



Barriers and opportunities to the implementation of clean energy initiatives: a platinum mine case study

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PREFACE AND ACKNOWLEDGMENTS

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ABSTRACT

Rapidly increasing energy demand, high electricity costs, unreliable grid supply and growing concern about the environmental impacts associated with the consumption of fossil fuel energy, call for implementation of sustainable clean energy in the mining industry.

Mining is recognised as an energy-intensive industry that is heavily dependent on fossil fuels as a source of energy used in various processes and activities (Levesque, 2015:41). Most platinum producers highly depend on electricity as a source of energy, especially electricity sourced from the national utility supplier Eskom, which is mostly coal-based (Ryan, 2014:299-303). The global and national energy supply is dominated by fossil fuels, which increased during the Industrial Revolution. The consumption of fossil-based energy causes detrimental environmental impacts, which include depletion of natural resources and emission of Green House Gases and carbon dioxide (Kusi-Sarpong, 2015:2; Dincer & Acar, 2015: 586). Because this industry relies heavily on fossil fuel energy, it is consequently one of the highest GHG emitters (Ryan, 2014).

Lastly, high electricity costs, unreliable grid supply facing South African mining companies and the growing pressure from investors and stakeholder expectation is another challenge affecting the industry (PWC, 2020:16; Gangazhe, 2016:8). To address the energy challenges facing the industry and support the Paris Agreement and associated global and national frameworks' goal to address climate change impacts, transition to alternative sustainable energy is essential (Dincer & Acar, 2015: 586; Ryan, 2014).

This research aims to explore the barriers and opportunities that influence the implementation of clean energy initiatives in platinum mining.

The research aim was achieved through the following objectives:

- Identifying and describing existing or proposed clean energy initiatives in the platinum mining case study.
- Identifying and characterising the barriers to implementing clean energy initiatives in platinum mining.
- Identifying and evaluating opportunities for implementing clean energy initiatives in platinum mining.

The research methodology adopted in this research is based on a case study approach, using qualitative methods which involve collection of data through semi-structured interviews and

document analysis. The research approach followed in this study involves adopting of existing theories on barriers and opportunities influencing the implementation of clean energy initiatives applied to a South African platinum mine case study. The specific case study was selected because of its position as a world-class platinum producer that has implemented clean energy initiatives and investigated opportunities to improve and transition to cleaner technologies while improving environmental performance.

It became evident from the case study that a lack of technical expertise required to implement and maintain clean energy technologies is a significant barrier that influences the implementation of clean energy initiatives. This was followed by the intermittency of renewable resources barrier, which caused inconsistent supply of energy to the operations. High start-up capital cost to implement clean energy technologies and the inability of fossil fuel energy to provide a positive business case due to its abundance, accessibility and affordability were the most important economic and financial barriers identified in the case study. The lengthy timelines and processes required to obtain necessary permits and approvals from various licensing authorities and government institutions became an important institutional barrier.

Increasing the skill set of workforces responsible for implementing clean energy technologies is a positive opportunity that stood out in the study to bridge the knowledge gap caused by a lack of technical expertise barrier. This can also be achieved through upskilling programmes in higher institutions and facilities. The opportunity to use hybrid technologies is a practical opportunity proposed to increase the reliability of energy supply to the operations and to overcome the intermittency of renewable resources barrier.

Fiscal instruments such as public funding and incentivising industries that implement clean energy initiatives can be used by the government to address the high start-up capital barrier and enhance the attractiveness of clean energy technologies. This public funding can also be extended to Research & Development in clean energy, pre-investment studies and project start-up. Lastly, mining companies, government, and other energy-intensive industries can form a consortium collectively to fund and develop clean energy projects to overcome this barrier. On a positive note, in addition, identifying the opportunities to address the barriers, the case study operations highlighted the actions that were successfully implemented by these operations to overcome most of the barriers identified that influence the implementation of clean energy initiatives.

