:*
- *prevent pollution and ecological degradation;*
- *promote conservation;*
- *secure ecologically sustainable development and use of natural resources, while promoting justifiable economic and social development”.*

While environmental management is one that is used to describe the management of human interaction with the environment, the term, waste management, refers to the management of the waste generated by humans as they interact with the environment in which they live. *“This is the collecting, treating, and disposing of solid material that is discarded because it has served its purpose or is no longer useful”* (Nathanson, 2023). Following on from the Stockholm Declaration, which sets out principles for a healthy environment (Common Home For Humanity, 2022), South African environmental management was initially governed by the Environment Conservation Act 73 of 1989 (ECA). This Act was partially repealed and replaced by the National Environmental Management Act 107 of 1998 (NEMA), and the National Heritage Resources Act 25 of 1999 while the National Water Act 36 of 1998 provided the fundamental reform of the law relating to water resources (Oelofse, 2021). The NEMA was the result of extensive public engagement between

the government and various relevant stakeholders within the environmental management field (Kidd, 1999).

2.5.2.2 The National Environmental Management Act 107 of 1998 (NEMA)

The NEMA (Republic of South Africa, 1998), gives effect to the Constitution's Section 24 as stated in its purpose. The Act does this, first, by defining the environment, then regulating the way people interact with it. Taking both Agenda 21 (United Nations , 1992) and later, the SDGs (The United Nations, 2015) into account to ensure sustainability in the management of the human interaction with the environment, the NEMA provides the regulatory control required for the governance of this interaction.

Through the NEMA principles laid out in the first chapter of the Act, the sustainable development legal considerations employ policy principles that communicated the anthropogenic agenda of the Act (Government of the Republic of South Africa, 1999). Having repealed the ECA, the NEMA laid the groundwork for the use of the fundamental principle of sustainability to drive environmental management decision making, while considering the global environmental management policies. The Act employs the environmental management principles to drive accountability for actions degrading the environment, it meters out authoritative powers to enforce the principles of Command-and-Control (CaC), Economic Instruments (EI), Participatory Approach (PA) or Mutual Instrument (MI). It provides for the costs of environmental management and protection and provides for co-operative governance throughout the relevant governmental departments (van der Linde & Feris, 2010; Department of Environment Forestry and Fisheries, Republic of South Africa, 2020).

2.5.2.3 The National Environmental Management Waste Act 59 of 2008

Further development of environmental legislation was expressed through the National Environmental Management Waste Act of 2008 (NEM:WA). This Act was the first to provide a legal definition of waste.

Continuing in this anthropogenic theme, (Bosman *et al.*, 2018), the National Environment Management: Waste Amendment Act 26 Of 2014 (NEM:WA), defines waste as:

- *“any substance, material, or object, that is unwanted, rejected, abandoned, discarded or disposed of, or that is intended or required to be discarded or disposed of, by the holder of that substance, material or object, whether or not such substance, material or object can be re-used, recycled or recovered and includes all wastes as defined in Schedule 3 to this Act; or*

- *any other substance, material or object that is not included in Schedule 3 that may be defined as a waste by the Minister by notice in the Gazette, but any waste or portion of waste, referred to in paragraphs (a) and (b), ceases to be a waste-*
- *once an application for its re-use, recycling or recovery has been approved or, after such approval, once it is, or has been re-used, recycled or recovered.*
- *where approval is not required, once a waste is, or has been re-used, recycled or recovered.*
- *where the Minister has, in terms of section 74, exempted any waste or a portion of waste generated by a particular process from the definition of waste; or*
- *where the Minister has, in the prescribed manner, excluded any waste stream or a portion of a waste stream from the definition of waste”.*

The Act takes on a predominantly CaC environmental management policy principle approach, by being deliberate in the way that it instructs and defines the parameters of interaction between the environment and people who live in it. In addition to this, the Act empowers the enforcement arm of the legal fraternity to ensure that Section 24 is achieved (Nel & du Plessis, 2001). The other approaches employed by the Act are the EI through the employment of tools such as taxes, levies, fines and penalties. Then there is the PA or MI that incorporate aspects such as public awareness and participation as well as international treaties and conventions (Nel & du Plessis, 2001).

South African legislation is heavily dependent on the CaC approach (Nel & du Plessis, 2001). As a developing nation, this approach is found useful as it establishes the parameters under which the environment is managed and protected (Blackman *et al.*, 2018). Learning from the waste management successes of developed nations such as Australia, legislation is embraced when all relevant stakeholders, particularly the citizens, are considered (Zaman, 2014). Clarity of the law is important and so is holding people accountable in a manner that clearly communicates zero tolerance of environmental management transgressions such as deliberate pollution to the environment (Bosman *et al.*, 2018).

To affect the country’s evolution towards a circular economy, the NEM:WA was amended in 2014. The amended legislation made specific contributions towards the enactment of sustainable development by amending the definition of waste in Section 1(i), to account for and effect the circular economy through the inclusion of the following “*substances, material or objects that can be re-used, recycled or recovered*” (*National Environmental Management: Waste Amendment Act 26 of 2014*) in the legislated definition of waste. In addition to this definition, the legislation accounts for sustainable waste management through the inclusion of the instruction for the provision of funding for circular activity as listed in Chapter 3A.(Government of the Republic of South Africa, 2014).

2.5.2.3.1 Waste Classification and Management Regulations (GNR. 634 of 2013)

Once defined as waste, through NEMA of 2008 and 2014, the the EoL PV installations are classified through SANS 10234, should the waste stream not be listed in Annexure 1 of the NEM:WA. According to the regulations, the waste must be classified, if it has not already been classified, within 180 days of generation by the waste generator. The properties used to classify the waste stream are listed and classified as hazardous due to the hazard posed to the environment, the physical well-being or the health of all organisms (Department of Forestry, Fisheries and the Environment of the Republic of South Africa, 2013). The EoL PV installations, are classified as hazardous (The Department of Environmental Affairs of the Republic of South Africa, 2013; Engineering News, 2023).

2.5.2.3.2 Norms and Standards for the Disposal of Waste to Landfill (GNR. 636 of 2013)

These norms and standards identify the waste streams that are to be disposed of at landfills as well as those that are prohibited from landfills. Through the Threshold for Leachable Concentration (TLC) and the Total Concentration Threshold (TCT), the risk profile for waste is determined. Waste types are classified into five categories, Type 0 to Type 4, where Type 0 is waste that has been prohibited from landfill (Engineering News, 2023).

The Type 0 waste is waste that is prohibited from landfill, according to Section 4 of GNR. 636 of 2013 of the Norms and Standards for the Disposal of Waste to Landfill. Furthermore, Section 5 of GNR. 636 of 2013 of the earlier mentioned Norms and Standards has a list of waste streams or parts thereof that have been prohibited from landfill. In applying this list to EoL PV installations, the installations would form part of the “*Lead-acid batteries(h), Other batteries (i), PCB containing waste (l), Hazardous Waste Electric and Electronic Other (n)*” (The Department of Environmental Affairs, 2013).

2.5.2.3.3 National Waste Management Strategy

In light of the South African determination to move waste up the waste hierarchy of reduce, re-use, recycle (Mativenga *et al.*, 2017) and enact the circular economy, empower its citizens through job creation within that economy, ultimately contributing to the global SDGs, the National Waste Management Strategy (NWMS) is a strategy that has identified challenges and priorities that need to be addressed and acted upon by the country’s officials, private sectors and citizens (Department of Forestry, Fisheries and the Environment, 2021).

Further to this, is the identification of waste electric and electronic equipment, which includes EoL PV installations, as a priority waste stream as it meets the criteria for the active involvement of multiple role players, both the public and private as well as citizens, to tackle it effectively, in line

with the requirement to minimize the disposal of the waste stream at the landfill sites (Department of Forestry, Fisheries and the Environment, , 2021: 46-59).

2.5.2.3.4 Industry waste management plans for electrical and electronic waste

In order to effect the plan to minimize waste, considering the challenge of constrained resources, and inadequate skills and capacity to enforce legislation within the government structures of South Africa (Department of Forestry, Fisheries and the Environment, 2021), as a means of collaborating with the private sector, the South African National Department of Forestry, Fisheries and the Environment, introduced Industry Waste Management Plans (IndWMP) in Part 7 of the fourth chapter of the Act, titled Waste Management Measures, sections 28 and 30 to 34. Section 28 instructs the person compiling the IndWMP what considerations the plans need to include, while section 30 to 34 discusses the contents, notification, considerations, specification of measures, and the review of the plans (Government of the Republic of South Africa, 2014).

The role of the government would be one of oversight over the IndWMP as these would be submitted on a voluntary basis per industry. As a co-regulatory instrument, the purpose of these plans is to address the participation of industry in the circular economy as well as the financing of the required infrastructure that drives the minimisation of waste while motivating waste generators to implement the diversion of waste from landfills (Baloyi & Masinga, 2011).

2.5.2.3.5 Extended producer responsibility regulations for electrical and electronic waste

With globalisation and technological advancement, WEEE has been cited as the fastest growing waste stream worldwide (Cucchiella *et al.*, 2015), This growth occurs in the midst of worldwide differences in WEEE management principles. The WEEE growth is believed to be increasing at an approximated rate between three and five percent annually (Shittu *et al.*, 2021). While there are countries that have strategies as well as practices to manage electronic and electric waste, with the European Union pioneering the publication of guidelines on the management of waste generated from WEEE, up until recently, the initial guidelines had yet to include waste generated from photovoltaic, or any other renewable energy installations that have reached their end-of-life, (EoL), either through use or as a result of damage before, during or after the installation. The directive to do so is recorded in 2012 as WEEE Directive 2012/19/EU (European Commission, 2012).

In various literature and the introductory text to the published guidelines pertaining to WEEE, electronic and electric waste is described as “*devices such as computers, fridges, mobile phones*” (Iberdrola, 2023) which have reached their end of life. The specific inclusion of waste generated as a result of EoL photovoltaic installation, or any other renewable energy components, was added as a result of the increased use of renewable energy as the 25-year lifespan of the initial

installations was drawing closer to the end within the European Union legislation. Currently, the European Union is the only entity that has developed explicit EoL waste management regulations (Weckend *et al.*, 2016). Having revised their initial WEEE regulations, EoL photovoltaic installations were subsequently include in 2012 (European Commission, 2012). In line with the SDGs, circularity is the preferred waste management practice for the WEEE with guidelines on the value chain of the practice being published and set as directives to the manufacturing and waste management sector through Extended Producer Responsibility (EPR) (European Commission, 2012; Xu *et al.*, 2018).

The intention of the EPR is to collaboratively address the sustainable management of generated waste once a product had reached its end of lifespan. As an environmental protection instrument that is producer focused, it is a regulatory measure that enforces lifecycle management of manufactured products, including electric and electronic products (Gu *et al.*, 2019). In South Africa, like other countries throughout the world, the regulations are tasked with effecting the sustainable management of waste, through the development of a circular economy (The South African Department of Forestry, Fisheries and the Environment, 2021). In spite of the victory of having WEEE legislation in place, though not specific to EoL solar PV installations, in South Africa, challenges regarding the collection infrastructure, the understanding of the true value of the waste and ultimately the pricing structure for the effective management of the waste stream and the low level of trust of South Africans at the management of the EPR fees by the South African government remain a challenge (Pillay, 2019).

Ultimately, the South African legislation is designed to manage the EoL in a manner that prioritises the needs of the citizens, ahead of the environment, though still attempting to limit harmful activity towards the environment. It identifies the waste stream that is EoL PV installations then sets principles, strategies, and legislation in place to manage the waste stream in a manner that contributes to sustainable and circular development, through the involvement of private and corporate citizens, as well as the government.

2.6 Negative impacts of EoL solar PV waste

Detailing the negative impacts of solar PV almost sounds counterproductive, but it is important to express the fact that *“not all that glitters is gold”* as the saying goes. As the document reviewed challenges of the utility scale solar projects on the ecosystems, migration patterns on migratory species, agriculture, socio-economic status of community, the negative impacts of the waste further compound the challenge at hand (Dubey *et al.*, 2013).

In reviewing the challenges that the hazardous nature of the EoL PV components present to the environment should the waste stream be ineffectively managed, threats or impacts became

apparent to the researcher. These included threats such as the contamination of the soil and water through leaching, and the possible combustion of the components should the waste fall into the wrong hands for handling, such as those of the informal recycler. The risk to the environment through air and ground pollution is increasingly worrisome, amongst other challenges described, in the midst of calls for further research into the risks related to waste generated by photovoltaic installations (Nain & Kumar, 2020). This is a challenge to vegetation, ground water, agriculture, animals, aquatic life and human health. As previously indicated, waste is not only generated at the end of the components' life, but it can also be generated throughout the lifecycle of the photovoltaic components, the negative impacts are therefore, present throughout the lifecycle of the components (Tawalbeh *et al.*, 2021).

As discussed in Section 2.4, a danger of the out of service panels that is scarcely discussed in research, hence the reference article mentioned dating back to 1983 and 1987, is their continued ability to generate electricity even at the end of the panels' lifespan (Carlos, 2021). Taking the fact that solar panels generate electricity through the conversion of solar energy into electrical energy, the direct current, that is converted into the alternating current required to power homes and business by an inverter (Sunworx Photovoltaic Systems, 2020), and considering the fact that the direct current is generated as a result of the solar energy striking the semi-conductor material of the solar panel, it stands to reason that as long as the panel remains in contact with the sun's rays, an electric current is generated. In the South African context, because of the informal recycling activity of the country (Godfrey, 2021) and the populations ineffective management of waste in general (Nyika *et al.*, 2020), depending on the amount of current generated, the EoL panels that are mismanaged and exposed to the public could pose a serious hazard to their health and safety. The described concerns are testament of the various complexities in managing the EoL PV installation effectively (Sharma *et al.*, 2019).

2.7 Opportunities related to EoL solar PV waste

The opportunities presented by the need to effectively manage waste generated from EoL PV installations is not limited to the management of the components, it extends to the infrastructure required for the collection and processing of the components as well (Heath *et al.*, 2020). Separation of the photovoltaic components for extraction requires a technical skill as the intricacy and hazardous nature of the components needs to be taken into careful consideration, thus providing additional opportunities of employment for fields such extractive metallurgist and technicians alike, particularly in light of the growth in volumes of the waste that could lend itself to the development of large scale separation facilities, once research has been able to identify one such successful and replicable separation process (Mahmoudi *et al.*, 2021).

Figure 2-5 and Table 2-1 above detailed the various rare earth and hazardous components of PV installations (Salim *et al.*, 2019; Peplow, 2022). This challenge is further complicated by the fact that there is specific technical expertise required for the EoL management process (Ndzibah *et al.*, 2022). This is important to note in the South African context of a depressed economy that is desperate for an injection of jobs, particularly for the youth of the country (Mseleku, 2022). As research and development is ongoing in this field, the reduction of recycling costs, the amendment of the PV component construction material to enable improved recyclability of the installations, and the ease of adaptability of the recycling infrastructure in response to the technical advances of photovoltaic components is improving with time, albeit a bit slow (Heath *et al.*, 2020).

In the South African context, this also includes the opportunities available for informal vendors to provide food to the workers at the processing facilities, new public transport routes for the transportation of workers, depending on the geographical position of the recycling activity, an addition of transportation services for the recycled equipment. The list of direct and indirect jobs is extensive, including the informal reclaimers that would have a place to drop off the components, providing them with an additional revenue stream to paper, plastics and cans (Godfrey, 2021).

2.8 Sustainable management of EoL solar PV waste

To manage EoL PV installations effectively, Figure 2-8 to follow is a description of the process that could be adapted for assessing the viability of recycling the end-of-life components of PV installations (Razzaq *et al.*, 2021). Aspects that need to be assessed when evaluating the viability of the recycling process include reviewing the amount of water and energy required during the process of separation of the various components of the installation for the purpose of recycling while also assessing the dangers associated with the hazardous nature of the components and the exposure to those hazards (Farrell *et al.*, 2020). As sustainable development also includes the provision of meaningful work opportunities, economic development is also a factor that is reviewed when determining the recyclability of a waste stream. This aspect contributes to the economy of scale of recycling (Fthenakis, 2000). Another important factor is the justification of the energy and water requirement for the recycling process.

Ultimately, sustainable management of the EoL PV installations is derived from the SDGs that consider the well-being of the environment in light of the well-being of the people within that environment. Considering Figure 2-8, the figure is a representation of the reiterative nature of effective EoL PV installation management, taking sustainable development into account.

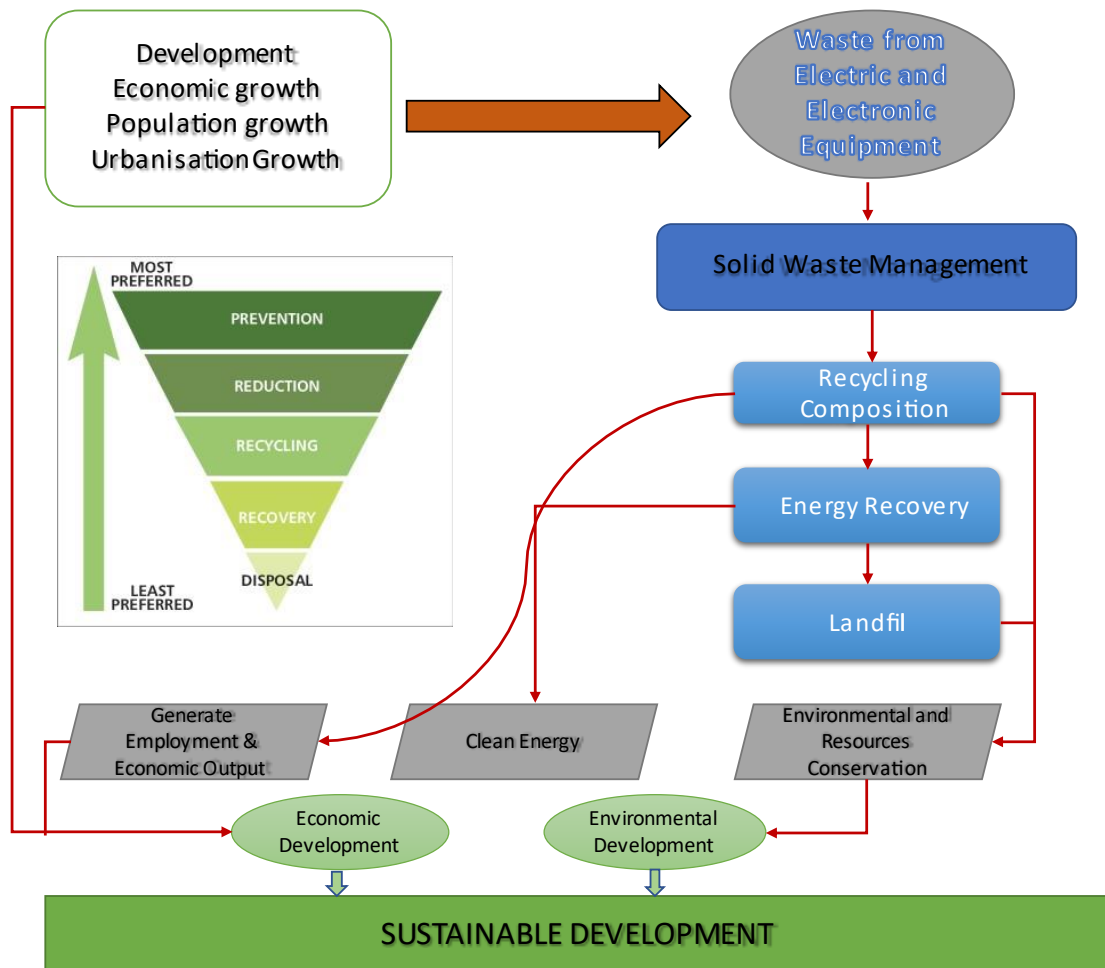


Figure 2-8: A description of determination of the recyclability of a waste material (Razzaq et al., 2021)

While viability is a key contributory aspect to circularity, the value of a grounded and well contemplated legislative framework cannot be understated. Legislative reinforcement enables the circularity of the photovoltaic industry through innovation (Peplow, 2022). Though, it must be said that legislation should not stifle innovation, but rather encourage it, through market creation, and the sovereign protection of country from an influx of recycled or second-hand PV components from other countries.

As a means of measuring viability, considering the challenge raised in Section 2.4.2, the composition of the solar installations requires a complex process of separation, considering the processes' requirement of water and energy (Ko et al., 2023; Bogust & Smith, 2020; Azeumo et al., 2019), therefore affecting the bankability of the recycling process. This is an aspect that needs to be researched, as the material used in PV installations varies, therefore influencing the process of separation in the preparation for recycling (Heath et al., 2020; Sica et al., 2018; Paiano, 2015;).

Once this challenge has been addressed, the challenge of the circular supply chain needs to be addressed (Tsanakas et al., 2020), ultimately securing a market for the recycled component while

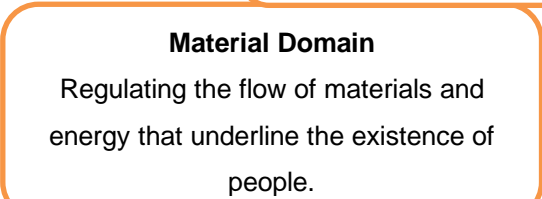
employing an efficient distribution chain. In light of the various employment opportunities that are possible throughout the value chain, there is little wonder of the excitement that is associated with the circular economy, the imperative is to ensure that the beneficiation occurs locally.

In response to this documented expectation of sustainability, world leaders came to the realisation that an equilibrium between the sustenance of resources and the consumption thereof had to be maintained (Upadhayay & Alqassimi, 2018). As a complex and multi-disciplinary challenge, it became increasingly apparent that the waste management challenge required a global, concerted, and collaborative effort to address it effectively and sustainably (Wilson *et al.*, 2015).

As sustainability is a complex system of multi-disciplinary activities working towards a goal that may not be finitely and absolutely reached (McMichael *et al.*, 2003), continuous evaluation of the progress made towards reaching that goal is a valuable monitoring tool that can be affected through the Plan-Do-Check-Act (PDCA) process (Lodgaard & Aasland, 2011). This process, also known as the Deming Cycle, entails setting goals to achieve specified results, acting on what was previously stated, evaluating the actions by monitoring the effectiveness of the actions then acting on the results of the evaluation process to improve the performance of the activity (Isniah *et al.*, 2020).

Sustainability takes on the PDCA process in a reiterative manner to effect change across the five core principles of sustainability (social, spiritual, material, economic and life described in Figure 2-9 to follow. The complex system of sustainability (Clayton & Radcliffe, 2018) is one that engages the various anthropogenic activities on earth that are degrading the environment in a systematic manner to establish a lasting sustainable environment (Arora *et al.*, 2018; Ben-Eli, 2018).

The first of these principles is the social principle. This is about the social interaction between humanity, humans and the environment, and humans and the animals on earth. The second principle, the spiritual principle, describes the human attitude and value system towards the earth and all its inhabitants. The third principle, material, is the regulation of the flow of raw material from the cradle that supports the existence of people on this earth. The fourth principle, economic, is the guiding framework for the creation and management of the wealth that is generated from the extraction of the earth's resources. The fifth and final principle, life, is the management of this anthropogenic behaviour on the earth (Ben-Eli, 2018). Figure 2-9 is an illustration of these core principles.



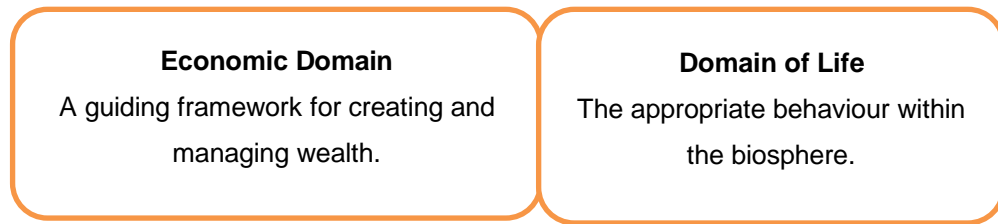


Figure 2-9: The core principles of sustainability (Ben-Eli, 2018)

2.9 Global practices of managing end-of-life photovoltaic installations

The research has, thus far, delved into the global and South African motivation for the use of renewable energy, the unintended consequences thereof, and the possible means of addressing the identified challenges, through the employment of the sustainability principles. Having identified various unintended consequences, these means of addressing the challenges were focused on the EoL PV installations as this is the aim of this research.

Considering the first research objective, of the exploration of the global practices of managing EoL PV installations, this section takes the various aspects of effectively managing the waste generated by the EoL PV installations into account by drawing from the activities of Ethiopia, as a developing African country (Shiferaw, 2017); Brazil, as a founding member of BRICS (Brazil, Russia, India, South Africa) (Library Of Congress, 2023), much like South Africa is; and of Australia, in light of their successes in the effective management of waste (Zaman, 2014), including EoL PV installations, as a country outside of Europe.

Global practices for the effective management of the EoL PV installations are a culmination of the legislative framework for the effective management of waste, then applying the relevant legislation for the management of WEEE to the management of the EoL PV installation (Mahmoudi *et al.*, 2021). Further to this, effective stakeholder engagement and partnerships in addition to the EPR contribute positively to the management of the EoL, while the level of effectiveness of either option is debatable (Khawaja *et al.*, 2021).

The global practices for the management of the EoL PV installations take the sustainability principles into account through social engagement by getting buy-in and cooperation from the citizens to participate in, not just the circular economy, but sustainable development as a whole (Lehtonen, 2004). This entails being deliberately inclusive of the citizens of a country in the development of that nation through the consideration of people's human rights, societal inequalities and the responsibilities of governments towards their citizens (Gupta & Vegelin, 2016). The practices consider the spiritual domain through an acknowledgement of the people's connection and sense of responsibility to the environment that they live in, or that they have

always lived in when considering the ancestral heritage of people, particularly indigenous people (Luetz & Nunn, 2023).

The practices also take the availability of the raw material, the third principle, to create products into consideration, as is reflected in the various extractive and mining regulatory framework. Fourthly, though the balance has been disturbed by economic aspirations, both politically of governments, as well as the private sector, through sustainability, global practices are acutely aware of the desperate need to find a nexus between extraction and consumption that avoids depletion (Krausmann *et al.*, 2017) that enables economic empowerment of the people of that land. The fifth principle of sustainability that has been considered in waste management and therefore in the management of EoL PV installations, is the consideration of the domain of life. This is a consideration of a culmination of all the other four principles into this fifth principle, to acknowledge the complex interconnectedness of the various aspects of life (Bijl, 2011). Ultimately, global practices have taken on these principle to solve a some what wicked problem that does not have simple and straight solutions, for a fluid and ever evolving state of affairs (Pryshlakivsky & Searcy, 2013).

The best practices that can be adopted from countries such as Germany, China and the United States of America include a well-established collection network infrastructure, that has recycling facilities that are close to the collection point and the creation of a market for the recycled goods from the EoL PV installations that is sourced by localised recycling or beneficiation facilities. It is important to note that this is made possible by a regulatory framework that supports the creation of a market for the recycled products and encourages innovative technological advancement, while protecting the domestic markets by monitoring and managing the influx of recycled products. Another important factor to consider in the list of best practices is the effective management of revenue generated by the EPR schemes (Weckend *et al.*, 2016).

Considering the country's extensive adoption of solar PV installation for the generation of electricity, India is also a country that is making headway in its management of the EoL PV installations. This is particularly the case as it realises the dire need for a wholistic approach, that is cognisant of the available waste management infrastructure, that requires clarity of legislative framework, that appreciates the value of an effective EPR programme, the presence of a commercialised and viable circular economy for the EoL PV installations and a collaborative effort by all relevant stakeholders (Sheoram *et al.*, 2022).Management of EoL PV solar installations in Ethiopia

As a country challenged by the complexities of municipal waste management due to poor infrastructure and legislative support, it would be fair to deduce that the management of WEEE is rather challenged at this stage in Ethiopia (Ongondo *et al.*, 2011). Corroborated by Maphosa and

Maphosa (2020), their review cites challenges such as the lacklustre political will in the development of legislation governing the management of e-waste in Sub-Saharan Africa and not just Ethiopia. While countries have little information in the way of volumes, the porosity of the borders do not help much in combating the movement of hazardous waste such as WEEE (Lawhon, 2012). This further exacerbates the challenge of effective management of WEEE as developed nations dump their obsolete electronic and electric waste on developing nations under the premise of recycling (Bhattacharjee *et al.*, 2023). Actions that are contrary to the Basel and Bamako Conventions (Zhavoronkova, 2020).

As citizens identify the value of recycling WEEE, without the proper infrastructure, rudimentary means of recycling are employed. While endangering the recycler's health, this further complicates the issue of hazardous waste contamination of the ground and water, as components leach from the waste material that has been improperly stripped (Farrell *et al.*, 2020). This is also the case with the unrecycled waste that finds its way to the landfills, in instances where landfills do exist, these landfills cannot handle the hazardous waste stream and therefore the waste collected ultimately has a detrimental effect on the environment as it is either dumped in open and exposed dumping areas or illegally on the streets of the urban areas. Should the waste not be disposed of or discarded, it is then traded illicitly (Pan *et al.*, 2022).

The enormity of this challenge presents a very important opportunity to informal recyclers to form part of the sustainability value chain with government assistance in the form of strict and well-enforced legislation (Ongondo *et al.*, 2011). Furthermore, is the use of solar power to provide energy to rural areas of the country where solar power accounts for 87% of the total installations (Tiruye *et al.*, 2021). It stands to reason that the management of waste from EoL photovoltaic installations will be challenged by infrastructure and legislation, particularly as it is mainly generated in the rural areas, areas of minimal infrastructure. In an effort to mitigate the lack of electrification of these areas in an environmentally friendly manner, much like what is happening in South Africa, the solution to one challenge has birthed another.

2.9.1 Management of EoL PV solar installations in Brazil

Brazil has been listed as the second highest generator of WEEE in the Americas (Ghimire & Ariya, 2020). Though electronic waste is not listed in Brazil's waste composition graph, this status is an indication of the magnitude of the WEEE challenge in Brazil. This lends itself to the level of awareness of the challenge at hand, the status of increasing volumes of a waste stream that is both valuable and toxic because of the leachability of components such as lead and cadmium as well as the rare earth elements such as palladium, that are both a health and environmental hazards (De Sousa *et al.*, 2023). As earlier mentioned, a country of limited infrastructure and with an eco-sensitive land, reverse logistics of the end-of-life components is a natural choice because

of its positive contribution towards the management of the carbon footprint of photovoltaic installations (Pan *et al.*, 2022).

Particularly in an economic climate that is inclined towards a labour-intensive circular economy. Due to the lack of structure dealing specifically with WEEE, infrastructure for the collection and processing of the waste is largely non-existent (Dias *et al.*, 2018). The legal framework currently in place is that EoL PV components do not have a specific management process, but the waste stream is rather included in the management of other electronic waste. This option allows the Brazilian government the opportunity to absolve themselves of the challenge by handing over the responsibility of the management of the waste stream to the producer of the product (De Sousa *et al.*, 2023).

2.9.2 Management of EoL PV solar installations in Australia

Australia has a well-developed, well-resourced waste management sector that is intent on operating in a manner that contributes to achieving the SDG strategy of SDG 3; 7; 8; 9; 11; 12; 13; 14; 15 and 17 (The United Nations, 2015). These goals aim towards providing clean air, the generation of affordable energy through the conversion of waste to energy, building sustainable cities and ultimately countries, acting against climate change through the reduction of greenhouse gas emissions, and the provision of protection from pollution of life under water and on land while working providing decent work and work opportunities in a collaborative manner. Governing bodies such as Zero Waste South Australia are key in achieving the strategy (Zaman, 2014; Zaman & Lehman, 2011).

It is in this context that citizens and governments such as those in Australia are increasingly making use of renewables as alternative sources of energy. While worldwide WEEE volumes have been estimated at 41.8 million tons in 2016 (Sharma *et al.*, 2019), Australia was ranked as the second highest contributor of the WEEE in the world in 2014 (Dias *et al.*, 2018). This is testament to the fact that WEEE, including EoL PV installation has been identified as the fastest growing primary waste stream of the very near future in Australia, thus emphasizing the need to prioritise its appropriate management (Mahmoudi *et al.*, 2020).

As a waste stream is born from the world's innovation and constant industrialisation, Australia's waste management strategies and legislative directives have been reliant on the directives issued by the European Union (European Commission, 2012). The current approach to the management of the waste stream is through the Extended Producer Responsibility (EPR). This principle gives the responsibility of the management of the end-of-life components to the manufacturer. The manufacturer would be responsible for the entire collection and recycling value chain, including the development of the necessary waste collection infrastructure, the transportation and

ultimately, the recycling station for the waste stream as mandated by the European Union European Commission on the Environment and taken on by Australia as a learning. Australia currently does not have legislation governing the management of end-of-life photovoltaic components (Oteng *et al.*, 2022)

The state of waste management within Australia is quite developed (Zaman, 2014). Their view of the management of the end-of life photovoltaic components is not just on the immediate management of the new waste stream, it includes an assessment of the entire consumption value chain, from the purchase of the photovoltaic installation to the management of the resultant waste and end of life (Oteng *et al.*, 2022). The assessment reviews the available infrastructure to ensure effective collection, while managing the carbon footprint for the consumers generating the waste stream (Oteng *et al.*, 2022). Even though Australia is a developed country, with a well developed and managed waste management system, it is challenged by the value chain complexities of the EoL PV components. Though to a lesser extent, considering the amount activity there is towards the circular economy in a formal and structured manner. This is evident in the discussion around the reverse logistics of the EoL photovoltaic panels in New South Wales, Australia (Nizami *et al.*, 2020). Reverse logistics is the consideration of logistics and economics and the recovery of waste materials (Beullens, 2004). Australia only needs to tweak its current management to include the additional waste stream, EoL PV installations, while continuing in its efforts to communicate and promote circularity of waste (Halog *et al.*, 2021).

2.9.3 Management of EoL PV solar installations in South Africa

South Africa faces a myriad of challenges that would negatively affect the effective management of waste. These range from ambiguity of the understanding of the waste management legislation (Hendersen, 2001), the lack of and inadequate management of the waste management infrastructure as a result of poor funding (Oelofse, 2021), the capacity to affect the legislation by the officials who are responsible for waste management (Zhakata *et al.*, 2016) as well as the capacity and effectiveness of the judiciary to affect the legislation (Murombo & Munyuki, 2019). The challenges plague the waste management sector as a whole and would therefore filter through to the management of the EoL PV installations.

The waste stream, once classified as hazardous, is prohibited from landfills through Waste Classification and Management Regulations (GNR 634 of 2013), National Norms and Standards for the Assessment of Waste for Landfill Disposal (GNR 635 of 2013), and the National Norms and Standards for the Disposal of Waste to Landfill (GNR 636 of 2013). It is managed through the IndWMP (Department of Environment, Forestry and Fisheries, 2021: 65) as a contributor to the circular economy, with funds collected through the EPR scheme. Though the EPR scheme is

a novel idea, the scheme has challenges of its own which could adversely affect its effectiveness on the management of EoL PV installations (Le Roux, 2021).

These challenges open opportunities to South Africa to build on the current situation, not only for waste in general, but for the management of the EoL PV installations as well, as for the public and private sector to join hands with the citizens of the country to effect meaning and sustainable change. These (the challenges) are listed in the NWMS as infrastructural challenges include the maintenance of old infrastructure as well as the development of new infrastructure in response to the evolution of people, the capacity of municipalities and their officials, the participation of the public in the strategy, and the effective enforcement of the legislation, the consequence management process of waste management (Department of Environment Forestry and Fisheries, Republic of South Africa, 2020; Department of Environment, Forestry and Fisheries of the Republic of South Africa, 2022).

The challenges continue in the wake of concerns and ultimately evidence that African countries are being used as dumping grounds for WEEE, treaties governing the transboundary movement of waste such as the Basel Convention which restricts the movement of hazardous waste streams across borders (United Nations Environmental Programme, 2011), as well as the Bamako Convention. The Bamako Convention which came into effect in 1998, is a treaty that prohibits the import into Africa of any hazardous waste, including radioactive waste (United Nations Environment Programme, 1998). With the ports in KwaZulu Natal, KZN being identified as points of entry for WEEE from developed nations, enforcement of the conventions is a desperate situation in light of the exponential growth of this waste stream (Maes & Preston-Whyte, 2022).

The E-waste management sector increasingly employs a combination of the CaC and FI approaches in managing the waste generated from this portion of the waste management section. The directive to avoid landfilling to manage greenhouse gas emissions is CaC, while the employment of Extended Producer principles similar to the European Union's directives employ the fiscal or market approach to meet pre-determined requirements or specifications (Maitre-Ekern, 2017). The enforcement of the two conventions, Basel and Bamako are mutual agreement instruments as they employ convention agreements in a preventative principle manner to protect the environment and its people (Matz-Lück, 2009).

The purpose of the Extended Producer Responsibility, (EPR) Schemes is to contribute positively to the implementation of the waste hierarchy and the enablement of the circular economy through the voluntary monetary contribution by industry participants within the paper and packaging industry, the waste electric and electronic equipment sector and the lighting industry. These industries contribute an EPR fee to their respective industry regulatory bodies or they contribute through the implementation of an EPR tax by the South African government (Pillay, 2020). Despite

this, South Africa has managed to recycle only 9.7% of its generated WEEE (Maes & Preston-Whyte, 2022).

In the South African context of the triple threat of poverty, inequality and unemployment (National Planning Commission in the Presidency, 2013), particularly in the most populous province of the country (South Africa Gateway, 2018), the economic value of waste cannot be understated or overlooked in Gauteng. In a province that is overburdened by growth that is not just attributed to new births but is also the result of people migrating into the province with the hopes of finding employment (Landau & Gindrey, 2008), the waste generated in Gauteng is an ever-present challenge. A challenge that further highlights the need for effective EPR activity within the industry by increased adoption of the regulations and participation by the manufacturers in the establishment of the infrastructure and market for recycling and the recyclable material.

In the context of limited employment opportunities and high competition for low skilled and unskilled employment opportunities, Gauteng has a thriving informal recycling sector which accounted for about 51% of the recycling of paper and plastic in 2017 (Godfrey, 2021). This serves as an illustration of the high level of activity of reclaimers within Gauteng. As a resident of Gauteng, you would be very distracted if you did not see reclaimers on the roads, particularly on the day that residential waste is collected within your neighbourhood. Taking the large contribution that private citizens make towards WEEE into account, informal reclaimers are also active within the WEEE sector. It is with this in mind that the capabilities of the reclaimers as well as the possibility of improved levels of recycling, that the consideration of further empowerment and equipping through EPR must be considered.

2.10 Chapter conclusion

As the rush is on to become sustainable and resource efficient, there seems to be a deficit in the attention required for the management of the entire value chain for the photovoltaic installation components within South Africa. Though these have been considered through the strength of the waste management legislation, the Industry Waste Management Plans as well as the Extended Producer Regulations, implementation is impeded by the lack of enforcement and infrastructure.

In light of the reviewed global practices of management of EoL PV installations, the varying challenges experienced are drawn from the individual country's capacity to manage waste and ultimately translate this into the management of EoL PV installations.

As the photovoltaic environment is dynamic, research is ongoing, particularly due to the hazardous nature of the components. While the chapter has delved into challenges effecting the circular economy, the review has highlighted the shortcomings that need to be addressed when reviewing the global waste management practices for the waste stream.

Chapter three will describe the research methods employed to achieve the second objective of this research. It will detail the sampling strategy employed and how the data will be collected in order to achieve the stated objectives. The chapter will describe the research process and design and provide details of the data collection process by presenting the questionnaire for the research interviews. Furthermore, there will be a description of the area of study, the process of data analysis, ethical considerations considered during the research, and finally, there will be a description of the limitations that came about throughout the data collection process.

CHAPTER 3 METHODOLOGY

3.1 Introduction

This chapter describes the methodology that was employed to review literature in response to the first objective and describe how the second objective of this research paper will be met. This will be achieved through the provision of the detail on the methodology that was employed to achieve the aim of the research. The chapter will describe how and why the stakeholders for the interviews were selected as well as present the structure and summary of the content of the research questionnaire. Lastly, this chapter will conclude by providing the ethical considerations of the research.

3.2 Research approach

A qualitative research approach is undertaken to achieve the aim of the research. The qualitative research method includes explorative questions that invite the respondents to the presented questionnaire to express their views (Creswell & Creswell, 2017). This is the approach of choice as the research seeks to understand stakeholder perspectives on solid waste management and subsequently, on the management of EoL photovoltaic installations in Gauteng. The qualitative approach is inherently inquisitive in nature as it seeks to discover the available research on the topic. The approach allows for an exploration of the topic, thus broadening the body of information with new experiences and perspectives of the respondents (Finlay, 2006). It values the opinions and experiences of the respondents in the research as it aims to provide a rich context to the problem statement identified in the research (Castleberry & Nolen, 2018). The descriptive nature of the approach provides the context of the research and describes the background or the experience in relation to the research questions (Merriam, 2002).

3.3 Research design

The research design adopted for this dissertation included both primary and secondary data collection. Primary data was collected through interviews (RO2), while secondary data was collected by means of a review of literature (RO1). Table 3-1 provides an overview of the research objectives, methods of data collection and justification thereof.

Table 3-1: Data collection

Research objective	Data collection	Justification
<p>RO1: To explore the global practices of managing end-of-life photovoltaic installations</p>	<p>Literature review</p>	<p>The purpose of the literature review is to investigate existing research with the purpose of identifying what is relevant to this research topic and to identify gaps within the research literature that can be addressed in this particular research (Palmatier <i>et al.</i>, 2018; Patriotta, 2020). It was done to display the extent of the challenge faced by the world as well as the advent of opportunity that the world is at the doorstep of in the form of EoL PV installation management.</p>
<p>RO2: To explore the perceptions of end-of-life management of photovoltaic installations in Gauteng</p>	<p>Interviews with various stakeholders</p>	<p>This research objective is an exploration of the lived experience of the respondents, considering their experiences within their sphere of influence or field of expertise. It also seeks out solutions from the respondents. Interviews are the chosen method of engagement because they are explorative in nature and encourage reflection as well as sharing of ideas over a particular topic (Gill <i>et al.</i>, 2008).</p>

3.4 Description of the case study

The case study area is the province of Gauteng of the Republic of South Africa (Figure 3-1).