Keywords: Barriers, clean energy, energy, initiatives, mining, platinum, renewable, technology

ABBREVIATIONS AND ACRONYMS

AAP	Anglo American Platinum
CDM	Clean Development Mechanism
CO ₂	Carbon Dioxide
CPV	Concentrated Photovoltaics
CSP	Concentrated Solar Power
CWR	Carbon War Room
DEFF	Department of Environment, Forestry and Fisheries
DME	Department of Minerals and Energy
DMRE	Department of Mineral Resources and Energy
DoE	Department of Energy
ESG	Environment, Social and Governance
FSB	Financial Services Board
GDP	Gross Domestic Product
GEISA	Green Economy Inventory for South Africa
GHG	Green House Gas
IEP	Integrated Energy Plan
IPP	Independent Power Producer
IRP	Integrated Resource Plan
MS	Microsoft
MW	Megawatt
ND	Not Defined
NDP	National Development Plan

NEES	National Energy Efficiency Strategy
NWU	North-West University
OEM	Original Equipment Manufacturer
PA	Paris Agreement
PAGE	Partnership for Action on Green Economy
PGM	Platinum Group Metals
PV	Photovoltaic
PWC	Price Water House Coopers
R&D	Research and Development
RE	Renewable Energy
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
REPS	Renewable Electricity Portfolio Standard
RSA	Republic of South Africa
SA	South Africa
SCRE	Senate Committee for Research Ethics
SDG	Sustainable Development Goals
SEA	Sustainable Energy Africa
SMP	Sustainable Mining Plan
TCFD	Taskforce on Climate Related Financial Disclosures
TwH	Terawatt-hour
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
JV	Joint Venture

KEY DEFINITIONS

Actions to address challenges	Actions already implemented by the case study to bridge the gaps caused by the barriers to the implementation of clean energy initiatives.
Clean energy	Clean energy refers to energy that comes from natural renewable sources or processes that are constantly replenished. Clean energy also refers to the use of technologies to improve energy efficiency, capture pollutants, recover and store energy.
Decarbonize	Reduction of the amount of carbon compounds released into the atmosphere.
EDF Renewables	An international independent power producer that specialises in production of renewable energy.
Opportunities to address challenges	Potential actions proposed by participants to overcome the barriers that influence the implementation of clean energy initiatives.
Renewable energy	Energy produced from resources (sources of processes) that constantly replenish naturally.
Wheeling	Transportation of electricity from a generator to an end-user located in another area using existing transmission networks.

TABLE OF CONTENTS

PREFACE AND ACKNOWLEDGMENTS	I
ABSTRACT	II
ABBREVIATIONS AND ACRONYMS	IV
KEY DEFINITIONS	VI
 CHAPTER 1 INTRODUCTION.....	 1
1.1 Background	1
1.2 Problem statement and rationale for the research.....	2
1.2.1 Research problem	2
1.2.2 Global energy supply	2
1.2.3 National energy supply	3
1.2.4 Fossil fuel impacts	4
1.3 Energy use in the mining industry	4
1.3.1 Energy use in the platinum mining industry.....	5
1.4 Rationale for the Study	7
1.5 Research aim and objectives.....	9
1.6 Scope of the research	9
1.7 Potential contribution of the research	9
1.8 Structure and outline of the dissertation	10
 CHAPTER 2 LITERATURE REVIEW.....	 11
2.1 Introduction	11
2.2 Overview of energy in the mining industry.....	11

2.3	Clean energy	13
2.3.1	Clean energy defined.....	13
2.3.2	Global context of clean energy implementation in the mining industry	14
2.3.3	State of clean energy implementation in SA mining industry	15
2.4	Drivers for clean energy implementation.....	16
2.4.1	Climate change risk	18
2.4.2	Greenhouse gas emissions	18
2.4.3	Energy security and demand	19
2.4.4	High electricity costs	20
2.4.5	Unreliable grid supply	21
2.5	Benefits of clean energy implementation	22
2.5.1	Environmental benefits	22
2.5.2	Social benefits	22
2.5.3	Economic benefits	22
2.6	Legal framework supporting the implementation of clean energy initiatives.....	23
2.6.1	The role of legal frameworks.....	23
2.6.2	The global legal framework supporting the implementation of clean energy initiatives.....	23
2.6.2.1	United Nations Framework Convention on Climate Change (UNFCCC)	24
2.6.2.2	Kyoto Protocol & Paris Agreement.....	24
2.6.3	The South African legal framework supporting the implementation of clean energy initiatives.....	24
2.6.3.1	The National Energy Act (2008).....	25

2.6.3.2	The National Development Plan (NDP).....	25
2.6.3.3	The White Paper on Energy Policy	26
2.6.3.4	The White paper on Renewable Energy	26
2.6.3.5	Renewable Energy Independent Power Producer Procurement Programme	26
2.6.3.6	National Climate Change Response White Paper	27
2.6.3.7	Integrated Energy Plan	27
2.6.3.8	National Integrated Resource Plan	27
2.6.3.9	National Energy Efficiency Strategy	28
2.6.3.10	Carbon Tax.....	28
2.7	Corporate policies and strategies for the transition to clean energy in platinum mining	28
2.8	Barriers to implementing clean energy initiatives in mining	29
2.8.1	Technical barriers	30
2.8.1.1	Intermittency of renewable resources	31
2.8.1.2	Accessibility of spares and equipment	31
2.8.1.3	Inadequate systems.....	31
2.8.1.4	Poor reliability and inappropriate technology	31
2.8.1.5	Lack of technical expertise.....	32
2.8.2	Economic and financial barriers	32
2.8.2.1	Access to funding	32
2.8.2.2	High start-up capital costs	33
2.8.2.3	Fossil fuel abundance, accessibility and affordability	33
2.8.2.4	High land acquisition costs	33

2.8.2.5	High technology importation costs	33
2.8.3	Institutional barriers	33
2.8.3.1	Inefficient government policies, inadequate incentives, and unrealistic targets	33
2.8.3.2	Bureaucratic complexities and permit acquisition constraints.....	34
2.8.4	Awareness and information barriers	34
2.8.4.1	Lack of information and knowledge.....	34
2.8.4.2	Inadequate research and development.....	35
2.8.4.3	Lack of consumer awareness	35
2.8.5	Land constraints barriers	35
2.8.5.1	Land availability	35
2.8.5.2	Land use constraints.....	35
2.9	Opportunities for integrating clean energy in mining	36
2.10	Replacing fossil fuels by integrating renewable energy sources in mining processes and transportation to reduce GHG emissions	37
2.10.1	Replacing fossil fuels with clean energy in mining processes and transportation	37
2.10.2	Integrating renewable energy to meet electricity demand and reduce GHG emissions	37
2.10.3	Types of renewable energy sources for integration in mining processes and activities.....	38
2.10.4	Biomass.....	38
2.10.5	Hydropower	39
2.10.6	Wind	39
2.10.7	Solar	40

2.11	Hybrid energy systems	41
2.12	Hydrogen production through renewable energy	41
2.13	Potential opportunities and actions taken to address the clean energy implementation barriers in the mining	42
2.13.1	Addressing technical barriers.....	43
2.13.1.1	Intermittent nature of renewable resources.....	43
2.13.1.2	Inappropriate technology	43
2.13.1.3	Lack of skilled expertise.....	43
2.13.2	Addressing economic and financial barriers.....	43
2.13.2.1	Public funding and Research and Development	44
2.13.3	Addressing institutional barriers.....	44
2.13.3.1	Practical policy and conducive regulatory frameworks	44
2.13.3.2	Addressing bureaucratic complexities and poor coordination in SA	45
2.13.4	Addressing awareness and information barriers	47
2.13.5	Addressing land constraint barriers.....	47
2.13.5.1	Land availability constraints.....	47
2.13.5.2	Land use constraints.....	47
2.14	Chapter summary	48
CHAPTER 3	METHODOLOGY.....	53
3.1	Introduction	53
3.2	Research design.....	53
3.2.1	Research case study	53
3.3	Sampling methodology	54