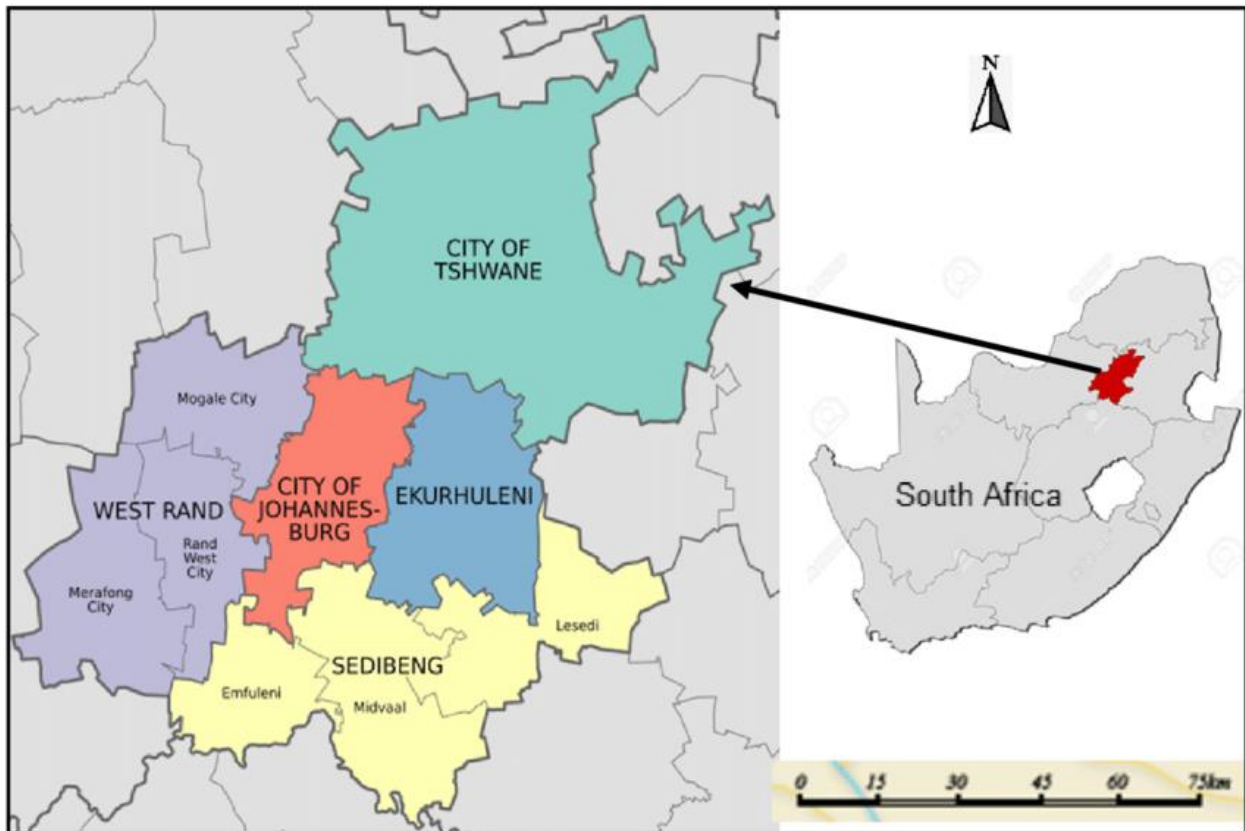


Figure 3-1: Gauteng Province of South Africa depicted with its municipalities (Nhamo *et al.*, 2021).

The sections below provide an overview of the motivation for selecting Gauteng as a case study area (Section 3.4.1) and a description of the case study area (Section 3.4.2).

3.4.1 Motivation for selecting Gauteng as a case study area

The Gauteng province in South Africa was selected as the case study area. As an economic hub of South Africa and the most populous province of the country (South Africa Gateway, 2018), Gauteng is the largest contributor of domestic waste and a large contributor of industrial waste as mining waste volumes are the highest waste volumes in the country (Muzenda *et al.*, 2012).

Though urbanised as a province, Gauteng does also have rural and underdeveloped areas (Oranje, 2015), which also face challenges of poor service delivery (Todes, 2012).

The myriad of challenges, as well as the nature of the province, is a fair representation of the country is the reason for the selection of this province as a case study. The province's socio-economic make up, demographics, spatial planning, political framing do well as a description of

South Africa as a whole (Downe *et al.*, 2016). It is also an area where we have seen proliferation in the development and implementation of solar PV technology.

3.4.2 Description of the case study area – Gauteng province

Gauteng is the smallest of the nine provinces in South Africa, but also the most populous. Gauteng is a province made up of eleven municipalities, five of which are metropolitan municipalities, while the other six are local municipalities with ten industrial and mining centres (Nhamo *et al.*, 2021). Waste contribution in the province is a direct consequence of both civilian consumption and economic activity (Hoorweg & Bhada-Tata, 2015). A province of great inequality, yet the source of hope for many as people migrate to the urban centres of the province from the outskirts of the province, other rural provinces of South Africa and other African countries (Everatt, 2014). As the centre of the of South Africa's trade and transport, the majority of South Africa arrive in and stay or pass through Gauteng (Landau & Gindrey, 2008).

Described as the largest generator of municipal solid waste in South Africa (Karani & Jewasikewitz, 2007), Gauteng is increasingly faced with the challenge of effective and sustainable waste management in the face of illegal dumping, the mushrooming of illegal dumpsites (Nkosi, 2014), the diminishing capacity of the province's landfill sites and the ineffective availability and utilisation of the waste management facilities and infrastructure due to poor utilisation of finances for development and maintenance purposes (Muzenda, 2012; Oelofse, 2021).

Considering the state of waste management in the province, the research seeks to understand the perceptions of the respondents on the effective management of the solid waste generated as a result of the EoL PV installations.

3.5 Data collection

The methods that were employed for the collection of data that contributed to the research topic included a literature review in response to the first research objective and the second research objective was addressed by conducting interviews.

3.5.1 Literature review

A literature review is a review of previous studies that have been published and are contributors to the body of knowledge on the topic at hand (Paul & Criado, 2020). The review established what is known as it built a firm foundation for future research on the topic of interest (Snyder, 2019). The literature review has been a presentation of the research themes, and a synthesis of the different bodies of work of the research theme that enabled a new proposition (Wentz, 2014). For

this research, the purpose of the literature review was to establish the global waste management practices of EoL photovoltaic installations (RO1).

In addition to Google Scholar, literature was sourced from the North-West University Library and Information Service webpage which gave access to journals such as Sage, and Springerlink as well as publication platforms such as Science Direct. Reports and published governmental management plans from various governmental departments, including the Department of Forestry, Fisheries and the Environment as well as the Department of Planning and Commissioning were sourced. Information was also sourced from past dissertations of South African students that have conducted research that explores South Africa's challenges such as intermittent power supply, the effects of spatial planning on waste management and service delivery levels in the country's municipalities. Lastly, due to the contemporary nature of the topic, technical magazines and websites discussing solar photovoltaic components and their recyclability were also sourced for information. A concerted effort was made to maintain the search of literature to publications within the last five years, but there were areas of discussion, such the establishment of the case study area's demographics, the discussion pertaining to the evolution of consumption patterns of the world from linearity to circularity or the discussion about the research techniques that warranted use of literary sources that were older than that.

Considering the wealth of knowledge, the depth of the challenge pertaining to waste management and sustainable development in Gauteng as well as the extent of the challenge of EoL PV installations management, it has been a challenge to ensure the research remained focused and avoided scope creep, eventually detracting from the research question (Barbour & Barbour, 2008). It was imperative that the research kept its focus on its aims and objectives. In this context, the following search terms were used in different combinations: *"end-of-life photovoltaic installations"*, *"solar PV waste"*, *"E-waste circularity"*, *"E-waste management"*, *"WEEE management"*, *"sustainable waste management"*, etc.

Literature on the management of EoL solar PV installations was obtained for Ethiopia, Brazil and Australia as case studies. The countries chosen were the countries of choice because Ethiopia is an unapologetically African country on the continent (Tibebu, 1996), Brazil is a fellow founding member of BRICS (Brazil, Russia, India China and South Africa) (Library Of Congress, 2023) and Australia was the researcher's developed nation of choice outside of the United States of America and Germany. Australia is making a concerted effort to manage waste in a sustainable manner (Department of Climate Change, Energy, the Environment and Water, 2023). These countries are presented in Sections 2.9.1 to 2.9.3 in Chapter 2 and the lessons deduced from the review of the countries are summarised in Section 4.2.1 of Chapter 4.

3.5.2 Interviews

To address research objective 2 (exploring perceptions around EoL solar PV waste management in Gauteng), this research made use of interviews. The interview process and questions posed enabled a discussion of the issues at hand and ignited a discussion on possible solutions or the identification of specific areas of concern (Harvey-Jordan & Long, 2001).

The sections below provide a discussion of the development and piloting of the interview questionnaire, the identification and selection of research respondents, and the process of conducting interviews.

3.5.2.1 Development of the interview questionnaire

A structured questionnaire (See **Annexure A**) was developed to guide the interview process. The questionnaire consisted of structured questions to gauge the attitude the respondents have towards the topic at hand (ranked by using a Likert-scale) (Croasmun & Ostrom, 2011), as well as explorative open-ended questions to enable the interviewer to probe the interviewee while guiding the conversation (Alshenqeeti, 2014) (**Annexure A**).

Questions were gleaned from the literature review compilation (Chapter 2) and the content of the questions were mainly guided by the European Union (European Commission, 2012) and research by Chowdhury *et al.*, (Chowdhury *et al.*, 2020).

The interview questionnaire consisted of 27 questions which have been structured into three sections. The first section gathered information on the background of the respondents, such as their job profile, number of years of experience, and highest qualification. The second section posed questions to determine respondents' perceptions on Gauteng's solid waste management and the readiness of the province to manage waste generated by the EoL PV installations. Lastly, the third section included a set of eight questions that sought for recommendations towards the improvement of waste management that would ensure the effective management of the EoL PV installations in Gauteng (**Annexure A**).

3.5.2.2 Piloting of the interview questionnaire

The interview questionnaire was piloted on a sample of three respondents, who were mainly peers within the waste management fraternity. The purpose of the pilot was to ensure that the questions raised were clear and understood by the respondents, while also ensuring that questions rendered responses that were in line with the research aim.

In the discussions about the questionnaire and the responses that came about, questions pertaining to the respondents' perception on the global state of EoL PV installation management

were removed as this objective was dealt with through the first research objective. These were also beyond the scope of the respondents and irrelevant to the second objective. The questionnaire was then further streamlined so as align to the second research objective.

3.5.2.3 Sampling and selection of research respondents

For this research, the respondent selection was through non-probability, purposive sampling. The respondents that form the sample were chosen particularly because of their experience within their respective industries and sectors, their knowledge of waste management practices in Gauteng, financing of renewable energy projects or renewable energy sectors. The following stakeholders were approached and invited to participate in the research, because they were considered as being able to inform aspects of the research (Sargeant, 2012):

- Waste management sector (provincial and local government, private waste management companies, waste generator as a large-scale solar installation consumer);
- Renewable energy sector (PV solar installers);
- Environmental management sector (Environmental assessment practitioners responsible for renewable energy projects); and
- Financial sector [solar project financiers, energy project development, economists studying the development of the Southern African Developmental Community (SADC)].

In addition to purposive sampling, the snowballing method was used, through which additional respondents to the research were identified through referral by the initial purposefully identified respondents (Acharya *et al.*, 2013).

As the sample is selected through non-probability, purposive sampling, the size of sample is not prescribed but is rather guided on a rule of thumb, depending on the data required by the researcher (Daniel, 2012). For the purposes of this research, a target of twenty (20) respondents was set. The sample size was chosen to gather sufficient perspectives, whilst limiting repetitive responses (Vasileiou *et al.*, 2018). The respondents of the interview process were chosen because of their professional experience within their respective sectors, their technical background and their lived experience of Gauteng and its socio-political setting that effects the level of waste management service delivery within the province.

3.5.2.4 Conducting interviews

An initial introductory phone call was made to the selected respondents which was followed with an e-mail that detailed the research that was being undertaken. See **Annexures B. Annexure B**

was attached to the introductory email that formalised the verbal request for an interview (Annexure B). Once a positive response was attained from the prospective interviewee, a discussion was held regarding the chosen method of interviewing, the choice given was between Teams or Zoom as virtual modes of contact or by face-to-face contact. Prior to the interview, the informed consent form with introductory commentary to the research was sent to the interviewee.

While the topic of the research sparked questions about the interviewer’s professional background amongst the respondents that were not familiar with interviewer, the curiosity served the interviewer well in winning the support of respondents that responded positively to the request for participation in the research. These questions were either discussed over e-mail, a telephone call or as part of the introductory discussion of the interview. The introductory conversation reiterated the informed consent and the respondents’ requirement to sign this form, the voluntary participation as well as the objectives of the research. It provided a brief overview of the structure of the questionnaire as well as the expected length of the interview. The interviews lasted between 50 and 75 minutes depending on the extent of the discussion and the depth of the introductory discussion. All interviews were conducted in English between the 23rd of June and 31st of July 2023.

The interviews were recorded, having received the respondents consent to record, while the interviewer took notes of the discussion during the interviews. The questions were displayed on the screen during the interview and these notes were typed on the research questionnaire document. In the instance of a face-to-face interview, notes were taken over the laptop in the presence of the interviewee. Due to unforeseen equipment failure, a recording of the respondents for the face-to-face interview was unsuccessful. This was detected early enough for the interviewer to run through the interviews and note down as much of the discussion as possible from memory and the notes taken during the interview session.

3.5.2.5 Description of interview respondents

Of the targeted twenty (20) respondents, sixteen respondents participated in the research (80% response rate). Table 3-2 provides a background on the interview respondents.

Table 3-2: Background information of respondents (n = 16)

Interviewee information	Number of respondents	Percentage
Industry of employment		
Waste management	9	56.25%
Energy management	3	18.75%

Interviewee information	Number of respondents	Percentage
Project proponent	1	6.25%
Other	3	18.75%
Years of experience		
0 – 5 years	3	18.45%
6 – 10 years	4	25%
11 – 15 years	4	25%
16 – 20 years	2	12.5%
>20 years	3	18.75%
Sectoral involvement		
Private	8	50%
Public	4	25%
Both	4	25%
Highest level of qualification		
National diploma	1	6.25%
Bachelor's degree	1	6.25%
Post-graduate diploma/Hons degree	5	31.25%
Master's degree	7	43.75%
Doctorate	1	6.25%
Other	1	6.25%

3.5.2.5.1 Sector of employment

Of the sixteen respondents, nine were from the waste management sector. The positions within the sector ranged between middle and senior or business unit managers. Three of the respondents were from the energy management sector. The positions within the field were officials, middle and senior management. One respondent was an Environmental Assessment Practitioner (classified as project proponent for the purposes of this research) and the final group of respondents were classified as “other” as their roles were within the financial as well as the futurists/strategic thinking fields.

3.5.2.5.2 Years of experience

The years of experience of the respondents ranged from three to over twenty years within their various sectors of employment. Three of the respondents have less than five years' experience in their field, four have between six- and ten-years' worth of experience, five respondents have between eleven- and fifteen-years' experience, two of the respondents have between sixteen- and twenty-years' experience and two of the respondents have over twenty years' experience.

3.5.2.5.3 Sectoral involvement

The respondents were from both the public and private sectors, with four of the respondents having experience in both sectors.

3.5.2.5.4 Highest level of qualification

The respondents have varied levels of education, ranging from national diplomas/Bachelor's degrees to doctoral degrees. Seven of the respondents have a master's degrees with the field of specialisation being Futures Studies, Business Administration, Chemical Engineering, Environmental and Water Engineering, as previously mentioned. The experience of these respondents ranges from three years to over twenty years' experience with their respective industries of employment.

3.5.2.5.5 Location

As the aim of the research is to explore the perceptions of the effectiveness of solid waste management of EoL PV installations in Gauteng, each interviewee resided or had resided and worked in Gauteng and was thus familiar with the waste management situation of the province, as well as the political and civil circumstances that effect the level of effectiveness of waste management services within Gauteng.

3.6 Data analysis

The data collected through the literature survey is analysed through two different processes, within-study and between-study literature analysis. Within-study literature analysis is the analysis of the contents of specific work, while between-study literature analysis is the comparison and contrasting of multiple literature sources (Onwuegbuzie *et al.*, 2012). Through the use of the within-study analysis, the sustainability framework was extracted from the research. The contents of the body of literature contributed to the analysis of the global activity that drives the sustainable management of EoL PV installations. Through this analysis, the domains of the sustainability framework, economic, material, spiritual, social and domain of life were discussed in order map the global management of the EoL PV installations on this framework. The within-study analysis compared the activity of the various countries in the effective management of their waste, and ultimately the management of EoL PV installations. This comparison was then mapped according to the sustainability framework, detailing the activities contribution to the framework through the various domains.

There are three different types of analysis for the data collected during the interview process. Employed during qualitative research, these are the quasi-statistical, thematic coding and grounded theory approach. Of the three, the thematic coding is the most frequently used in research and thus is also the method of choice for this research (Alsaawi, 2014). Responses to

structured questions were ranked through use of an ordinal (Likert scale) to measure the level of agreement/satisfaction/readiness etc. based on the statements posed. Frequency of ordinal-scale responses are presented in a frequency table.

Qualitative data (narratives) collected through open-ended questions were analysed through intuitive thematic analysis by measurement of frequency of the mention of a particular phrase or notion in response. In reviewing the justifications, it is imperative to manage the data collected in the interviews with care so as capture the essence of the response and not to detract from the integrity of the information and devalue it through incorrect interpretation (Alshenqeeti, 2014). Specific themes were identified based on phrases and are also presented in a frequency table.

Similar to the analysis of the literature review, which collated the views and concepts identified within the review and presented these in view of the principles of sustainable development, the results of the interviews conducted are presented in a similar fashion. The responses of the respondents have been presented in accordance with the principles of sustainability, namely social, economic, spiritual, material and the domain of life. The respondents' responses were analysed to determine which of the five principles that the response to a particular question expresses. Once this was determined, the response was assigned to a principle. The frequency of expression of a principle was then illustrated through a tree map, while detailing the expression within the tree map.

3.7 Ethical considerations

This research was undertaken in accordance with the North-West University's ethical requirements. The research proposal was submitted for review and was subsequently approved for research by the Environmental Management Scientific Committee and the Faculty of Natural and Agricultural Science Research Ethics Committee (NWU-01217-23-A9).

The stakeholders as well as the organisation that they represent will remain anonymous so as not to place any undue influence on the data received from the responses of the interview questions (Alsaawi, 2014).

This is a low-risk research paper in that the stakeholders of the research are people who fully aware of the context of research. The stakeholders are well capable of making an independent decision on whether to participate in the research. The stakeholders have been supplied a consent form to sign before the commencement of the research (Alshenqeeti, 2014). The interviewer would have also made a concerted effort to contact the stakeholder prior to the interviews to discuss the content of the interview (Alshenqeeti, 2014). The stakeholders would have also been told of the option to stop the interview at any time during the process should they feel uncomfortable in any way or choose not to participate any further. Should the respondent

decide not to participate any further, they have a choice whether to furnish the interviewer with reasons for the termination of their participation. At the risk of losing the stakeholder, it is important to be transparent to enable the stakeholders to decide upfront concerning their participation in the research rather than having them cancel in the middle of the interview (Knox & Burkard, 2009).

3.8 Methodological limitations

While conducting the research there were limitations that were identified that would require clarification and qualification by the researcher. The first of these limitations is the subjective nature of the responses of the respondents (Bumbuc, 2016). As the research delves into the perceptions of the respondents, the responses are subject to their personal experiences (Kalu, 2019). The expansion of the research that delves into proposals for the improvement of the state of waste management and ultimately cultivating a more effective response to the management of the EoL PV installations continues to revolve around personal and professional experiences. Further to this limitation of bias is the selection of respondents, as this is dependent on what the researcher aims to achieve in their research and how they perceive the respondents will contribute to the research (Lundberg *et al.*, 2023).

As characterised by ethnography, the researcher needs to interpret the response from the respondents from their perspective (Nurani, 2008). In spite of this, the researcher's perspective is from the waste management context, as this is their professional experience. The researcher was determined to respond to the complexity of the aim of this research by considering a multi-disciplinary response (Queiros *et al.*, 2017: 376).

A total of sixteen respondents from different backgrounds were interviewed for the purposes of this research. The researcher would have wanted to interview more respondents in the energy management and environmental impact assessment sectors. This would have been to, firstly, get an understanding of whether the sectors are considering the management of EoL PV installations. Secondly, the researcher would have wanted to get an understanding of the level of consideration of the waste stream within the sectors; and lastly, the inclusion of these sectors could possibly have given an indication of the sense of cross-sector collaborations for the management of the EoL PV installations. When approached, in spite of the presentation of the background of the research and the reason behind the researcher's belief that that they would add value to the research, the prospective respondents declined to participate citing that they did not believe that had anything of value to add. The reason provided by the energy sector candidate was that they had no experience with the waste management sector. The reason provided by the Environmental Impact Assessment Practitioner was that they were not involved in small or domestic scale solar PV installations. Considering the level of response saturation achieved after approximately ten

to twelve interviews, it is believed that the sixteen respondents included in the research were sufficient to address the research objectives.

The research questions have been put to the respondents by way of a structured interview questionnaire. Though the researcher's aim for the questionnaire was to extract as much information in response to the second objective of the research as possible, the conversation and responses to the questionnaire had to be as focused on the topic at hand (Queiros *et al.*, 2017: 377-378) (i.e. the effectiveness of solid waste management of end-of-life photovoltaic installations in Gauteng). Regardless of the structured nature of the questionnaire, the questions raised needed to be interrogated in response to each aspect of the research to provide a holistic picture of the state of waste management, the state of readiness to manage EoL PV installations, and possible solutions to address the challenges raised (Barbour & Barbour, 2008). It was, therefore, important to strike a balance between the restrictive structured questionnaires and the open-ended in-depth questions through the expansion of the questions during the interview to get conclusive information from the respondents.

Another challenge that became apparent was the stark differences in the service levels between the public and private sectors and the resultant difference in the level of satisfaction between the two sectors. The questionnaire did not take the two different sectors into account in its questions, but it the differences were raised and expounded upon during the interviews.

3.9 Chapter summary

Chapter 3 provided a description of the method of research employed. It discussed the qualitative research approach, detailing the reasons behind the choice of approach employed. It also explained the qualitative design method, analysis of state and process at the time of research as the design method of choice in responding to the objectives of the research. The data collected will be presented in Chapter 4.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Introduction

Chapter 4 is a report of the results of the research conducted on the topic at hand. The aim of the research, the exploration of the perceptions of the effectiveness of solid waste management of end-of-life (EoL) photovoltaic (PV) installations in Gauteng, was addressed through the following objectives:

1. To explore the global practices of managing EoL PV installations.
2. To explore the perceptions of EoL management of PV installations in Gauteng.

This chapter presents the results of the research conducted that addressed the second research objective. This chapter will first detail the results of the first objective, the exploration of the global practices of managing the EoL PV installations by delving into the question of global sustainability. It will describe how this concept came about and how it permeated the environmental and waste management principles to influence the legal framework that governs the management of waste as a whole and EoL PV in particular. It will then detail the results of the second objective which were obtained through interviews.

The research undertaken to achieve the first objective was through a literature review. Research in response to the second objective was conducted through interviews. The interviews were conducted through a semi-structured questionnaire of three sections. The first section detailed the background of the interviews, while the second and third sections were the results of the investigation into the second objective of this research. The questionnaire is depicted in Annexure A.

The discussion that will ensue from the results obtained will also be detailed in this chapter, as well as an interpretation of the results. It will place the results of the interviews into context of the background of the interviewee and the circumstances under which the interviews were conducted. Through a systems-thinking approach (Arnold & Wade, 2015) due to the complex nature (Salvia *et al.*, 2021) of the challenge of EoL PV installation management, the results will be interrogated so that conclusive recommendations can be made to affecting the effective management of solid waste generated from EoL PV installations.

4.2 Results related to RO1: Exploring global practices of managing end-of-life photovoltaic installations

Table 4-1 provides a summary of global practices related to the management of EoL PV solar installations from literature. The literature review chapter, Chapter 2, provides a detailed overview of these practices, while Table 4-1 summarises the context related to:

- Sustainability principles;
- Global treaties, conventions and international law;
- Related sustainable development goals; and
- Activities governed by legislation.

As explained in Section 3.6, Table 4-1 unpacks these elements by viewing it through a “sustainable development lens” as discussed in Section 2.8 of this dissertation. This was to supplement the contribution that the effective management of EoL PV installations would have towards sustainability.

- **Economic:** The economic aspect of sustainable development entails the use of renewable energy, although not limited to this, to sustain the economic aspirations of nations, while also acknowledging the finitude nature of resources that contribute to development. It takes on a humanistic perspective of economic development (Harris, 2003). It acknowledges the need for economic independence through the use of country’s resources, end encourages the use of these resources in a manner that considers the needs for economic independence of future generations.
- **Material:** This is the use of extracted material for the economic benefit of nations. In light of sustainable development, this activity needs to be enacted in a manner that does not detract from the energy-water-environment nexus that ensures continued sustainability, while contributing to the global sustainable development goals (Shahzad *et al.*, 2017).
- **Social:** The social aspects of sustainability is about social cohesion. It takes the inclusion of all the people of a nation, regardless of their social setting, race or gender, into account while building a sustainable nation (Gupta & Vegelin, 2016) that encourages active citizenry (Jeronen, 2020). Social cohesion involves the empowerment of the citizens to meet their own needs, by addressing inequality, unemployment and poverty (Scheifer & van der Noll, 2017). It also fosters social interaction and inclusivity amongst all the citizens in a respectful and considerate manner (Prause *et al.*, 2019).

- ***Spiritual:*** Not to detract from the value of science, the consideration of the spiritual aspect of development is important as this affects the land that the resources are extracted from in order to create products. It enables the interrogation of the state of perpetual consumption to facilitate a state of stewardship by the current generation for future generations (Jain & Jain, 2019).
- ***Domain of life considerations:*** Considering the complex nature (Pryshlakivsky & Searcy, 2013) and the anthropogenic perspective (Oosthuizen *et al.*, 2018) of sustainable development, the domain of life is an integral part of sustainable development (McMichael *et al.*, 2003), as it takes the both the needs of the people as well as capacity of the planet into account in a manner that promotes the long-term view (Bijl, 2011).

Though the objective of the research was to understand the global practices of managing the EoL PV installations, context was provided of the challenge at hand within the research that included the mining and extraction of the rare earth elements that make up the various components of renewable energy installations, the environmental management factors that are affected by the installation throughout their life cycles as well as within the project lifecycle of utility scale installations.

The listed principles of sustainability expound on the concept of sustainability by presenting the justification for the global legal framework employed, the treaties entered into by various nations and the country specific strategies that are guided by the regulatory framework employed to affect the effective management of EoL PV installations. This is summarised in Table 4-1 to follow.

Table 4-1: Global practices for the management of EoL PV installations: A summary

ECONOMIC	MATERIAL	SOCIAL	SPIRITUAL	DOMAIN OF LIFE
1. Sustainability principles influencing the global conversation on the effective management of EoL PV installations				
A guiding framework for creating and managing wealth	Regulating the flow of materials and energy that underline the existence of people	Social interaction	Attitude and value orientation	The appropriate behaviour within the biosphere
2. Global treaties and agreements influencing the legal framework of countries around the world affecting the effective management of EoL PV installations				
Brundtland Commission	Brundtland Commission	Basel Convention	Rio Declaration	Rio Declaration
Kyoto Protocol	Basel Convention	Bamako Convention		Kyoto Protocol
	Bamako Convention			Brundtland Commission
Agenda 21 on Sustainable Development				
3. Sustainable Development Goals affecting the global treaties and agreements that affect the effective management of EoL PV installations				
SDG 7 - Affordable clean energy	SDG 7 - Affordable clean energy	SDG 3 - Good health and well-being	SDG 3 - Good health and well-being	SDG 7 - Affordable clean energy
SDG 8 - Decent work and economic growth	SDG 11 - Sustainable cities and communities	SDG 8 - Decent work and economic growth	SDG 14 - Life below water	SDG 8 - Decent work and economic growth
SDG 14 - Life below water	SDG 12 - Responsible consumption	SDG 14 - Life below water	SDG 15 - Life on land	SDG 11 - Sustainable cities and communities
SDG 15 - Life on land		SDG 15 - Life on land		SDG 13 Climate Action
SDG 17 - Partnerships of goals				
4. Activities governed by the legal framework that affects the environmental law principles for the management of waste in a manner that affects the effective management of EoL PV installations				

ECONOMIC	MATERIAL	SOCIAL	SPIRITUAL	DOMAIN OF LIFE
Waste collection policies and laws				
Waste collection infrastructure - facilities, collection vehicles				
Waste services rates	Waste separation at source	Communication	Community involvement and buy-in	Community involvement and buy-in, infrastructure development
Management of the waste value chain - from inception to end of life	Waste value chain - from inception to end of life	Community involvement and buy-in	Environmental protection	Environmental, migratory species, agricultural activity, aquatic life protection
Consequence management for behaviour that is destructive to the environment	Recycled material market development	Human health protection, infrastructure development		Consequence management for behaviour that is destructive to the environment

As outlined in Table 4-1, the effective management of the EoL PV installations is underpinned by the factors outlined in the sections below which all ultimately support sustainable management of the waste through the consideration of the five sustainability principles as discussed previously within the research (Section 2.8) and in the preamble to Table 4-1:

- The drive towards sustainability should not just be limited to the use of renewables in the drive to achieve clean and affordable energy (Elavarasan *et al.*, 2023), it must evaluate the lifecycle and value chain of PV installations. It cannot only consider the generation of energy, it needs to evaluate the effects of PV installations on ecological activity such as animal and plant species activity as well ground water and other water sources and aquatic life of an area, the people of the area and their needs to provide for themselves, while maintaining good quality of life for all role players involved.
- While this research focused on the EoL PV installations, during the research activity it became evident that the waste from the EoL PV installations is not only generated at the end of the said twenty-to-30-year lifecycle, but waste is generated throughout the life of the PV installations (Kim & Park, 2018). Further to this, there are instances where the PV components lose their efficiency or fail to meet their intended purposes before the expected time frame of twenty to 30 years due to various reasons, such as the obsolescence of the technology employed in the installations or damage as a result of severe weather conditions, replacement of components due to maintenance on the installations and therefore waste can be generated sooner than expected (Curtis *et al.*, 2021). It is important to anticipate and plan for the waste stream early as the execution of the plan will not be simple.
- EoL PV management infrastructure must consider the carbon footprint of the infrastructure that forms part of the installation as well as the collection infrastructure available for the waste generated as a result of the EoL PV installations to reflect true sustainability. The waste management facilities need to be easily accessible and within a good proximity of the collection points, much like waste landfill sites (Chowdhury *et al.*, 2020).
- Clear communications of the government's expectations that are directed at the citizens of the country with regards to the effective management of the EoL PV installations must be achieved (Ndzibah *et al.*, 2022). This communication includes a presentation of the expectations, the means of effecting the expectations and the consequences of ignoring or failing to adhere to the expectations as prescribed by the legislation (Taylor *et al.*, 2021).
- Effective management of the EoL PV installations will have to involve citizens, private companies and the public sector as the challenge is complex and multi-faceted (Guiseppe *et al.*, 2021).

- The revenue generated from the EPR must be ploughed back into the effective management of EoL PV installations to encourage private sector innovation and to further develop the required infrastructure (Tarek & El-Haggar, 2019).
- The sovereignty of a nation must be safeguarded to protect the market for recycled products of the EoL within the country by keeping material and product from other countries out, thus detracting from the country's ability to locally extract value through job creation, skills and technology development from the beneficiation of the waste stream, a micro, meso and macro-economic opportunity (Nikolaou & Tsagarakis, 2021).
- While the consideration of the global treaties and commitments is important, legislation should encourage innovation and not stifle it, while also protecting the establishment of a market within the country. Globalisation should enhance the activities that develop a circular economy of the country, not detract from it (Sharma *et al.*, 2019; Malandrino *et al.*, 2017).
- In spite of the identified gaps of ambiguity and enforcement, the legislation to effectively manage the waste generated from EoL PV installations already exists as it is an extension of the legislation to manage waste. As knowledge of the PV installations grows and as the knowledge influences an evolution in the technology used, so too can legislation, to eventually ensure complete circularity of the PV installations and thus drastically reduce or eventually eliminate the use of virgin material to manufacture the components (Ndzibah *et al.*, 2022).
- Globally, for the countries that have established the EPR and circular economies, it is about using what they have within their waste sector and building on those principles to add the EoL PV installations by being intentional about the waste stream. This is particularly the case in the instance of the European Union and China (Weckend *et al.*, 2016).

4.3 Results related to RO2: Exploring the perceptions of end-of-life management of photovoltaic installations in Gauteng

The second research objective was pursued through interviews with sixteen respondents, as explained in Section 3.5.2 of this dissertation. The first section below (Section 4.3.1) provides the responses to the structured questions that was measured through a Likert-scale, while Section 4.3.2 (and its related sub-sections) discuss the results of the analysis of open-ended questions.

The demographic information of respondents is provided in Section 3.5.2.5 of this dissertation and will not be repeated here.

4.3.1 Perceptions of EoL PV waste management in Gauteng

To explore the perceptions/views of the respondents on the management of the EoL PV installations, the Section B of the questionnaire delved into their perceptions of the current state of general waste management within Gauteng. It then asked what the level effectiveness of the management of EoL PV installations would be, taking the current state of waste management into account. Questions were framed against the current legal framework for waste management, its implementation, and effectiveness thereof, for waste management from the respondents' perspective. Responses were measured through as ordinal (Likert) scale. Responses of the sixteen respondents are summarised in Table 4-2. Numbers provided in Table 4-2 indicate the number (or frequency) of respondents and their extent of agreement with each statement (also expressed as percentages).

Structured questions were followed-up by an open-ended question to determine the reasons for respondents' responses. These responses were thematically analysed, as explained in Section 3.6, and presented in Figure 4-1.

Table 4-2: Statements related to EoL PV waste management in Gauteng and responses from respondents (n = 16).

Statements and level of agreement				
<i>Indicate your level of satisfaction with the current state of waste management within Gauteng?</i>				
A: Completely unsatisfied	B: Unsatisfied	C: Neither unsatisfied nor satisfied	D: Satisfied	E: Very satisfied
4(25%)	4 (25%)	5 (31%)	3 (19%)	0 (0%)
<i>In your professional opinion, how would you describe the state of preparedness of the waste management services of Gauteng for the management of EoL PV installations?</i>				
A: Completely ill-prepared	B: Ill-prepared	C: Neither ill-prepared nor prepared	D: Prepared	E: Well prepared
4 (24%)	7 (44%)	5 (31%)	0 (0%)	0 (0%)
<i>How would you describe the effectiveness of government's use of legislative instruments to cause change in behaviour towards effective E-waste management?</i>				
A: Completely ineffective	B: Ineffective	C: Neither ineffective nor effective	D: Somewhat effective	E: Effective
2 (13%)	4 (25%)	5 (31%)	5 (31%)	0 (0%)
<i>How would you describe the effectiveness of government's use of levies and taxes to cause change in behaviour towards effective E-waste management?</i>				
A: Completely ineffective	B: Ineffective	C: Neither ineffective nor effective	D: Somewhat effective	E: Effective
2 (13%)	6 (38%)	4 (25%)	2 (13%)	2 (13%)
<i>How would you describe the effectiveness of government's use of penalties and fines to cause change in behaviour towards effective E-waste management?</i>				
A: Completely ineffective	B: Ineffective	C: Neither ineffective nor effective	D: Somewhat effective	E: Effective
3 (19%)	7 (44%)	3 (19%)	3 (19%)	0 (0%)
<i>How would you describe the effectiveness of government's use of Extended Producer Responsibility (EPR) to cause change in behaviour towards E-waste management?</i>				
A: Completely ineffective	B: Ineffective	C: Neither ineffective nor effective	D: Somewhat effective	E: Effective
0 (0%)	5 (31%)	7 (44%)	4 (25%)	0 (0%)

4.3.1.1 Indication of the level of satisfaction with the current state of waste management within Gauteng

Eight of the sixteen respondents (50%) (Respondents 2, 5, 8, 10, 11, 13, 15, 16 from the private and public waste management sector, project proponent and other sector) indicated that they were either completely unsatisfied or unsatisfied with the current state of waste management in Gauteng (Table 4-2). Five of the respondents (Respondents 1, 6, 9, 12 and 14 from the other, energy and public waste management sectors) indicated that they were neither satisfied nor unsatisfied. Only 19% of respondents (Respondents 3, 4 and 7 of the other and public waste management sectors) indicated that they were satisfied, with none of the respondents opting for “very satisfied” as an option (Table 4-2).

4.3.1.2 A description of the state of preparedness of the waste management services of Gauteng for the management of EoL PV installations

Reflecting on the perceived state of preparedness of waste management services in Gauteng for the management of EoL PV installations, a combined 68% of the respondents indicated that they perceived waste services in the province as being ill-prepared (44% of the respondents, Respondents 1, 5, 6, 11, 13, 15, 16 of all the sectors, except the project) or completely ill-prepared, as described by Respondents 2, 8, 10 and 11 of the private waste management sector and project proponent of who believed that of the public sector (24%). None of the respondents indicated that they perceived waste services to be prepared or well prepared to manage EoL PV solar installations in Gauteng (Table 4-2).

4.3.1.3 A description of the effectiveness of governments use of legislative instruments to cause a change in behaviour towards effective E-waste management

Of the sixteen, two respondents, (Respondents 11 and 14 of private waste management and energy sectors), (13%), and four respondents, (Respondents 1, 2, 6, 11 of the other and private and private waste management sectors), (25%) believed that the governments use of legislation was completely ineffective and ineffective, respectively towards effective e-waste management practices. Five (Respondents 5, 8, 9, 10, 16 from all the sectors) (31%) believed that the use of legislative instruments was neither effective nor ineffective, while another five (Respondents 3, 4, 7, 13, 15 from the other, waste and energy sectors) (31%) thought they were somewhat effective. None of the respondents believed that the government’s use of legislative instruments was effective towards the management of E-waste. Instead, Respondent 1 from the other sector, and Respondents 10 and 11 from the private waste management sector were pro private sector’s adoption and use of the waste legislation towards effective E-waste management because of the business case it represents as they rather bemoaned the government slow pace of adoption.

4.3.1.4 A description of the effectiveness of government's use of levies and taxes to cause a change in behaviour towards effective E-waste management

In response to the government's use of the financial instruments, levies and taxes, to change the behaviour of the management of E-waste towards circularity, three (19%) of the respondents (Respondents 2, 9, 12 of the waste and energy sectors) viewed the government's actions as completely ineffective and seven (Respondents 1, 5, 6, 10, 11, 15, 16 of the other, energy and waste management sectors) (44%) of them viewed the government's actions as ineffective. The opinion of three, (Respondents 8, 13, 14 from the project proponent, waste and energy sectors), (19%) of the respondents was that the government's actions were neither ineffective or effective, while the remaining three (Respondents 3, 4, 7 of the other and public waste management sectors) (19%) respondents considered the actions of the government as somewhat effective. None of the respondents considered the use of the financial instruments by the government as very effective.

4.3.1.5 A description of the effectiveness of government's use of penalties and fine to cause a change in behaviour towards effective E-waste management

In response to the measurement of the government's use of penalties and fines to cause a change in behaviour towards effective E-waste management, three (19%) of the respondents (Respondents 9, 12 and 14 of the waste and energy sectors) believed that the government's efforts were completely ineffective, and seven (44%) of the respondents (Respondents 1, 5, 6, 10, 11, 15, 16 of the other, energy and waste management sectors) believed that efforts were ineffective. Three of the respondents (Respondents 2, 8, 13 from the waste management sector as well as the project proponent), believed that the efforts were neither effective nor ineffective, while the remaining three respondents (Respondents 3, 4, 7 of the other and public waste management sectors) believed that the efforts of the government were somewhat effective. None of the respondents believed that the government's efforts towards causing a change in behaviour of citizens towards effective E-waste management was effective.

4.3.1.6 How would you describe the effectiveness of government's use of Extended Producer Responsibility (EPR) to cause change in behaviour towards effective E-waste management

Seven (44%) of the respondents (Respondents 1, 5, 6, 10, 11, 15, 16 of the other, energy and waste management sectors) considered the government's use of the EPR system to effect change towards circularity to be neither effective or ineffective and five (31%) respondents 2, 8, 9, 12, 13 from the waste, project proponent and energy sectors) believed that this was not the

case and said it was ineffective. Four (25%) of the respondents (Respondents 3, 4, 7 and 14 of the other and public waste management and energy sectors) were more optimistic and believed that the government's use of the system was somewhat effective, while none of the respondents considered the government's efforts to be completely ineffective or effective.

After determining the level of agreement to the statements (as outlined in Table 4-2), a follow-up question was asked to determine the reasons behind respondents' responses. In the exploration of the responses depicted in Table 4-2, Figure 4-1 is a description of the phrases mentioned in response to the open-ended questions pertaining to the effectiveness of waste management in Gauteng. The figure has aligned these responses in a manner that either supports sustainable waste management, which would then ultimately support effective management of the EoL PV installations or detract from sustainability by not responding effectively to the challenges identified through the review of the province's state of waste management. Themes related to effective, sustainable waste management are grouped towards the left of the figure, while responses related to the current state of waste (indicating mostly challenges) are grouped towards the right of the figure.

4.3.2 Perceptions of EoL PV waste management in Gauteng

Figure 4-1 is supported by Table 4-3, which provides the frequency of the mentioned themes related to the follow-up questions regarding the reasons for state of waste management in Gauteng and implications for EoL PV solar waste management. Table 4-4, which provides opportunities for improvement of EoL PV solar waste management. The respondents were required to expand on their responses. The nature of the respondents' responses, whether it supports sustainability through circularity or linearity through ineffective management, is depicted in the schematic diagram in Figure 4-1.

The figure has presented the different phrases of response in light of its inclination towards circularity or linearity.

The exploration of the perceptions of end-of-life management of photovoltaic installations in Gauteng.