3.3.1	Sampling size	54
3.3.2	Selection of participants.....	54
3.3.3	Selection and identification of the study operations	56
3.3.3.1	Selection of study operations.....	56
3.3.3.2	Location and type of case study operations	56
3.4	Data Collection	57
3.4.1	Document analysis	57
3.4.2	Interviews	58
3.4.2.1	Interview methodology.....	58
3.4.2.2	Design of the interview questionnaire	58
3.4.2.3	Pilot interview	60
3.5	Data analysis.....	60
3.5.1	Determining the importance ranking of the top barriers.....	61
3.6	Ethical considerations	62
3.7	Methodological assumptions and limitations.....	62
CHAPTER 4	RESULTS AND DISCUSSION.....	64
4.1	Introduction	64
4.2	Demographic data of the participants.....	64
4.3	Existing and proposed clean energy initiatives in the platinum mining case study.....	65
4.4	Barriers to the implementation of clean energy initiatives identified in the case study.....	71
4.4.1	Most important barriers based on the identification of all barriers by participants.	72

4.4.2	Most important barriers based on the identification of the top two barriers by participants.....	73
4.4.3	Most important barriers to the implementation of clean energy initiatives.....	74
4.4.4	Technical barriers.....	76
4.4.4.1	Lack of technical expertise.....	76
4.4.4.2	Accessibility of spares and equipment.....	77
4.4.4.3	Intermittency of renewable resources.....	77
4.4.4.4	Inappropriate technology.....	78
4.4.4.5	Lack of infrastructure support.....	79
4.4.4.6	Least important technical barriers.....	80
4.4.5	Economic and financial barriers.....	80
4.4.5.1	Fossil fuel abundance, accessibility and affordability.....	80
4.4.5.2	High start-up capital costs.....	81
4.4.5.3	High running costs.....	82
4.4.5.4	Least important economic and financial barriers.....	82
4.4.6	Institutional barriers.....	82
4.4.6.1	Permit acquisition constraints.....	82
4.4.6.2	Bureaucratic complexities.....	83
4.4.6.3	Inefficient government policies.....	83
4.4.6.4	Inadequate incentives.....	84
4.4.6.5	Least important institutional barriers.....	84
4.4.7	Awareness and information barriers.....	84
4.4.7.1	Inadequate research and development.....	84

4.4.7.2	Least important awareness and information barriers.....	85
4.4.8	Land constraints barriers	86
4.4.8.1	Land use constraints.....	86
4.4.8.2	Land availability	86
4.4.8.3	Land use constraints.....	87
4.4.8.3.1	Security constraints	88
4.5	Opportunities for the implementation of clean energy initiatives identified in the case study.....	89
4.5.1	Technical opportunities.....	90
4.5.1.1	Hybrid of energy technologies	90
4.5.1.2	Battery storage	91
4.5.1.3	Infrastructure development	91
4.5.1.4	Training and development programmes.....	92
4.5.1.5	Subsidizing and developing clean energy learning programmes.....	92
4.5.1.6	Redesigning clean energy technologies.....	93
4.5.2	Economic and financial opportunities.....	93
4.5.2.1	Public funding and incentives	93
4.5.2.2	Phased approach project implementation	93
4.5.2.3	Upskilling the workforce	94
4.5.2.4	Working in a consortium	94
4.5.3	Institutional opportunities	95
4.5.3.1	Review of sectoral policies and regulations	95
4.5.3.2	Enforcing policies and regulations	95