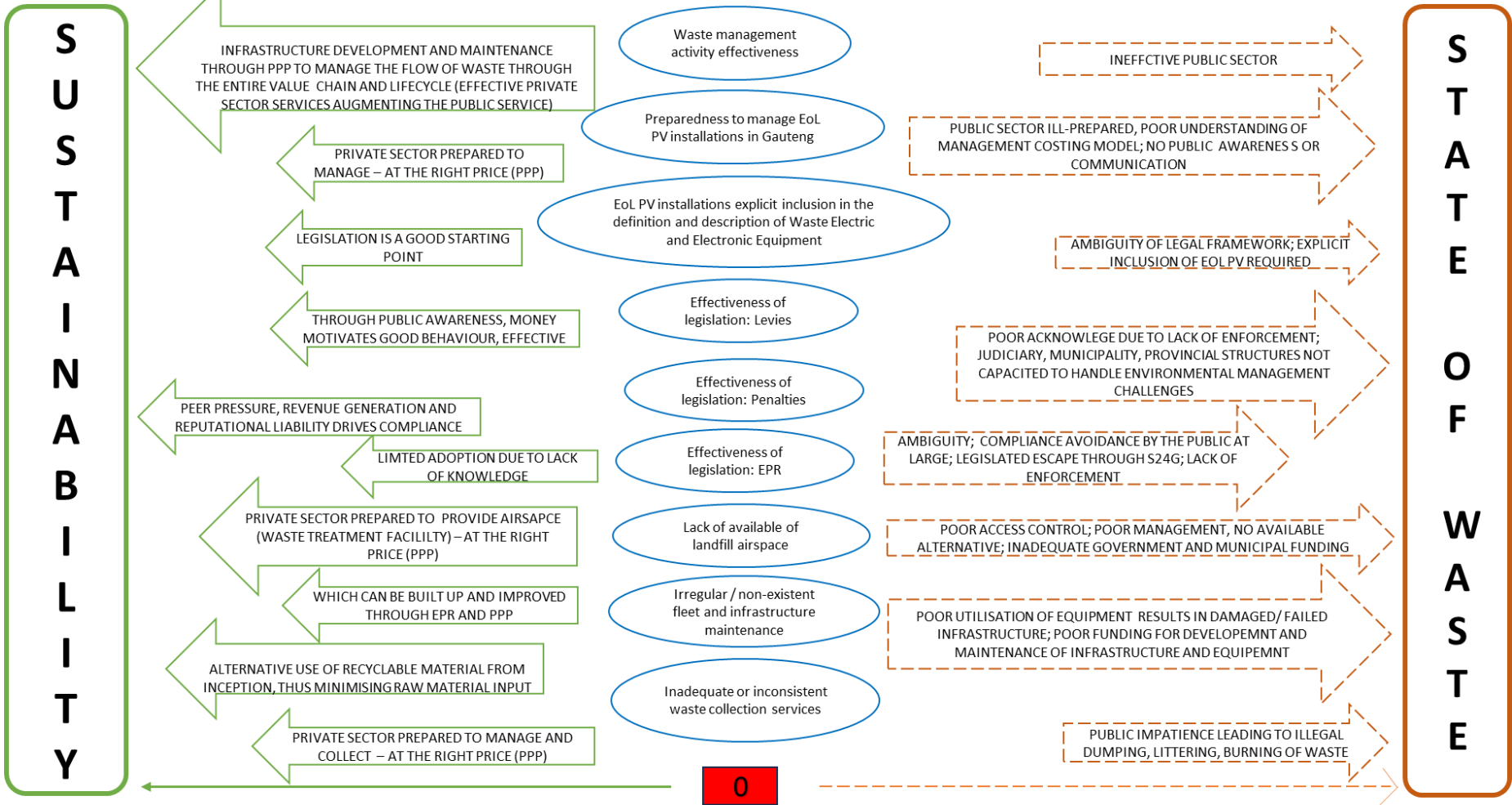


Figure 4-1: Themes emerging from interview questions on the exploration of the perceptions of EoL management of PV installations in Gauteng.

Table 4-3: Themes related to follow-up questions regarding the reasons for state of waste management in Gauteng and implications for EoL PV solar waste management (n = 16)

Themes related to the current state of waste management in Gauteng	Number	Percentage
Poor management of infrastructure, enforcement of prohibitions from landfills	16	100%
No available recycling alternative or strategy for implementation	16	100%
Existing legal framework	16	100%
Evasion of compliance by the public at large, deliberate lack of enforcement	15	94%
Lack of government capacity to enforce EoL PV solar waste management	15	94%
Explicit inclusion required of EoL in legislated WEEE definition or lists is required for effective management of the waste stream	15	94%
Lack of enforcement due to poor knowledge of legal framework and capacity of enforcers on public sector	14	88%
High level of informal recycling due to inefficiencies in the collection of waste	14	88%
Ineffective public sector involvement	13	81%
Illegal dumping, littering, burning of waste	12	75%
Poor funding for development and maintenance of infrastructure and equipment	11	69%
No available alternatives to landfill sites for household waste	10	63%
Ambiguity of legal framework	9	56%
Poor access control	8	50%
Damaged/ failed infrastructure due to poor utilization of equipment at landfill sites by municipal waste management departments	7	44%
Enforcement capacity of private sector	3	19%
Evading compliance through Section 24g	3	19%
Judiciary involvement and understanding of the policies and legislation	2	13%

4.3.2.1 Poor management of infrastructure, enforcement of prohibitions from landfills

All sixteen respondents (100%) mentioned that the poor management of infrastructure, and enforcement of landfill disposal prohibitions are cause for concern. According to Table 4-2 and section 4.3.1.2, when reflecting on the state of preparedness for the management of EoL PV installations, 44% of the respondents believed that Gauteng was ill-prepared, corroborating the opinions of poor management infrastructure and enforcement of the prohibitions of EoL PV installation components from landfills. The shortcomings of municipalities were presented, with mention of the illegal dumping that occurs in open spaces throughout the province due to the poor management of the waste collection fleet, amongst other possible reasons (Figure 4-1).

Furthermore, examples of the ill-managed landfill sites with their airspace reducing at alarming rates in the City of Johannesburg, City of Ekurhuleni, City of Tshwane and the Emfuleni municipalities were mentioned (Muzenda, 2012). Additionally, the waste management sector, particularly the private sector, bemoaned the lack of enforcement of regulations at the landfills emanating from poor governance of the municipalities as a whole. This ultimately raised the statement/question by Respondent 7 from the public waste management sector, *“if we cannot manage our landfills and the landfill equipment properly by acting on and following the laws that govern the management of these assets and infrastructure, how do we suppose we will ensure that we do not accept the EoL PV installations into the municipal landfills, transgressing the laws that have been put in place to ensure the effective management of waste?”* (Figure 4-1). These concerns are in agreement with the challenges mentioned by Oelofse (2021).

In addition to the already mentioned commentary, Respondent 1, a futurist from the other sector expressed that due to the *“capitalist”* system of the private sector, the privately owned landfill sites are *“well-managed and properly run”* for fear of the *“reputational damage that accompanies poorly managed private landfill sites,”* as opposed to the municipal owned sites. This was corroborated by all of the Respondents as they all agreed that the private sector acted on different service delivery principles.

4.3.2.2 No available recycling alternative or strategy for implementation

The all too familiar phrase, *“where will it go, how will it get there”* was echoed in the concerns raised by all sixteen (100%) of the respondents regarding the lack of alternatives towards EoL PV waste management and the lack of strategies for its implementation. This is a reverberation of some of the criticism raised during the Chemical and Waste Phakisa (Department of Planning, Monitoring and Evaluation, 2014; Department of Forestry, Fisheries and the Environment, of the Republic of South Africa, 2022). The nine respondents within the waste sector expressed their concerns stating that *“the sentiments, policy and legislation is present, it’s there, as described in*

the first goal of the NWMS of both 2011 and 2020, (Department of Environment Forestry and Fisheries, Republic of South Africa, 2020), while the Respondent 1, the futurist from the other sector, added to the sentiment with the statement, *“but not enough is being done to drive implementation through infrastructure development”* (Figure 4-1). The government is heavily reliant on the private sector for help but the sentiment that prevailed in the discussion with the respondents is that the road map on what must be done is *“not clear”* (Figure 4-1) (Waste and Recycling: Middle East and Africa, 2022).

Though the views of respondents described recycling as a whole, not all of their arguments applied to EoL PV installations. EoL PV installations is included as WEEE, which has been identified as a key contributor to the circular economy (Department of Environment, Forestry and Fisheries of the Republic of South Africa, 2020). The strategy and implementation thereof on how both the public and private will collaborate to enact the circular economy for this waste stream, however, remains unclear (Hoosain *et al.*, 2023; Debrah *et al.*, 2022).

In spite of this, the private sector is generally well prepared for the circular economy, particularly large corporates which implement Environment Sustainability and Governance (ESG) Reporting, and engage with service providers whose business purpose is to provide complete waste management services that include recycling and the sourcing of waste treatment facilities that are legally compliant and alternatives to landfilling (Figure 4-1).

4.3.2.3 Existing legal framework

The consensus amongst all the respondents (100%) is that South Africa has sound waste management legislation. The eight respondents within the waste management sector, Respondent 8 (the project proponent) and Respondents 12 and 14 from the energy sector similarly mentioned that *“you can see what the government is trying to do”* and *“its clear that the government has consulted with role players in the drawing up of the legislation”* and *“we have legislation that is comparative with European Union laws”*. Though the existence of a good legal framework has been praised, the four waste management private sector respondents raised that *“poor implementation of the legislation is rendering it ineffective”* (Figure 4-1). These sentiments were in line with the concerns raised by Zhakata *et al.* (2016) and popular press in (ReSource, February 2023). Judging from the Likert scale results pertaining to the level of effectiveness of the legislation, none of the respondents believed that the legislative framework was effective.

This emphasised, the need to act on what we have so that we can have a better understanding of our shortfalls as a country when reviewing the effectiveness of the legislation on sound waste management practices and sustainability. As 31% (five) of the respondents, two of which were from the energy sector, another two were from the economics sector (other) and the fifth

respondent was from the private waste management sector (Respondents 12, 14, 3, 5 and 2 respectively) believed that the legislation was neither ineffective nor effective, the choice communicated the frustration of the respondents with the lack of implementation of the legislation.

In the instance of the EoL PV installations as a waste stream, the prevailing waste management legislation governs the management of the waste stream, without specific norms and standards or regulations for EoL PV installations as a waste stream. The waste stream, however, has been implicitly provided for as part of industry waste management plans for E-waste, and extended producer responsibility (EPR) for E-waste (Figure 4-1).

4.3.2.4 Evasion of compliance by the public at large, deliberate lack of enforcement

Respondent 1 (other sector) bemoaned “*Eish mara South Africans and the law*” regarding the lack of enforcement of laws, a public sector waste management official, Respondent 7 (public waste management sector) voiced out their despondency saying, “*bribery of officials is very common*”, “*those NO DUMPING ALLOWED signs are a joke*” was a comment made by a respondent from the private waste sector. These are three of the comments that came through in the discussion pertaining to legislation. These three comments comically describe the concerns that fifteen (94%) of the respondents raised regarding intentional evaluation of compliance by the public, as well as the deliberate lack of enforcement from government (i.e. mention of “*corruption*” and “*bribery*”) (Figure 4-1).

Much like Respondent 7, Respondents 9 and 13 (public waste management sector) and Respondent 11 (private waste management sector) and cited the concerns around the South African government’s “*disregard for the law*” and not implementing it, reiterating the sentiments around naming “*single-use plastic as the country’s national flower*” – specifically highlighting the disregard of the public regarding the Plastic Carrier Bag Regulations (Witbooi, 2003). Citizens buy plastic carrier bags thoughtlessly. The fifteen respondents bemoaned the general “*lawlessness in South Africa*” with “*evasion of compliance by citizens*”. They highlighted the poor consideration of the law amongst citizens in the “*acts of littering*”, while “*municipal government landfill sites are in disarray and chaos*”. Respondent 3 (other sector) does agree that the sector has challenges, but offers that they are trying to do better. (Figure 4-1).

The efforts of the government to implement and enforce their own legislation were viewed as “*lack-lustre at best*” by Respondent 10 (private waste management sector), highlighting the reluctance of government department to “*hold their counterparts accountable as deliberate lack of enforcement*”. The lack of enforcement of waste-related legislation is also acknowledged in the 2020 National Waste Management Strategy (NWMS) (Department of Environment, Forestry and Fisheries of the Republic of South Africa, 2020). In light of the discussed factors, a concern

was raised pertaining to the effective management of EoL PV installations in the form of the question *“if we cannot even get the basics right for municipal waste, how will compliance to legislation for PV EoL management be enforced?”* (Figure 4-1).

The private waste management sector (Respondents 2, 10, 11, 15), however, bemoaned the *“deliberate singling out of large corporates while municipal landfill sites or treatment facilities were not under the same level of scrutiny”*. This inconsistency inspired very little confidence in the enforcement of legislation that ensured the circularity of EoL PV installations (Figure 4-1). It is evident that implementation is a cause of concern. The one respondent who didn't completely agree with this statement was adamant that the government was taking steps to address the issue and thus believed that judgement was *“premature”*.

4.3.2.5 Lack of government capacity to enforce EoL PV solar waste management

Considering the technicalities of waste as a whole, waste stream composition, and in particular the management of the EoL PV installations, the *“current level of capabilities of officials”* have been raised as a cause of concern by Respondent 2 (private waste management sector). This sentiment has been corroborated by reflections in the 2020 NWMS on the gaps, challenges and lessons learned based on Goal 8 of the 2011 NWMS (Department of Forestry, Fisheries and the Environment, 2021).

Fifteen (94%) of the respondents were concerned by the *“capacity of the officials to interpret and enforce the legislation”*. Respondent 16 (public waste management sector) mentioned that enforcement is *“more than just the boots on the ground enforcing”*. This concern was heightened by the novelty and unique characteristics of certain waste streams such as EoL PV components and mentioned *“uncertainty pertaining to the composition of the components”* was raised by Respondent 11 (private and public waste management sector). Respondent 4 (public waste management sector) added that *“while enforcers of law may have a basic understanding of waste management and what the law requires, it is also important that the official have an understanding of the waste classification process and the implementation thereof”* (Figure 4-1).

Apart from mentioning adequate knowledge and skills as a concern, all fifteen respondents also generally felt that there is *“a lack of adequate resources”* and that *“we may not have sufficient numbers of government officials to enforce law”* (Figure 4-1).

4.3.2.6 Explicit inclusion required of EoL in legislated WEEE definition or lists is required for effective management of the waste stream

While legislation has evolved to deliberately consider WEEE through the EPR schemes in the form of GNR 43880 (Department of Forestry, Fisheries and the Environment, 2020), EoL PV

installations are yet to be included in the mentioned list of WEEE items. Currently, they are only inferred to through the generic description of electric and electronic equipment, that describes a range of items.

A concern mentioned by fifteen (94%) of the sixteen respondents that definitions of E-waste/WEEE in legislation are left to the reader to interpret. Respondent 7 (public waste management) sector mentioned that *“in a country of many official languages, this may expose EoL PV installations management in Gauteng to all sorts of vulnerabilities”*. This statement agrees with concerns raised by Oelfose & Godfrey in the article titled, *“Defining waste in South Africa: Moving beyond the age of “waste”*”, regarding a lack of clear guidance on the interpretation of definitions. Respondents suggested the explicit listing of the EoL PV installations, much like the instances of lead-acid batteries or the listing of cell phones and hairdryers. Respondent 11 (public and private waste management sector) mentioned that explicit listing/inclusion of EoL PV installation as part of the legal framework would *“just make things simple, and the simpler things are, the easier it is to implement”* (Figure 4-1).

The sixteenth respondent, Respondent 6 (public energy sector) was adamant of the clarity of the definition of WEEE and considered it to be *“inclusive”*.

4.3.2.7 Lack of enforcement due to poor knowledge of legal framework and capacity of enforcers

Similar to the discussion of point 4.3.2.5, pertaining to the capacity of the officials, fourteen (88%) of the respondents also mentioned that the challenge of lacking capacity was not limited to the waste management sector, but also included those *“enforcing the by-laws as well, such as the municipal police department officials”* as initially mentioned by Respondent 4 (public waste management sector) and later echoed by Respondent 16 of the public waste management sector and Respondents 11 and 15 (private waste management sector). Respondent 10 from the public and private waste management sector also corroborated the statement, while Respondents 1, 2, 6, 7, 8, 9, 12, 13, and 14 made comments that were in general alignment to the theme of the point raised. The concerns raised referred to *“their understanding of the legal framework as well as their ability to interpret and enforce the legislation”* (Figure 4-1). The lack of knowledge of the current legal framework for waste management is a challenge mentioned in the 2020 NWMS (Department of Environment, Forestry and Fisheries, 2020).

It is important to note that the poor level of implementation does have an effect on the level of confidence on the effectiveness of the legislative framework of the country as according to the Likert scale depicted in Table 4-2, point 4.3.1.3, none of the respondent believed that the legislation was effective.

4.3.2.8 High level of informal recycling due to inefficiencies in the collection of waste

In the South African context where there are high levels of unemployment, inequality and poverty, and low levels of investment into the country, (National Planning Commission in the Department of the Presidency of the Republic of South Africa, 2020), informal recycling is very active (Godfrey, 2021) due to the inefficiencies in the regular collection of waste, as agreed upon by fourteen (88%) of the respondents.

The respondents had mixed emotions about informal recycling (through waste pickers) and its potential impact on EoL PV installations. Some perceived it as an opportunity towards enhancing the circular economy of EoL PV installations, while others regarded it as an obstacle/barrier. *“We have become accustomed to the reclaimers pushing their trolleys on suburban roads”* and *“their stocking up on material on open fields”*, an activity that is commonly regarded to as *“sorting”* in the waste management sector. *“Were it not for the lack of recycling infrastructure and the irregular or inadequate waste collection services, this would not be so prevalent”* were comments made to varying degrees by Respondents 1, 6, 7, 8, 13, 14, 15 and 16 of the listed sectors. Respondents 10 and 11 of the private and public waste management sector, and the private waste management sector respectively, however, expressed their concerns about the *“health and safety of waste pickers”* who are *“working with components that they do not know the hazardous nature of.”* Mention was made that the *“toxicity of the components of EoL is not communicated to end-users and the possibilities of damaged or ineffective panels being discarded along with other household waste exists”* by Respondents 2, 4 and 9 of the private waste management sectors, as well as Respondent 5 of the other sector.

Although legislation is in place to prevent EoL PV installation from going to municipal landfill sites or being discarded with household waste, respondents felt that the correct waste management practice for the EoL PV installation is not well communicated. The expressed opinion of Respondent 2 is that compliance, therefore, *“is highly dependent on the moral compass or level interest in doing the right thing”* of or by the consumer.

The challenge with this, in the instance of household or small business solar installations, is that as essentially related by the respondent and summarily captured, *“reclaimers rummage through the waste bins on curbs on the waste collection days of the suburbs, exposing themselves to unknown and poorly understood health and safety risks”*. This is a challenge that further adds to the list of unintended potential consequences of the use of solar PV, while adding to the challenges of the management of EoL PV installations.

4.3.2.9 Ineffective public sector involvement

According to Malan (2005), the silo culture within the various governmental spheres, both vertically and laterally, is unfortunate for the citizens of South Africa. Respondent 4 of the waste management sector mentioned that *“The different departments of the public sector from the national level through to the municipal level don’t talk to each other”* (Figure 4-1). This view which was expressed in some form or the other, by thirteen (81%) of the respondents, Respondents 2, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15, 16 of all the sectors, is corroborated by of the NWMS (Department of Environment, Forestry and Fisheries of the Republic of South Africa, 2020).

Masiya *et al.* (2021) highlighted that the instability of the South African local government political landscape further renders the public sector ineffective. Additionally, the capacity of the officials, the power struggle between the national government of one political party and the local government of another, poor oversight of the performance of the officials and internal bureaucracy, further exacerbates the situation.

Furthermore, though the private sector participates in and affects waste management strategy through the Industry Waste Management Plans (IndWMP), Integrated Waste Management Plans (IWMP) for municipalities or the lack thereof, reflect the poor level of involvement of the public sector (Masiya *et al.*, 2021). A concern that has been identified within the NWMS and addressed through the strategy (Department of Forestry, Fisheries and the Environment, of the Republic of South Africa, 2020: 66-67).

Respondent 4 (public waste management sector) continued to mention that *“without the government’s effective involvement, incentives to recycle, the accountability to the implementation of IndWMPs and IWMPs and EPR schemes for the management of the EoL PV installations, the development and maintenance of waste management infrastructure are at risk of being rendered useless or being viewed as a mere paper exercise”*(Figure 4-1).

4.3.2.10 Illegal dumping, littering, burning of waste

Considering the ineffectiveness of waste collection services in Gauteng, that was expressed by the respondents in point 4.3.1.1, Respondent 1 (other sector) mentioned that *“no wonder people dump waste as they please, burn it (referring to waste) and litter with little to no regard for the effects of it all”* (Figure 4-1). Illegal dumping, littering and the burning of waste are prevalent in informal settlements and low-income areas of Gauteng (Haywood *et al.*, 2021). There’s an acknowledgement of the failings of government to provide regular, reliable waste collection services to all of the citizens of the country (Muzenda *et al.*, 2011).

Furthermore, twelve (75%) of the sixteen respondents, Respondents 1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 13, 16 of all the sectors similarly raised “*the occurrence of the illegal dumping of builder’s rubble in the open spaces or fields of Gauteng’s affluent suburbia*”, as well as “*littering and illegal dumping*”, and the “*disregard of citizens for by-laws that is fueled by poor enforcement thereof*”, as discussed in Section 4.3.1.5, as concerns. Rasmeni and Madyira (2019) echo these concerns and mention that illegal dumping one of the biggest waste management concerns in the City of Johannesburg.

Challenges related to littering, dumping and burning of waste raised concerns about “*the effective management of EoL PV installations, due to the hazardous nature of its components, being a challenge that is yet to be fully understood at this stage*” (Figure 4-1), as related by Respondents 2 and 7 (private and public waste management sectors respectively). This would be a challenge in light of instances where consumers were either unaware of their responsibilities towards disposing of the waste in an environmentally sound manner, they refused to comply with legislative requirements for the effective management of the waste stream or the willingness to comply with legislative requirements was not catered for by the municipality, manufacturer or distributor of the PV installations. The remaining respondents did not explicitly mention illegal dumping, littering or the burning of waste as a challenge and delving into the reasons for this omission would be speculative on the part of the researcher.

4.3.2.11 Poor funding for development and maintenance of infrastructure and equipment

“*In the race for funds within the municipal budget allocations, waste management competes with housing, health, education, and roads and infrastructure*”. The statement by Respondent 16 (public waste management sector) was echoed by eleven (69%), (Respondents 2, 4, 5, 6, 7, 8, 9, 10, 11, 13, 16 of all the sectors), of the sixteen respondents. This concern is often discussed as part of budgeting processes of municipalities and is also mentioned by Nkomo (2019) and in popular press (Engineering News, 2021).

According to Respondent 4 (public waste management sector), the sad reality that “*competing responsibilities of local government*”, the painful “*effects of corruption that steals money from the fiscus*” (Goto & Ogunnubi, 2014) and the “*increased demand for social relief packages that provide assistance to the indigent*” (Mazenda et al., 2022) “*detracts from the effective management of waste in Gauteng*”, This was echoed in various forms by the other ten of the eleven respondents that agree with this statement.

This harsh reality resulted in the limited confidence in Gauteng’s municipal governance structure to effectively manage the EoL PV installations.

4.3.2.12 No available alternatives to landfill sites for household waste

In an effort to contrast the challenges that have been previously mentioned by the respondents, there was a shift to the desire to contribute to the *“sustainable management of waste”* as raised by the eight public and private waste management sector respondents, and in the instance of EoL PV installations, *“to doing the right thing”* in this regard. However, the lack of alternatives to landfilling to affect the circular economy was mentioned by ten (63%), (Respondents 2, 4, 5, 6, 7, 8, 9, 10, 11, 13 of all the sectors) of the sixteen respondents. The lack of alternatives is regarded as a serious limiting factor towards achieving the waste management hierarchy in literature (Ichikowitz & Hattingh, 2020).

Continuing from the earlier statement, the eight waste management sector respondents, Respondent 1 from the other sector and the tenth respondent, Respondent 5 (other sector), also from the other sector mentioned that *“the lack of alternative sites to landfill for the recycling purposes detracts from the willingness to comply”*, and the general statement of the ten respondents was about, *“where do we take them to?”* The question then remains, which was articulated by Respondent 1 (other sector), *“if we can’t manage normal household recyclable waste, how will we manage a waste stream like EoL PV installations?”*

4.3.2.13 Ambiguity of legal framework

While huge emphasis has been placed on the implementation and enforcement of waste management legislation, Respondent 11 (private waste management) mentioned that *“the ambiguity in some pockets of the legislation does little to inspire confidence in the legal framework”*. (Zhakata et al., 2016) agree that ambiguity in legislation leads to enforcement challenges.

As mentioned by nine (56%) of the respondents, the eight from the waste management sector and the ninth, Respondent 6, from the public energy sector, instances of ambiguity have been raised in the *“definition of waste”*, for a start (Oelfose & Godfrey, 2008) and *“the interpretation of the waste classification procedure that determines whether the EoL PV installations can go to landfill or should be recycled are confusing because you have to make an assumption that this is part of the WEEE”* (Figure 4-1).

Another confusing factor, mentioned by Respondent 7 (public waste management sector), *“is the composition of the PV installation components, as the components that are imported into the country are mainly from China”* (Bloomberg, 2023) as the largest manufacturer of silicon PV cells (Zhang & He, 2013) *“as opposed to the cadmium-telluride, (CdTe) based solar panel components that are mainly found in the United States of America”* (Bosio et al., 2011).

Furthermore, questions were also raised on the battery storage systems and inverter components as Respondent 7 further reiterated their own question, “do we really know what we are dealing with here and which components are regarded as EoL PV waste?” This speaks to the foundational understanding of the legislation that is required in order to apply and implement the law correctly for the effective management of the EoL PV installations (Figure 4-1).

4.3.2.14 Poor access control

Eight (50%) of the respondents (Respondents 2, 7, 9, 13, 10, 11, 15, 16 of the waste management sector), mentioned that issues regarding access control to waste management facilities: “*the municipal landfill sites are overwhelmed by informal recyclers*”, “*Onderstepoort remained open longer than it should because reclaimers would not let it close*”, “*the shootings and killings in Jo’burg’s landfill sites are because of poor access control*”, “*the activity of both the Zama Zamas and reclaimers at Simmer and Jack Landfill Site is a big concern*”. These statements are testament of poor access control arrangements to landfill sites in Gauteng, and its undesirable implications (Figure 4-1).

Onderstepoort Landfill Site stopped receiving waste two years after it was announced that it would close its gates (Infrastructure News, 2019). The reasons for the protracted closure were not officially supplied by the municipality, but it is suspected that the presence of unauthorised reclaimers at the site played a role. The deadly activity at Johannesburg’s Robinson and Goudkoppies Landfill Sites has, in the past, claimed at least two lives (Khumalo, 2022; The South African Government, 2022). Additionally, the turf war at Simmer and Jack, between the reclaimers above ground and illegal miners underground, is cause for concern (Mkhabela, 2023).

Considering the context provided above, respondents expressed their concerns about access control to municipal owned sites where EoL PV installations are stored, recycled, reclaimed and/or disposed of (Figure 4-1). Respondent 4 (public waste management sector) contributed by stating, “*The private sector has better control of their waste treatment facilities.*”

4.3.2.15 Damaged/ failed infrastructure due to poor utilisation of equipment at landfill site and within the waste management departments of municipalities

Challenges mentioned by seven (44%) of the respondents (Respondents 2, 4, 7, 10, 11, 13, 16) who had a good understanding of the operations at landfill sites included: “*poor compaction ratios of the cells at the municipal landfill site*”; “*there is limited understanding of the actual waste volumes entering the municipal site because there is either no operational weighbridge, an uncalibrated weighbridge or there just isn’t any personnel doing the weighing in and out of the waste vehicles*” and “*non-existent maintenance records of the landfill equipment*”. This list is a compilation of some of the challenges that were volunteered by the respondents in terms of failed

infrastructure due to poor utilisation of equipment at landfill sites. These comments are corroborated by the reports of an “*ill-managed fleet*” by Respondent 16 (public waste management sector) that resulted in waste “*collection backlogs*”, fuelling “*illegal dumping*”, while poor fleet availability was also blamed on the mismanagement of municipal funds (Kali, 2021; Stephan, 2023) (Figure 4-1).

These shortcomings lead to concerns pertaining to the development, building and maintenance of the EoL PV installations’ management infrastructure, particularly if it were to be managed by the public sector. This resulted in comments such as “*the private sector will just have to step up to the plate*”. The private sector has already accepted this role in the form of public private partnerships, while stakeholder participation is recognised as an important contributor to the integrated waste management (Joseph, 2006). “*Accountability by both the citizens towards the officials to perform their duties, and the officials towards citizens to effect legislation is important,*” contributed Respondent 11 of the private waste management sector.

4.3.2.16 Evading compliance through Section 24G

Linked to Section 4.3.1.4 (evasion of compliance), three (19%) of the respondents, (Respondents 4, 8 and 10 of the public and private sector) who are familiar with the NEMA Section 24G process (Figure 4-1) considered it to be the “*scapegoat to compliance clause*”, reiterating the Animal Farm quote by George Orwell, that “*all animals are equal, but some are more equal than others*” (Figure 4-1).

The sentiments amongst these three respondents were that “*Section 24G has left many environmentalists uncomfortable in response to the discussion around enforcement or the lack thereof*”. Respondent 10 (who has served in both the public and private waste management sector, but is currently in the private waste management sector) added that “*Section 24G is susceptible to corruption in an effort to evade compliance and accountability*” (Figure 4-1).

Discussions related to this topic indicated concerns regarding the management of WEEE and EoL PV installations through the evasion of EPR. Comparison was made between EPR industry stakeholders and the e-tolls situation in Gauteng of blatant refusal to comply by the citizens (Automobile Association, 2020).

Much like the exit strategy that Section 24G provides to people that are managing non-compliant waste treatment facilities, the hesitancy and lack of clarity from the South African government pertaining to WEEE EPR contributes to the challenge of EoL PV waste management. This has created a gap that stakeholders want to exploit by ignoring the legislative requirements under the premise that government has not ironed out all the issues raised pertaining to the legislation, thus

kicking the proverbial can down the endless road. Similarly, private sector can exploit the gaps of EPR to their advantage.

4.3.2.17 Enforcement capacity of private sector

Three (19%) of the respondents (Respondents 1, 2 and 5) believed that the private sector's role in enforcement of the waste management legislation remained effective in the form of, what Respondent 2 (private waste management sector) referred to as "*peer-pressure*" or what is referred to in environmental management policy instruments as "Mutual Agreement Instruments". This is affected through the implementation and requirement of the corporate sector for a uniform management system that standardises the approach to environmental management practices. It is also a voluntary system that is entered into by corporates. Respondent 5 (other sector) mentioned that "*businesses need to hold each other accountable in the absence of effective enforcement capabilities of the government*". The "*implementation of environmental management system commitments*" was mentioned by Respondent 1 (other sector) (Figure 4-1). This commitment is communicated to the public through the implementation of the environmental management standardised system, the ISO 14001 (Nel & Alberts, 2018: 50-51; 53-64).

Considering the temptation to ignore the EPR requirements mentioned in Section 4.3.1.7, the collective commitment towards a sustainably developed country propels the private sector towards the ethical and responsible implementation of the circular economy development strategy. An example of the recent EPR activities where vouchers were awarded for E-waste dropped off at Makro stores in October 2023 (Makro, 2023) is a step in the right direction. Ultimately, the private sector may not have the "*legal stick*" that enforces legislation. They do, however, have a powerful impact in terms of mutual and peer agreements, that has been proved to be highly effective in the implementation of the command-and-control legislative requirements when the two instruments are used together (Figure 4-1) (Arimura *et al.*, 2008).

4.3.2.18 Judiciary involvement and understanding of the policies and legislation

Lastly, two (13%) of the respondents (Respondents 4 and 7) who are public waste management officials, believed the judiciary, referring to the legal practitioners that would be involved in the prosecution of cases of transgressors of the environmental management legislations, was not fully vested in the enforcement of the environmental legislation, questioning their "*commitment to the understanding of the legislative framework*". This was expressed through commentary such as "*not on their list of priorities*", and that "*environmental management is not a factor, unless it is something that has garnered a lot of media attention*".

As EoL PV installations are a novel waste stream, it is deemed imperative that the judiciary continuously educate themselves in the environmental legislative framework in light of the

evolving global landscape that influences the local legislative activity of South Africa (Markowitz & Gerardu, 2012). The effective enforcement of the environmental legislation by the judiciary would counteract the negative sentiment expressed and prove the commitment to an effective collaborative effort for the management of waste, not just limited to the EoL PV installations (Figure 4-1).

4.3.3 Opportunities towards effective, sustainable EoL PV solar waste management in Gauteng

As explained in Section 3.5.3, open-ended questions regarding identifying opportunities towards effective, sustainable EoL PV solar waste management in Gauteng were posed. Phrases mentioned were thematically analysed according to theme, as described in Section 3.6.

Table 4-4 provides an overview of the themes mentioned by respondents as it relates to opportunities towards effective, sustainable EoL PV solar waste management in Gauteng. This emphasises the move towards sustainability, while identifying the detractors from sustainability and contributors to ineffective management of waste that would translate to the ineffective management of EoL PV installations.

Table 4-4: Themes related to opportunities for improvement of EoL PV solar waste management in Gauteng (n = 16) – towards effective, sustainable waste management

Factors affecting effective EoL PV solar waste (Opportunities)	Number	Percentage
Improved education, awareness and communication to the public	16	100%
Increased accountability	16	100%
Increased enforcement	16	100%
Awareness of rebates, money motivates	16	100%
Infrastructure development and maintenance through PPP to manage the flow of waste through the entire value chain and lifecycle (effective private sector services augmenting the public service)	14	88%
Increased private sector participation	13	81%
Inter-governmental and public private partnerships to affect EPR accountability	11	69%
Capacitating the officials	8	50%

Factors affecting effective EoL PV solar waste (Opportunities)	Number	Percentage
Building capacity through science, technology, education and mathematics (STEM)	5	31%
Alternative use of recyclable material from inception, thus minimizing raw material input	2	13%

4.3.3.1 Improved education and communication to the public

All the respondents agreed that education and communication regarding recycling in general, and recycling of EoL PV installation needs to be improved upon. Respondent 6 from the energy sector mentioned that: *“It’s easy at work, because you have a champion driving it, but at home, just like they hammered us about the COVID vaccine, they need to do the same about recycling”*. The consensus amongst the respondents was that in spite of the recycling emblem on packaging or plastic bottles, unless there is a concerted effort to effectively tell people to recycle, how to recycle and why residents need to recycle, recycling initiatives won’t really get the attention and effort it deserves (Read, 1999).

It is important that education and communication strategies focus on the greater goal towards sustainability, particularly in light of the WEEE recycling (Darby & Obara, 2005). This concept has been proven to be successful in countries such as Australia with a household waste diversion rate of approximately 52% in 2005/2006 (Oke *et al.*, 2009), in comparison to the South African 2018 household recycling rate of only 10% (Statistics South Africa, 2018) as reported by Statistics South Africa in the “In depth Analysis of Household Survey 2002 – 2016.”

Respondent 15 of the private waste management sector also mentioned that *“labels are not enough”*; *“recycling benefits and ways of recycling need to be communicated to us”*. These statements emphasised the need to employ multiple channels of communication to get the message of E-waste recycling out to the public (Moustaira *et al.*, 2022). The officials that have been part of the government’s attempts at enforcing *“separation at source, (S@S)”*, also stated that it was easier and quicker to get adoption from the more *“affluent residents”*, as they were *“already aware of the need to recycle”*, *“though that did not necessarily translate into increased rates of recycling.”* Research conducted into ways of improving recycling rates amongst residents further emphasizes the need for clear communication, awareness raising and education (Wang *et al.*, 2020).

In the instance of EoL PV installations, it would be of particular importance to educate the public on the proper management of the waste stream, considering its prohibition from landfill as highlighted in Section 2.5 which describes the legal framework that is applicable to the EoL PV

installations, as well as its hazardous nature due to its varying composition as discussed in Section 2.4.

4.3.3.2 Increased accountability

All respondents agreed that the level of accountability for the protection of the environment and the responsible management of waste must improve. An aspect that was noteworthy was that the perceptions regarding “*who is accountable*” differed amongst the different role players.

Perspective, perception and experience shaped this response as the private waste management sector, Respondent 10 and 11 (private waste management sector) bemoaned “*unwarranted scrutiny*” while criticising the “*lack of accountability of the public officials*”. On the other hand, public waste management officials (Respondent 7) accused the private sector of “*finding creative ways to escape accountability*”.

Ultimately, the responses indicated that there are divergent opinions and a deficit in the level of responsibility and accountability in the Gauteng, and the feeling was that this will negatively impact the effective management of the EoL PV installations. Without leadership, guidance, and direction towards sustainability and away from linearity of careless discard, According to Respondent 10 (public and private waste management sectors) “*Gauteng runs the risk of being overwhelmed by the waste stream, similar to what happened with the single-use plastics*”. In addition to this statement, Respondent 11 (private waste management sector) contributed to the discussion by stating that “*though the country is slowly redressing the use of single use plastics, the habits are formed, and the damage is done. The same will happen with EoL PV solar waste if we do not assign clear roles, responsibility and accountability*” (Abdellatif *et al.*, 2021).

Examples that further highlighted the importance of accountability, and the lack thereof in Gauteng, is the high level of illegal dumping that is not just limited to the high-density, low-income areas, but is prevalent in suburbia as well (Haywood *et al.*, 2021). Taking this into account, the question raised by Respondent 6 (public energy sector) in reference to the EoL PV installation was “*who is going to make me do it?*”

4.3.3.3 Increased enforcement

A requirement that, like the other two earlier mentioned phrases, was raised by all the respondents, was the need from increased enforcement. Aligned with the challenge of increased accountability, was the requirement for the enforcement of the legislation to increase and improve. Respondent 4 (public waste management sector) added that “*From the start with the officials, right through to the law enforcement agencies, environmental law needs to be enforced and enforced effectively, where consequences are boldly visible to the public.*”

A statement that has been corroborated as part of the NWMS (Department of Environment Forestry and Fisheries, Republic of South Africa, 2020:69-70; Kotze, 2009). The strategy highlights the importance to encourage and foster a culture of compliance and respect for the law. Considering the increase in household use of solar PV highlighted by Figure 2-2, developing and enforcing compliance for the management of EoL PV installations is imperative.

4.3.3.4 Awareness of rebates (motivation through economic instruments)

The requirement to distribute information about possible rebates and raise the awareness level of the public was highlighted by all (100%) the respondents. Respondents 1, 2, 3, 5, 7, and 11 similarly mentioned that *“Money is a great motivator today, its rough out there!”* This was well illustrated by the overwhelming response from the public to drop off their WEEE from households at Makro for vouchers (Makro, 2023).

Though all respondents were in agreement about the role of money as a motivator towards the implementation of the circularity of EoL PV installations, some of the respondents (six), however, cautioned that the rebates needed to be meaningful in order to have the desired effect on the public, as described in Table 4-2, ten (63%) respondents (1, 5, 6, 9, 10, 11, 12, 14, 15 and 16) had previously bemoaned the government’s use of the economic instruments, with 19% (three - Respondents 9, 12 and 14) of the ten respondents stating that the use of the economic instruments was completely ineffective, and the remaining 44 % (seven of the ten respondents – Respondents 1, 5, 6, 10, 11, 15, 16) stating that it was ineffective. This statement is supported by Nahman & Godfrey (2010).

4.3.3.5 Infrastructure development and maintenance through PPP to manage the flow of waste through the entire value chain and lifecycle

While two (13%) respondents (Respondents 3 and 13 from the other and public waste management sectors respectively) remained resolute in the belief that the capabilities of municipal government to execute the effective management of waste were adequate, fourteen (87%) of the respondents were of the opinion that the successful management of waste (and ultimately of EoL PV installations) required well-coordinated and defined partnerships between the public and private sectors (also referred to as public-private partnerships or PPP).

South African service delivery levels are considered to be low, and citizen satisfaction levels continues to decline (Masiya *et al.*, 2021; Statistics South Africa, 2017) in the face of frequent service delivery protest action by the public. After almost 30 years at the helm, the South African government has finally acknowledged the benefits of involving the private sector in the development of the country. Case in point is the Renewable Energy Independent Power Producers Procurement Programme, (REI4P) (Eberhard & Naude, 2016).

Responses from Respondents 2, 6, 10 and 11 (private and public waste and energy sectors) were quite extreme and included phrases that *“They (government) broke it”; “they (government) cannot do it alone”; “this is controversial, but it must be said, cadre-deployment is a serious problem that the government is non-committal about addressing!”; and “private sector involvement is needed to address this mess”*. These statements clearly expressed the respondents’ level of dissatisfaction with public waste management services. The two respondents (Respondents 3 and 13 of the other and waste management sectors) that were satisfied with the capabilities of the government were of the opinion that *“the government knows what is wrong and they are working to address it, look at the action plan that is addressing the power crisis!”* In typical fashion of a complex problem, the answer is never one-sided or straight-forward.

4.3.3.6 Increased private sector participation

Linking to Section 4.2.3.5 on proposed public-private partnerships, thirteen (81%) respondents (Respondents 2, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15 and 16 of the waste, energy, other and project proponent sectors) believed that private sector participation needed to be increased. Respondent 11 reiterated their statement that *“The private sector needs to step up to the plate and stop complaining!”* was the prevailing opinion when discussing public sector participation in the waste management sector.

Though the government has implemented the requirement for IndWMPs from the private sector and IWMPs from the municipalities through the focus areas of the NWMS (Department of Environment, Forestry, and Fisheries of the Republic of South Africa, 2020: 66-67), the adoption of the goal within the private sector is not at the levels desired by the Department. Judging from the availability or the lack thereof of recent or updated published municipal IWMP, the participation of the municipality is not that much better than the private sector. Regardless, the overall perceptions from public-based respondents were that the private sector needs to play a bigger role in the management of EoL PV installations.

4.3.3.7 Inter-governmental and public private partnerships to affect EPR accountability

Again, phrases mentioned by respondents highlighted partnerships between private- and public entities towards affecting EPR accountability.

Eleven (69%) of the respondents (Respondents 2, 4, 7, 8, 9, 10, 11, 12, 13, 15 and 16 of the waste, energy, other and project proponent sectors) really believed that, as articulated in the interview, *“if this [EPR] can properly executed, it would be great for the sector”*. The respondents mentioned the importance of partnerships and relationships between the public and private sector towards effectively implementing EPR. Proper execution means accountability on all fronts, for

the public and private sectors (Wang *et al.*, 2020). In response to the Likert questions raised and the results thereon depicted in Table 4-2, 44% of the respondents believed that the EPR was neither effective nor ineffective. Regardless, the EPR system was not considered an absolute failure, in spite of the opinions of five of the respondents who believed that it was not effective.