4.5.3.3	Streamlining the licensing application and approval process	95
4.5.4	Awareness and information opportunities	96
4.5.4.1	Subsidize learning and skilling programmes	96
4.5.4.2	Knowledge sharing and research and development	96
4.5.5	Land opportunities	96
4.5.5.1	Building clean technologies on top of structures	96
4.5.5.2	Partnership with industries and government	97
4.5.5.3	Community development	97
4.5.6	Existing and planned clean energy initiatives by other mining companies.....	98
4.6	Actions taken by the case study operations to address clean energy initiative implementation barriers.....	98
4.6.1	Addressing technical barriers.....	98
4.6.1.1	Hybrid of energy technologies	98
4.6.1.2	Training and skills development.....	99
4.6.2	Addressing economic and financial barriers.....	100
4.6.2.1	Risk ranking during project evaluation	100
4.6.2.2	High efficiency inverters and rooftop solar panels	101
4.6.3	Addressing institutional barriers	101
4.6.3.1	Relaxed licensing requirements	101
4.6.3.2	Energy reduction targets and incentives and public funding.....	101
4.6.4	Addressing awareness and information barriers	102
4.6.4.1	Knowledge sharing	102
4.6.4.2	Research and development.....	102

4.6.5	Addressing land constraints barriers.....	103
4.6.5.1	Community engagement.....	103
4.6.5.2	Construction of clean technologies on top of structures.....	103
4.7	Chapter summary	103
CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS		105
5.1	Introduction	105
5.2	Existing and proposed clean energy initiatives	105
5.3	Barriers and opportunities to the implementation of clean energy initiatives.....	106
5.4	Recommendations.....	108
5.5	Areas of future research	110
BIBLIOGRAPHY		111
ANNEXURE A		123

LIST OF TABLES

Table 2-1:	Potential renewable electricity projects in South African mining companies (Labuschagne, 2020).	41
Table 3-1:	Summary of the key participants interviewed.....	55
Table 3-2:	List of operations that was included in the case study.....	57
Table 4-1:	Demographic data of the participants interviewed.....	64
Table 4-2:	Clean energy initiatives implemented/planned by AAP (AAP12:2022:17-18; AAP2, 2021:58-63; AAP4, 2020:57; AAP8, 2012; AAP9, 2014; AAP10, 2015).....	67

Table 4-3: Total number of barriers identified during literature review and interviews.	71
Table 4-4: Overall importance ranking of the top 11 barriers, based on the results of the identification of all barriers and the top two barriers.	74

LIST OF FIGURES

Figure 1-1: Global energy consumption by source. The unit measure for primary energy consumption is terawatt-hours (TWh) (Ritchie <i>et al.</i>, 2020).....	3
Figure 1-2: Total energy distribution in SA, 2016 (Akinbami <i>et al.</i>, 2021: 5078).	4
Figure 1-3: AAP energy consumption and GHG emissions (AAP2, 2021:60).	6
Figure 2-1: SA's energy distribution per industry (Ratshomo & Nembahe, 2021:22).	12
Figure 2-2: State of renewable energy implementation by global mining companies (Igogo <i>et al.</i>, 2020:8).	15
Figure 3-1: Geographical location of AAP operations in South Africa that formed part of the study (AAP11, 2021:3).	57
Figure 4-1: Carbon neutral roadmap for Anglo American (AAP4 2021:14).	66
Figure 4-2: Most important barriers based on the identification of all barriers by participants.	72
Figure 4-3: Most important barriers based on the identification of the top two barriers by participants.	73
Figure 4-4: Opportunities identified by the case study operations to address the barriers.	90

CHAPTER 1 INTRODUCTION

1.1 Background

Energy is the driving force behind economic growth and social development (Pollet *et al.*, 2015:16686; Angwe, 2014:1; Winkler *et al.*, 2005:27). Its primary function is to transform natural resources into goods and services that are useful and important to all human activities (Hinrichs & Kleinbach, 2013:1-2). Before civilization, many people relied on the sun as a primary source of light and biomass such as wood as a source of energy, mainly used in cooking and lighting at night. Although the conventional practices such as burning wood are associated with environmental emissions, limited population at the time made it possible for the environment to absorb the emissions naturally (Angwe, 2014:6). The demand for energy use evolved since the Industrial Revolution, where an increase in demand for energy was seen worldwide. The increase in population and industrial activity resulted in increased fossil fuel use in many countries (Hinrichs & Kleinbach, 2013:3). These activities use fossil fuels such as coal, gas, oil and others (Ward, 1999:3).