A challenge that needed to be overcome was what the Respondent 4 (public waste management sector) described as the “*governmental silo mentality*”. This is a concern that was raised in the NWMS and was addressed within the second pillar as the strategic thrust that was purposed with strengthening the inter-governmental department relationships as well as the public private partnerships in order to ensure “*effective and strategic waste services*” raised by Respondent 11 (private waste management sector) (Department of Forestry, Fisheries and the Environment Republic of South Africa, 2020: 36-37).

4.3.3.8 Capacitating officials

Eight (50%) of the respondents (Respondents 3, 4, 7, 8, 9, 12, 13 and 16 from all the listed sectors) were adamant about the importance of “*capacitating the officials*” responsible for waste management. Considering the complexity of the waste stream, EoL PV installations, described in Section 2.4.2, the rate of growth of installations described by Figures 2-2 and 2-3, their concerns were not misplaced.

As indicated in the NWMS, highlighted as the eighth goal in the 2011 NWMS and the progress thereof of the capacity building for the enforcement of the Waste Act reported on in the NWMS of 2020, capacity building is a concern. While the NWMS has focused on the Environmental Management Inspectors, it is important to note that the respondents were concerned about the capacity of the officials across “*different departments*” that are linked to waste management within the municipal systems, the Gauteng Department of Agriculture and Rural Development as well as at a national level. The building of capacity through science, technology, education and mathematics (STEM) was specifically mentioned (see Section 4.3.2.9) below.

4.3.3.9 Building capacity through science technology education mathematics (STEM)

Five (31%) of the respondents considered the primary and secondary school level of education to be a turning point for the development of expertise to manage and process the waste from EoL PV installations effectively. Respondent 6 (public energy sector) stated that “*Through the development and empowerment of children at high school level of education, South Africa can position itself well to benefit its own waste*”. Some of the respondents also mentioned the importance of education and capacity building at a primary school level. Respondent 12 (public energy sector) expressed that “*If you want parents to change their behaviour, teach the children, they will definitely correct their parents!*” and Respondent 2 (private waste management sector)

added *“We cannot decide that high school is the place to develop engineers if we haven’t done so by giving them the proper foundation at the start at a primary school level.”*

Only three (19%) of the respondents (Respondents 1, 8 and 16 of the other, project proponent and public waste management sector) raised primary school education as a starting point for the change in perspective from linearity to circularity. In the researcher’s view, it was unfortunate that the foundational phase of the education system of South Africa was considered by such a low number of respondents, considering the extreme level of inequality and inadequacy of the educational system of the country (Salisbury, 2016).

The reason this would impact the effective management of EoL PV installations in a negative manner is that - the content taught in primary school and even earlier, in early childhood development, can establish the foundation of understanding of the children, setting them up for success in subjects such as those within the STEM, thus, as earlier indicating, making a positive contribution towards the circularity of Gauteng’s economy through innovative ways to enact the economy.

4.3.3.10 Alternative use of recyclable material from inception, thus minimizing raw material input

Lastly, two (13%) of the respondents (Respondent 8 as a project proponent and Respondent 11 of the private waste management sector) mentioned the importance of using recyclables instead of raw materials when manufacturing PV solar installations.

“Sustainability is not a quick-fix and cannot be applied as an after-thought” and *“We should provide for recyclable materials from EoL as inputs into the manufacturing of new PV installations”*. These were the opinion of two of the waste management sector respondents, who firmly stated that research into the use of recyclable material must be expedited for us to be truly recyclable. As indicated by the NWMS of 2020, the two strategic points of entry into the circular economy is the prevention and the consideration of waste as a resource, rather than an item to be discarded (Department of Environment Forestry and Fisheries, Republic of South Africa, 2020: 26-28).

Considering the entire value chain of PV installations, as discussed in Section 2.3, much like the absolute ban of the use of Chlorofluorocarbons (CFCs) as ozone depleting substances through the Montreal Protocol (Velders *et al.*, 2007), renewable energy components need to be constructed from recyclable material. This ensures the circularity and ultimately, the sustainability of renewable energy installation components.

4.3.4 Recommendations for sustainable management of EoL solar PV installations

The last section of the interview questionnaire required respondents to make recommendations towards the sustainable management of EoL solar PV installations. The question was open-ended, and responses were thematically analysed, as explained in Section 3.6 of the dissertation.

Figure 4-2 depicts the results of the thematic analysis, with respondents' recommendations for sustainable management of EoL solar PV installations. The results are presented in the context of sustainability (similar to Table 4-1). As the ultimate goal of environmental management, an all-encompassing field whose building blocks includes the management of waste, sustainability is the result of the evolution from linearity to circularity. It is about stewardship over the earth and its resources, acknowledging that the present generation needs to look beyond themselves (King *et al.*, 2018). Considering this shift towards sustainability, Figure 4-2 considered the recommendations made by the respondents that would contribute towards building an inclusive circular economy in the province, taking the five domains of sustainability into account.

RECOMMENDATIONS TOWARDS THE SUSTAINABLE MANAGEMENT OF EoL PV INSTALLATIONS

■ SOCIAL ■ DOMAIN OF LIFE ■ ECONOMIC ■ SPIRITUAL ■ MATERIAL

<p>Effective enforcement of regulations Communicate well to get buy-in from all relevant stakeholders.</p> <p>Persistent stakeholder education, engagement and involvement on WEEE management</p> <p>Communicate the information around the tax breaks effectively to the public.</p> <p>Clarity of roles and responsibilities on EPRs pertaining to WEEE for both public and private sectors.</p> <p>Capacitation of officials is important as the waste stream is technical and so is the enforcement of the regulations.</p> <p>Approach to the effective management of the EoL PV installations cannot be a blanket approach.</p> <p>Technical capacitation and begin the process early with STEM in high schools to build up the expertise to manage the waste stream locally.</p> <p>Enforce the requirements as discussed in the NWMS and regulations</p> <p>Persistence in the enforcement of the applicable WEEE management legislation to enable the effective management of the EoL PV installations.</p> <p>Concerted effort by the public sector to effect EPR and legislations by engaging in the necessary PPPs.</p> <p>Programmes around the effective management of EoL PV installations need to be specific and focused</p> <p>Communicate the relevant WEEE and EoL PV installation regulatory information effectively.</p> <p>Persistent communication on EoL management</p> <p>Solutions need to speak to the issues on the ground. Collaborations are important</p>	<p>Effective enforcement of regulations</p> <p>Communicate the information around the tax breaks effectively to the public.</p> <p>Open-mindedness and tolerance must be practiced, must keep the bigger picture in mind.</p> <p>Approach to the effective management of the EoL PV installations cannot be a blanket approach.</p> <p>Enforce the requirements as discussed in the NWMS and regulations.</p> <p>Persistence in the enforcement of the applicable WEEE management legislation to enable the effective management of the EoL PV installations.</p> <p>Concerted effort by the public sector to effect EPR and legislations by engaging in the necessary PPPs.</p> <p>NWMS programmes must have the bigger picture in mind Programmes around the effective management of EoL PV installations need to be specific and focused.</p> <p>Policy clarity required in light of the uncertainty around the policy directives.</p> <p>Communicate the relevant WEEE and EoL PV installation regulatory information.</p> <p>Persistent communication on EoL management. Collaborations are important.</p>	<p>Transparency on what the collected money is used for. Use the levies or taxes collected effectively towards providing solutions such as infrastructure for the sector</p> <p>Communicate the information around the tax breaks effectively to the public The levies and tax-breaks must be impactful</p> <p>Technology and multi-sector or industry collaborations for the enforcement of regulations and the waste minimization strategy Solutions need to speak to the issues on the ground</p>	<p>Persistent stakeholder education, engagement and involvement on WEEE management</p> <p>Open-mindedness and tolerance must be practiced, must keep the bigger picture in mind</p> <p>Collaborations are important</p> <p>Policy clarity required in light of the uncertainty around the policy directives.</p> <p>Communicate the relevant WEEE and EoL PV installation regulatory information effectively.</p> <p>Persistent communication on EoL management</p> <p>Solutions need to speak to the issues on the ground</p>
<p>SOCIAL</p>	<p>DOMAIN OF LIFE</p>	<p>ECONOMIC</p>	<p>SPIRITUAL</p>
		<p>MATERIAL</p>	<p>Capacitation of officials is important as the waste stream is technical and so is the enforcement of the regulations.</p> <p>Technology and multi-sector or industry collaborations for the enforcement of regulations and the waste minimization strategy</p> <p>Raw material used in the manufacturing of the components should be legislated to be recyclable to ensure circularity</p> <p>Technical capacitation and begin the process early with STEM in high schools to build up the expertise to manage the waste stream locally</p> <p>Programmes around the effective management of EoL PV installations need to be specific</p>

Figure 4-2: Recommendations towards effective EoL PV solar waste management based through the lens of sustainability.

4.3.4.1 Recommendations related to the social domain

The respondents confirmed the importance of community engagement in achieving the social aspect of sustainable development in the context of managing EoL PV solar installations. This aligns with existing documents like the NWMS and Operation Phakisa (Department of Forestry, Fisheries and the Environment, Republic of South Africa, 2020; Department of Planning, Monitoring and Evaluation, 2014). Collaboration with the community is crucial for the success of the circular economy, which is essential for developing, constructing, and maintaining the necessary infrastructure to implement the planned strategy.

This is particularly vital in light of the increasing number of solar installations in the province (Pandaram *et al.*, 2019). Involving stakeholders across the entire value chain, including government officials, consumers, and manufacturers, is key to executing the prioritized circular economy as outlined in Operation Phakisa for sustainability and circularity (Hoosein *et al.*, 2022).

In discussions about the effective management of any waste stream, especially in a developing country, it is essential to consider the informal recycling sector. Both industry and the government should leverage the positive contributions that informal recyclers bring to the table.

Regarding the management of end-of-life PV installations in Gauteng, given the prevalence of solar use in households and emerging or micro enterprises, the inclusion of private citizens and reclamation workers is of utmost importance (Godfrey, 2021).

4.3.4.2 Recommendations related to the domain of life

The respondents provided recommendations for addressing the domain of life in sustainable development by effectively managing EoL PV solar installations. These recommendations focus on factors impacting the quality of life for Gauteng citizens and their relationship with the environment, particularly concerning this emerging waste stream.

Given the relatively new status of EoL PV installations in South Africa, it is crucial to raise awareness among citizens about the proper handling of this waste. They must understand the boundaries for handling it and the potential consequences of exceeding these limits. Communication about these consequences should go beyond a command-and-control approach, emphasizing a holistic, sustainable way of life.

To ensure circular management of this waste stream, several actions are necessary:

- Market development for the EoL PV installations must be taken seriously, a lesson that can be derived from the circular activities of Australia (Oteng, 2023).

- Gauteng officials should take deliberate steps to enforce regulations (Makgae, 2011, pp. 75-77).
- Private sectors must fulfil their responsibilities as outlined in the IndWMPs and EPR regulations to ensure efficient implementation of the plans, to manage the waste stream in a manner that contributes positively towards the SDGs (Department of Forestry, Fisheries and the Environment, Republic of South Africa, 2020).
- Citizens of Gauteng need to actively participate in waste stream management initiatives and hold manufacturers, retailers, and officials accountable (Larsen, 2009).

By taking these steps, a collaborative effort can be fostered to manage EoL PV installations in a circular and sustainable manner.

4.3.4.3 Recommendations related to the economic domain

In the daily struggle for both corporate and private citizens to go about their daily activities in Gauteng, energy is imperative to the success of businesses and the peace of mind of the private citizens. Solar energy offers a viable alternative, given its generation and storage capacity and affordability, especially when compared to the inconsistent energy supply provided by Eskom (Lenoke, 2017). To enhance the economic domain of sustainable development, it is vital to focus on the circular management of end-of-life PV installations.

This circular approach to economic activity that manages waste is significant because it represents a rapidly growing sector within the country's economy. Such growth can play a key role in addressing the challenges of unemployment and inequality in South Africa (Roman *et al.*, 2021). Additionally, it has the potential to contribute to cost improvements in PV installations through the reduction of virgin material and the subsequent development of an economically viable means of recycling EoL solar PV installations (Chowdhury *et al.*, 2020).

4.3.4.4 Recommendations related to the spiritual domain

Considering the significance of spirituality, African indigenous religions, and the reverence for land in ancestral relationships across the continent, not just in Gauteng, it is vital to acknowledge the role of the spiritual domain in sustainable development and the promotion of a circular economy (Lockhart, 2012). Unlike Lockhart's perspective, similar to indigenous religious practices, Christianity emphasizes stewardship over ecosystems, as articulated in the Book of Genesis (2:15, Amplified version of the Bible) instructing humanity "*to cultivate and keep it.*"

This highlights the value that sustainability and circularity bring to preserving the tranquillity and equilibrium of the land we inhabit. It underscores the importance of the recommendations,

emphasising that the plans, strategies, and legal framework adaptations for managing end-of-life PV installations are not merely well-intentioned words but a delegation of stewardship to the province's citizens. It's about using the available resources responsibly.

4.3.4.5 Recommendations related to the material domain

The primary objective is to use recyclable materials for manufacturing various components of EoL PV installations. However, it is crucial to prioritise technological advancements that reduce the mining of rare earth elements and its environmental impact. This objective aligns with the first pillar of the 2020 NWMS (Department of Forestry and Fisheries and the Environment, Republic of South Africa, 2020: 33-36).

Innovation is key to safely separating components for economically viable material recycling, allowing the citizens of Gauteng to actively participate in the circular economy. Furthermore, there is a need to instil a culture of innovation and technology utilization from a young age to facilitate waste treatment and the avoidance of waste landfilling, specifically in ensuring the circularity of EoL PV installations.

The conceptual framework in Figure 4-3 considered the listed domains and affected these into the management of the EoL PV installation. Considering this, the diagram is an illustration of the process of generation of the waste stream, EoL PV installations in this instance, its classification in order to determine the correct treatment path, the applicable logistical plan for the relevant management process, the infrastructure requirement, and ultimately the treatment process employed. It is evident from this illustration that the development and implementation of the relevant policy from the onset influences the entire waste stream management value chain, the infrastructure, equipment, use of technology or innovation and though not physically drawn into the figure, none of this would be possible without the people to drive, implement and enact the change (Ndzibah *et al.*, 2022).

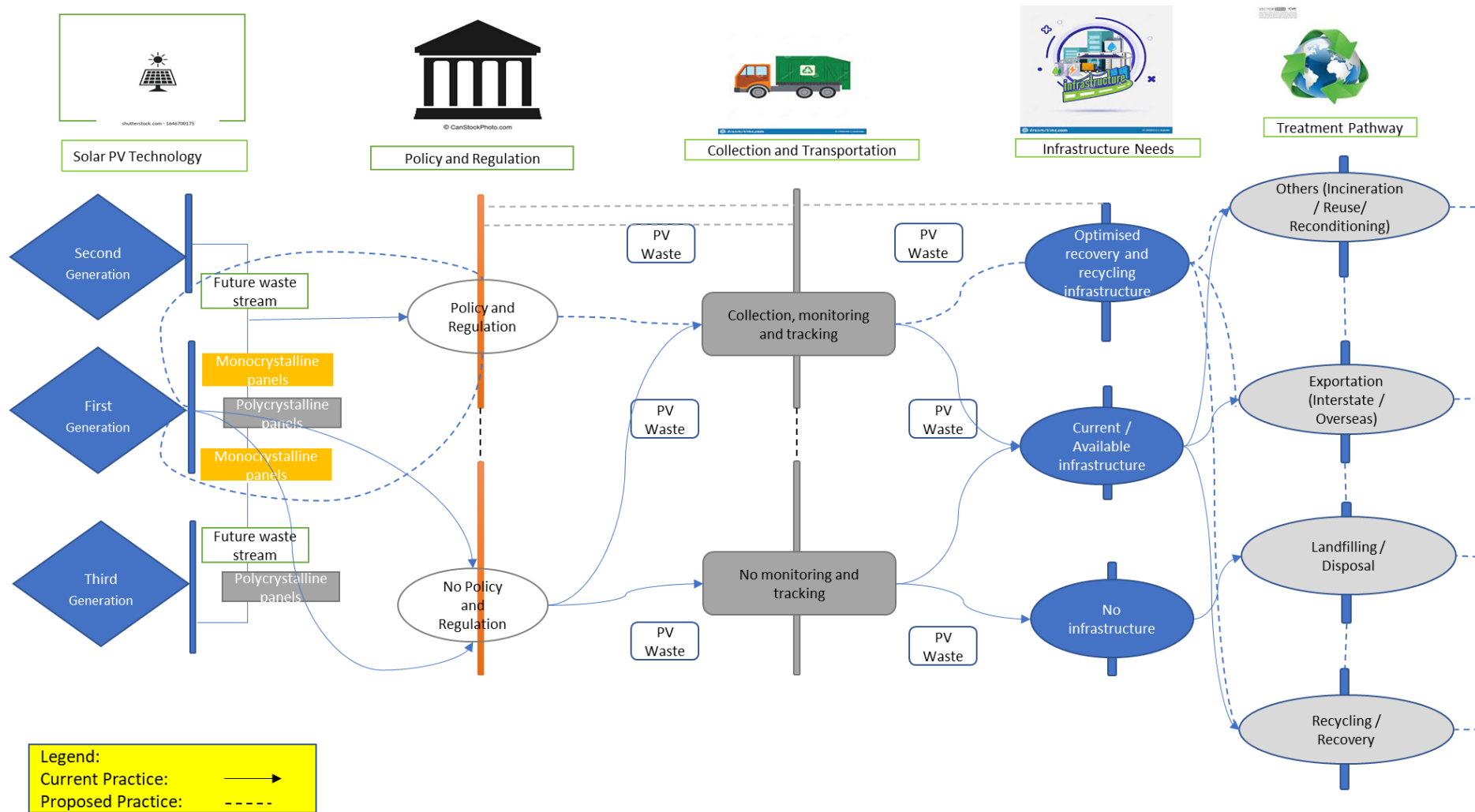


Figure 4-3: Conceptual Framework recommending a process of effective management of End-Of-Life Photovoltaic Installation Components (From: Oteng *et al.*, 2022)

4.4 Chapter summary

Chapter 4 has synthesised the results obtained from the literature survey that responds to the first objective and the response from respondents that responded to the second objective. The results of the first objective have been interpreted considering the global goals towards sustainability and the South African strategy of enacting a circular economy, that empowers the citizens as much as it addresses the country's sustainability aspirations.

Chapter 5 to follow is a synthesis of the results obtained as the research draws to its conclusion. It is a conclusive consideration of the objectives of the research and a discussion of the recommendations that have evolved as a result of this research.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

As South Africa tackles the challenge of intermittent energy supply with the procurement of renewable energy on a large scale, and the encouragement of small-scale installations, the country faces ill-fated consequences of the resultant waste generated by the EoL PV installations.

The aim of this research was to explore the perceptions of the effectiveness of solid waste management of end-of-life photovoltaic installations in Gauteng. This was to be achieved through the following two research objectives:

1. To explore the global practices of managing EoL PV installations.

In response to this question, the researcher evaluated the world's response to Agenda 2030 and the reduction of greenhouse gas emissions through the use renewable energy. Considering the global change towards a state of sustainable existence, at the realisation of the finite nature of the earth's resources, the global Sustainable Development Goals (SDGs) were born out of a need to affect treaties, protocols and agreements that affected the change.

In the enthusiastic fight against greenhouse gas emissions, one of the consequences thereof is the generation of a new waste stream, the end-of-life (EoL) components of the renewable energy generating equipment. This research was focused on the management of EoL photovoltaic (PV) installations. In order to ascertain this, the researcher reviewed the increased use of solar PV installations as an energy source, the unintended consequences of the use of this source of energy, the development of global waste management practices, and the application of these waste management practices on the effective management of EoL PV installations.

2. To explore the perceptions of EoL management of PV installations in Gauteng.

Taking the review of global practices of managing EoL PV installations into account, the researcher further explored the question of management of EoL PV installations in Gauteng through interviews of various stakeholders within the waste management, energy, environmental, finance and economic sectors. Considering the review conducted in response to the first objective, the second objective of the research which was tackled from a waste management perspective, explored the multi-disciplinary views of the management EoL PV installations in Gauteng. Having reviewed the global influences on South Africa's, and more specifically, Gauteng's waste management practices, the

researcher reviewed the level of prepared of the province to manage EoL PV installation in light of the goal to manage waste sustainably, through the circular economy.

5.2 Conclusions

Section 5.2.1 provides the conclusions related to the two research objectives.

5.2.1 Conclusions on RO1: The exploration of the global practices of managing EoL PV installations

The global practices of managing EoL PV installations are the result of the global concerted effort to develop and exist in a sustainable manner (Sharma *et al.*, 2019). This is evident through the permeation of sustainability in the development of the various treaties that manage the interaction between humans and the environment. The world has been deliberate in its effort to evolve from linearity to circularity in its economy and the management of its waste. This has taken place through the earlier mentioned enforcement of treaties, protocols and agreements, that culminated into the recent SDGs. The influence of this activity is evident in the global legislative framework that has been developed to manage waste in a sustainable and circular manner.

Influenced by global best practices, the South African legal framework has evolved to affect the circular economy (Godfrey & Scott, 2010). The National Waste Management Strategy (NWMS) of the country has identified where South Africa is as a country in relation to the effectiveness of its waste management activity and provided direction towards a solution for the various challenges raised. Though EoL PV installations are not explicitly listed in waste legislation but are rather inferred to in the definition of electrical and electronic equipment described in the Regulations Regarding Extended Producer Responsibility, Section 4 (1) of the Schedule of the Extended Producer Responsibility Scheme for the Electrical and Electronic Equipment Sector (The Department of Forestry, Fisheries and the Environment, 2020), the country does have a map of where it wants to go in the management of the waste stream. The challenge, however, is the “how”, referring to the development and maintenance of the recycling and waste stream management infrastructure, the level of understanding of the challenge at hand with respect to the composition of the waste stream, the capacity of our consequence management structures and their level of understanding in effecting the legislative framework, and the enactment of an effective collaboration between the government, the corporate and private citizens.

5.2.2 Conclusions on RO2: The exploration of the perceptions of EoL management of PV installations in Gauteng

As the question is localised to the South African context, the challenge of “how” is one that is well known to all sectors of society in Gauteng and well-articulated by the multi-disciplinary

respondents. The respondents presented their responses to the interview questions as citizens of Gauteng and industry specialists in both the public and private sectors. Their perceptions reiterated the view of the National Waste Management Strategy that Gauteng, amongst other South African provinces, needs to collaboratively work towards building a sustainable province, through the implementation of a circular economy that includes the participation of all the citizens of the province (Department of Forestry, Fisheries and the Environment of the Republic of South Africa, 2020).

In the meantime, in response to the EPR, it was noted that the private sector has gradually started to act on their responsibility of affecting and empowering the circular economy of South Africa, there are pockets of success that the country can build on. One such incident is that of the submission of household electric and electronic waste at any Makro in the country that took place over the weekend of the 14th to the 15th of October 2023. The event was so well supported that the organisers had to re-evaluate the initial process and so as to build on this success and come back to collect the waste in exchange for vouchers at Makro once the model has been improved (Makro, 2023; Prior, 2023).

Deduced from the response gathered in the interviews, it is clear that the policy and legal framework, the infrastructural, funding and capacity challenges are all intertwined (McDonald & Pearce, 2010), testament to the complex nature of sustainability (Salvia *et al.*, 2021), and ultimately waste management as a problem. The ramifications of a shortfall in any one of the listed aspects will influence the effectiveness of the management of waste as a whole, inevitably affecting the management of EoL PV installations. The deductions from the energy sector respondents emphasised the need for education and better communication of the challenge that would be posed by EoL PV installations to the residents of the Gauteng (Kim *et al.*, 2018). It was clear that there was a “*penny that dropped*” with regards to responding to one challenge, and subsequently creating another, particularly as the deduction from the introductory discussions during the interviews with the sector representatives and the representatives from other sectors (economics and finance) was that the adoption of renewable energy was to respond to the country’s energy deficit. This is particularly evident with the two amendments to the legislation on the increase in the generation threshold from 1MW to 100 MW for the requirement of a license in small scale solar installations as well as the tax incentives provided for the use of solar PV installations in households, micro-enterprises (Section 2.2.2).

Though somewhat defensive in some of their responses, the public waste management sector conceded to their shortcomings, but not without harshly criticising the private sectors for what was expressed as arrogance. In spite of the friction, it was clear to all parties, that the challenges that were highlighted for the management of EoL PV installations needed to be addressed as a joint

effort where all parties involved held each other accountable for their roles in building the circular economy that would manage the waste stream effectively (Ndzibah *et al.*, 2022).

Ultimately, while the country is in a precarious position that has resulted in a constrained economy (Lenoke, 2017) and poorly maintained infrastructure due to a variety of reasons mentioned in Chapter 4 of the research (Oelofse & Godfrey, 2008), the state of awareness of the current situation does bring hope for change as solutions come to the fore. Taking the country's legislation into account, building on its strength and addressing the pitfalls of poor consequence management (Bray, 1995), ambiguity of some aspects of the legislations (Henderson, 2001) and the development and maintenance of a recyclable waste collection infrastructure (Ichikowitz & Hattingh, 2020), it is possible to improve the current level waste management in Gauteng, ultimately improving the level of effectiveness of the circular management of WEEE and EoL PV installations (Zhakata *et al.*, 2016).

5.3 Recommendations and areas of future research

5.3.1 The exploration of the global practices of managing EoL PV installations

As deduced from the case study considered in this research, Australia's use of reverse logistics for the management of its recyclables can easily be adapted to the management of EoL PV installations (Islam *et al.*, 2021). In addition to the EoL PV installation specific EPRs as per the European Union (European Commission, 2012) and the activities of Germany (Chowdhury *et al.*, 2020), South Africa should adapt a similar stance of addressing a waste stream (EoL PV installation) that can easily overwhelm the country due to its volumes in a better coordinated and succinct manner. This would require South Africa to effectively and urgently address its infrastructural challenges (Ichikowitz & Hattingh, 2020) while the education and the empowerment of officials, including those in the judiciary, must be addressed to ensure the effective implementation of industry specific waste management plans and the enforcement of the legislation to effectively manage the EoL PV installations. Furthermore, the accountability of transgressors must be visible to all citizens to contribute to compliance as currently, from the response received in the survey conducted, the framework has lost its effectiveness as a result of the citizens' disregard for the law. It would be safe to say, taking from the results of the survey, that the legislation seems to be great, on paper. And it ends there. This sentiment cannot be left unchallenged, when it's possible to affect the law, as seen elsewhere in the world.

Further lessons that can be learned from the success of Australia's waste management sector is the effectiveness of their recycling programme, which is testament to the power of the inclusion of the public in the sector (Cramer, 2022). Getting buy-in from all role players, particularly the public, enables an increase in the success rate of waste management (Patwa *et al.*, 2021), further

highlighting South Africa's need to effectively and continuously educate its citizens on effective waste management and the need to then support the lessons with the relevant infrastructural and effective official support (O'riordan *et al.*, 2012).

While both Ethiopia and Brazil have similar challenges to each other and South Africa, with regards to the lack of EoL PV management practices, it would also stand to reason that the countries have a lot to learn from each other. As the three countries find their feet in the development of infrastructure, the effective incorporation of their informal recyclers and the inclusion of their citizens in the solutions to the challenges, they can all share in their experiences as neighbours on the continent and as fellow BRICS members (Brazil, Russia, India, China and South Africa) respectively. The search for literature pertaining to the effective management of EoL PV installations was challenging as countries are at varying stages of understanding the extent of the challenge at hand. The lifespan of the components is also still under review as the varying climatic conditions of the countries also plays a role in the durability or lifespan of the components (Salamah *et al.*, 2022).

5.3.2 The exploration of the perceptions of EoL management of PV installations in Gauteng

The lessons derived from the first objective have been cemented by the contribution of the respondents. Relating this to the five domains of sustainability, as a country desperately seeking change for the betterment of the lives of its citizens, the social, domain of life and economic aspects of sustainability were considered the highest priority, respectively, while the spiritual and the material domain followed.

This confirmed the call for the development and empowerment of the circular economy. People want action. They want an end to the parasitic relationship between the government and the citizens, and rather want to collaborate symbiotically to create the Gauteng, and ultimately, the South Africa we all dream of, using the resources that we have effectively. People are aware of their responsibilities to each other as well as the environment and are not opposed to living sustainably, they just need the means to do so and to be guided on the ways to do this. Taking this into consideration, the conceptual diagram depicted as Figure 4-3 describes the possible pathways of management of the EoL PV installation, having determined the recyclability of the waste stream.

Figure 4-3 considers the lessons learnt from the global practices for the effective management of EoL PV installations, as well as the contribution of recommendations made during the interviews and presents a flow of activity, that manages the waste that would result from the EoL PV installations in a circular manner. It describes a process that would need to be driven

collaboratively by Gauteng's public sector, private sector and private individual citizens, to build a sustainable province. It is clear that for renewable energy to be truly sustainable, the entire value chain of the installation must be managed circularly, in addition the circular activity that occurs at the end of the PV installation's lifecycle.

5.3.3 Recommendations for further research

In the midst of the research that was undertaken, there were areas of that were unearthed that required further research, particularly within the African and South African context. These areas are listed as follows:

- An investigation into the cradle to the grave circularity of PV installations of South Africa.
- An evaluation of the lifespan of the PV installations considering the South African climate.
- An investigation into the unintended consequences of renewable energy in South Africa.
- An investigation into the incorporation of the informal recycling sector into the formal management WEEE in collaboration with the private and public sectors for the effective management of EoL PV installations.
- An investigation of the infrastructure requirement for the effective implementation of the EPR scheme for WEEE.

Though the research indicated that all is not lost in the battle for the effective management of EoL PV installations, Gauteng still does have areas of improvement in the effective management of waste. As discussed in the research, Gauteng's challenge of managing waste effectively inevitably spills over to the management of EoL PV installations, in spite of the headways our environmental management legislation has made. The National Waste Management Strategy, current legislative framework, EPR scheme and Industry Waste Management Plans are proof that the Department of Forestry, Fisheries and the Environment of South Africa is acutely aware of the challenges at hand. Similarly, there is an awareness that the solution requires the active involvement of both the corporate and private citizens, together with the public officials, to effectively manage waste. In addition to this, is the relevant positive reinforcement of good behaviour as well as visible, public and effective consequence management that ultimately contributes towards effectively managing EoL PV installations.

Ultimately, while Gauteng gains momentum in the use of renewable energy, to contribute to the reduction of greenhouse gas emissions, and the Sustainable Development Goals, it has to remain cognisant of the fact that sustainability is affected through circularity. While sustainability is the goal, circularity is a means by which sustainability is achieved. Solar energy is a welcomed innovative energy source, but it only truly contributes to sustainability once all aspects of the value

chain, from inception to the end of its lifespan, have been viewed through the lense of circularity. The effective management of EoL PV installations through circularity is an optimal starting point.

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ANNEXURE A

Interview questionnaire

Question number	Question and options
Section A: Background of research respondents	
Question A1a	Please indicate with an “X” the industry that you are currently employed in. A: Waste Management; B: Energy Management; C: Contractor; D: Other
Question A1b	If your answer to A1 is ‘D: Other’, kindly elaborate on the industry you are currently employed in
Question A2	Please indicate with an “X” the number of years you have been employed in the chosen industry at Question A1? A: 0 - 5 years; B: 6 – 10 years; C: 11 – 15 years; D: 16 – 20 years; E: more than 20 years
Question A3	Please indicate with an “X” the sector of the industry that you have been a part of throughout your employment history. A: Public sector; B: Private sector; C: Both
Question A4	Please indicate with an “X” your highest level of education.

Question number	Question and options
	A: National Diploma; B: Bachelor's degree; C: Honour's or Postgraduate diploma; D: Master's degree; E: Doctorate; F: Other
Question A5	Kindly elaborate on your background and field of specialisation.
Section B: The perceptions of EoL PV waste management in Gauteng	
Question B1a	Please indicate with an "X", your level of satisfaction with current the state of waste management within Gauteng? A: Completely unsatisfied; B: Unsatisfied; C: Neither unsatisfied nor satisfied; D: Satisfied; E: Very satisfied
Question B1b	Kindly elaborate on the reason for your selection in Questions B1a, by explaining the motivation behind your level of satisfaction or dissatisfaction.
Question B2a	Considering the current state of waste management within Gauteng (Adeleke <i>et al.</i> , 2021), in your professional opinion, how would you describe the state of preparedness of the waste management service of Gauteng for the management of EoL PV installations? Please indicate with an "X". A: Completely ill-prepared; B: Ill-prepared; C: Neither ill-prepared nor prepared; D: Prepared; E: Well prepared.
Question B2b	Kindly elaborate on the reason for your selection in Questions B2a, by explaining the motivation behind your level of satisfaction or dissatisfaction.
Question B3	In light of the non-explicit inclusion of EoL PV installations in South Africa's legislated definition of WEEE, in your professional opinion, how would this effect the effective management of the waste stream?
Question B4a-1	The South African government has made use of certain legislative instruments such as regulations to encourage a change of behaviour of both manufacturers and consumers of WEEE towards the circular economy (Blackman <i>et al.</i> , 2018; Mickwitz, 2003; Nahman, <i>et al.</i> , 2008). How would you describe the effectiveness of the government's use of these mentioned environmental management instruments? A: Completely ineffective; B: Ineffective; C: Neither ineffective nor effective; D: Somewhat effective; E: Effective
Question B4a-2	The South African government has made use of certain legislative instruments such as levies or tax breaks to encourage a change of behaviour of both manufacturers and consumers of WEEE towards the circular economy (Blackman <i>et al.</i> , 2018; Mickwitz, 2003; Nahman, <i>et al.</i> ,

Question number	Question and options
	<p>2008). How would you describe the effectiveness of the government's use of these mentioned environmental management instruments?</p> <p>A: Completely ineffective; B: Ineffective; C: Neither ineffective nor effective; D: Somewhat effective; E: Effective</p>
Question B4a-3	<p>The South African government has made use of certain legislative instruments such as penalties and fines to encourage a change of behaviour of both manufacturers and consumers of WEEE towards the circular economy (Blackman <i>et al.</i>, 2018; Mickwitz, 2003; Nahman, <i>et al.</i>, 2008). How would you describe the effectiveness of the government's use of these mentioned environmental management instruments?</p> <p>A: Completely ineffective; B: Ineffective; C: Neither ineffective nor effective; D: Somewhat effective; E: Effective</p>
Question B4a-4	<p>The South African government has made use of certain legislative instruments such as the Extended Producer Regulations to encourage a change of behaviour of both manufacturers and consumers of WEEE towards the circular economy (Blackman <i>et al.</i>, 2018; Mickwitz, 2003; Nahman, <i>et al.</i>, 2008). How would you describe the effectiveness of the government's use of these mentioned environmental management instruments?</p> <p>A: Completely ineffective; B: Ineffective; C: Neither ineffective nor effective; D: Somewhat effective; E: Effective</p>
Question B4b-1 to B4b-4	<p>In considering your response to Question B4a-1 to B4a-4, please elaborate on your answer to the question?</p>
Question B5-1	<p>In light of the province's challenge with the existing waste management resources such as the diminishing airspace (Oelofse, 2021), how would you perceive these challenges hinder effective management of EoL PV components.</p>
Question B5-2	<p>In light of the province's challenge with the existing waste management resources such as the lack of regular maintenance of fleet and infrastructure (Patience & Nel, 2021), how would you perceive these challenges hinder effective management of EoL PV components.</p>
Question B5-3	<p>In light of the province's challenge with the existing waste management resources such as inconsistent and inadequate waste collection services, (Department of Forestry, Fisheries and the Environment, 2021), how would you perceive these challenges hinder effective management of EoL PV components.</p>

Question number	Question and options
Section C: Recommendations towards the effective waste management of EoL PV installations in Gauteng	
Question C1	<p>C1. In your professional opinion, how can the effectiveness of the following legislative instruments be improved so that a positive contribution can be made towards the management of EoL PV installations? C1-1: Regulation</p>
	<p>C1. In your professional opinion, how can the effectiveness of the following legislative instruments be improved so that a positive contribution can be made towards the management of EoL PV installations? C1-2: Levies or tax breaks</p>
	<p>C1. In your professional opinion, how can the effectiveness of the following legislative instruments be improved so that a positive contribution can be made towards the management of EoL PV installations? C1-3: Penalties or fines</p>
	<p>C1. In your professional opinion, how can the effectiveness of the following legislative instruments be improved so that a positive contribution can be made towards the management of EoL PV installations? C1-4: The Extended Producer Regulations</p>
Question C2	<p>One of the National Waste Management Strategy’s (NWMS) focus areas is to develop a culture of re-use, recycling and reduction of the disposal of solid waste at landfills within the citizens of the country, therefore enacting a circular economy. (Department of Environment, Forestry, and Fisheries of the Republic of South Africa, 2020). In line with this strategy, landfilling of WEEE has been prohibited. In your professional opinion, how can both corporate and private citizen participation in the circular economy in Gauteng be improved with respect to EoL PV installations?</p>
Question C3	<p>The Extended Producer’s Responsibility (EPR) is a principle aimed at extending the producer of a product’s responsibility to the end of the product’s lifecycle once (Nahman, 2010). In consideration of this responsibility, in your view, what can the manufacturers and government entities do better to improve the overall support of the implementation of this legislated requirement?</p>

Question number	Question and options
Question C4	Taking the current legislative framework that broadly categorises EoL PV installations as large equipment electronic waste (E-waste) into account (Farrell <i>et al.</i> , 2020), in your professional opinion, how can this be improved and streamlined to improve the current management practices employed for this waste stream?
Question C5	As South Africa is a country plagued with a high rate of unemployment (Smit, 2023), the country's waste management sector is synonymous with reclaimers (Mvuyane, 2018) who would employ rudimentary recycling tactics to extract value from the EoL PV waste (Daum <i>et al.</i> , 2017). In light of the dangers, such as the presence of heavy pollutant and hazardous metals such as silicon, copper, silver and lead within the components of EoL PV (Farrell <i>et al.</i> , 2020), in your professional opinion, how can the Gauteng government help prevent a health and safety as well as environmental disaster in this respect?
Question C6a	In your professional opinion, what infrastructural challenges do you foresee regarding the management of household and industrial scale EoL PV installation components?
QuestionCc6b	Taking the response to Question C6a into account, how can Gauteng's public and private sector address these infrastructural challenges to achieve effective management of waste generated from EoL PV installations?
Question C7	Are there any other recommendations that you would like to make towards the improvement of managing EoL PV installations?

ANNEXURE B

Institution: North-West University

Campus: Potchefstroom

Field of Study: Master of Environmental Management

Mini-dissertation title: Exploring the perceptions on the effectiveness of solid waste management of end-of-life photovoltaic installations in Gauteng.

Student Name: Kamohelo Bongwiwe Letlole

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Co-Supervisor: Professor Claudine Roos (Claudine.Roos@nwu.ac.za)

Ethics number: NWU-01217-23-A9

Dear Participant,

My name is Kamohelo Letlole, I am a registered student at the North-West University, for a Masters in Environmental Management, specialising in waste management.

You are hereby invited to participate in my Masters' study which aims to explore perceptions on the effectiveness of solid waste management of end-of-life (EoL) photovoltaic (PV) installations in Gauteng.

The objectives of this research are as follows:

- 1) To explore the global practices of managing EoL PV installations.
- 2) To explore the perceptions of EoL PV solid waste management in Gauteng.
- 3) To make recommendations towards the effective solid waste management of EoL PV installations in Gauteng.

The data obtained from participants such as yourself will add value to my research by way of adding to the body of knowledge on the perceptions of management of end-of-life photovoltaic installation components.

This semi-structured questionnaire has been structured into three sections. The first section seeks to establish your background as a participant. The second section questions your perceptions of EoL PV waste management in Gauteng. The third section discusses the recommendations made towards the effective management of EoL PV installations in Gauteng.

Please note:

- a) Your participation in this study is entirely voluntary and you can withdraw from participating in the research at any time for whatever reason you see fit.
- b) There are no risks associated with this study.
- c) The interview process will take approximately 45 – 60 minutes. Interviews will be recorded for transcription purposes only.
- d) No information pertaining to your identity or organisation will be expressed without your prior consent. Your privacy and confidentiality as a participant are guaranteed.
- e) All transcripts will be given codes to ensure that the participants' names and institutions are not in the public domain. Institutions will be described either as public or private sector.
- f) Please confirm that you understand your role as a participant in this study. Should you wish to get clarity on the research at any time, you are welcome to ask.

Thank you for your valuable time and participation in this study.

Kind regards,

Kamohelo B. Letlole

Background information and informed consent:

Dear Sir/Madam

I appreciate your interest in my research project. Before participating, please carefully read the information provided.

Research title:

To explore perceptions on the effectiveness of solid waste management of end-of-life (EoL) photovoltaic (PV) installations in Gauteng

Introduction:

My name is Kamohelo Letlole, with student number 29458714. I am a registered student at the North-West University for a Masters in Environmental Management with specialisation in waste management under the supervision of Dr Leandri Kruger and co-supervision of Proff. Claudine Roos.

Purpose of the study:

The aim of this research is to explore perceptions on the effectiveness of solid waste management of end-of-life (EoL) photovoltaic (PV) installations in Gauteng.

Methodology of the study:

Interviews (structured questionnaire) will be conducted between the researcher and participant face-to-face or via a platform such as Microsoft Teams and the researcher will record the answers. Participants are more than welcome to ask for clarity throughout the interview should they need more clarification on the questions.

Benefits of the research:

This research will add to the body of academic knowledge focusing on solid waste management in Gauteng.

Confidentiality:

The privacy of any personal information is ensured. The names of the participants will not be mentioned or used in the report.

Possible risk:

Participation in the study poses no risk to participants.

Rights of participants:

Participation in this study is completely voluntary and participants are able to withdraw from the interview at any point.

Compensation:

No payment will be made to participants for taking part in the study.

Ethical approval:

This study was approved by the Faculty of Natural and Agricultural Sciences Research Ethics Committee (FNAS-REC) of the North-West University Potchefstroom Campus (NWU01217-23-A9).

Participant consent:

I have read and understood this information document. My questions prior to answering the questionnaire have been answered to my satisfaction. I understand that I am free to request further information at any time.

I know and understand that:

1. My participation in the study is voluntary;
2. My personal information will be kept confidential;
3. I am free to withdraw from participating in the study at any time;
4. By signing this document, I agree to participate in the study.

Signature of participant:		Date:	
Printed name:			