The way fossil-based energy resources are harnessed and used by various sectors is of global concern (Angwe, 2014:1). The current methods of consuming, producing, and transporting these energy resources do not demonstrate sustainability and contribute to global, regional, and local environmental concerns such as environmental degradation, air pollution and global warming (Winkler *et al.*, 2003:27; Kusi-Sarpong, 2015:2 & Hilson, 2001:27).

The mining sector is one of the highest consumers of energy that relies heavily on fossil fuels as a source of energy (Levesque, 2015:41; Igogo *et al.*, 2021:5). The 2021 South African Energy Sector Report reveal mining is the third largest consumer of energy in the country while chemical and petrochemical industries are the highest energy consumers in the country. Of the total energy of 183 435TJ consumed by the industry in 2021, electricity accounts for 58%, followed by petroleum products and coal at 38% and 4%, respectively (Ratshomo & Nembahe, 2021:21-23).

Ryan (2014:299-303) reported that most platinum producers are also high consumers of energy, especially electricity, consuming more than 70% of the energy mix. These platinum producers use electricity that is mainly sourced from the national utility supplier, Eskom. This suggests that environmental pollution, such as carbon emissions associated with platinum mining activities, are higher than compared to other mining sectors.

The platinum mining case study for this research is one of the energy users and has committed itself to achieving carbon neutrality across its operations by 2040 through various clean energy initiatives (AAP5, 2020:38-45).

1.2 Problem statement and rationale for the research

1.2.1 Research problem

For more than 14 years, many writers have conducted research exploring barriers that influence the adoption and implementation of clean energy initiatives by various sectors. Although many types of barriers, such as infrastructure, regulatory, economic, financial, technical, social, educational and information, were identified in previous studies, Martin and Rice (2012:126) still believe more barriers related to these factors exist in one shape or another. This suggests a delay in investment and dissemination of clean energy initiatives by many industries (Ganghazhe, 2016: 1; Ryan, 2014:299).

According to Liu (2014: 412), to enable favourable conditions that support the greater adoption of clean energy systems by industries, it is essential to see the barriers that hinder the adoption and implementation. The author is confident that this knowledge will become useful to policy-makers responsible for developing policies and frameworks that support the implementation of clean energy initiatives as well as measures needed to overcome the barriers.

Most mining companies are under pressure to demonstrate sustainability when it comes to the use of natural resources (PWC, 2020:16). This is because most mining activities cause significant environmental impacts and degradation due to high consumption of natural resources (Hilson, 2001:27). This industry is faced with increasing energy prices and decreasing commodity prices which impacts their businesses negatively. Furthermore, growing pressure from interested and affected stakeholders demands mining operations to operate in a sustainable manner (Gangazhe, 2016:8).

However, this industry is also faced with internal drivers, such as increasing energy prices and decreasing commodity prices, energy security and unreliable grid supply, which impacts their businesses negatively. These drivers also require the mining industry to operate sustainably and in a cleaner way.

1.2.2 Global energy supply

A significant amount of the global total primary energy supply was met by fossil fuels, constituting more than 80% of the energy consumption (Ritchie *et al.*, 2020; Dincer & Acar, 2015:585). Figure

1-1 demonstrates that globally, oil is the dominant source of energy supplied, followed by coal and gas. Although renewable energy supply started to emerge in 2010, the global energy mix is still dominated by fossil fuels, which was observed to increase during the Industrial Revolution.

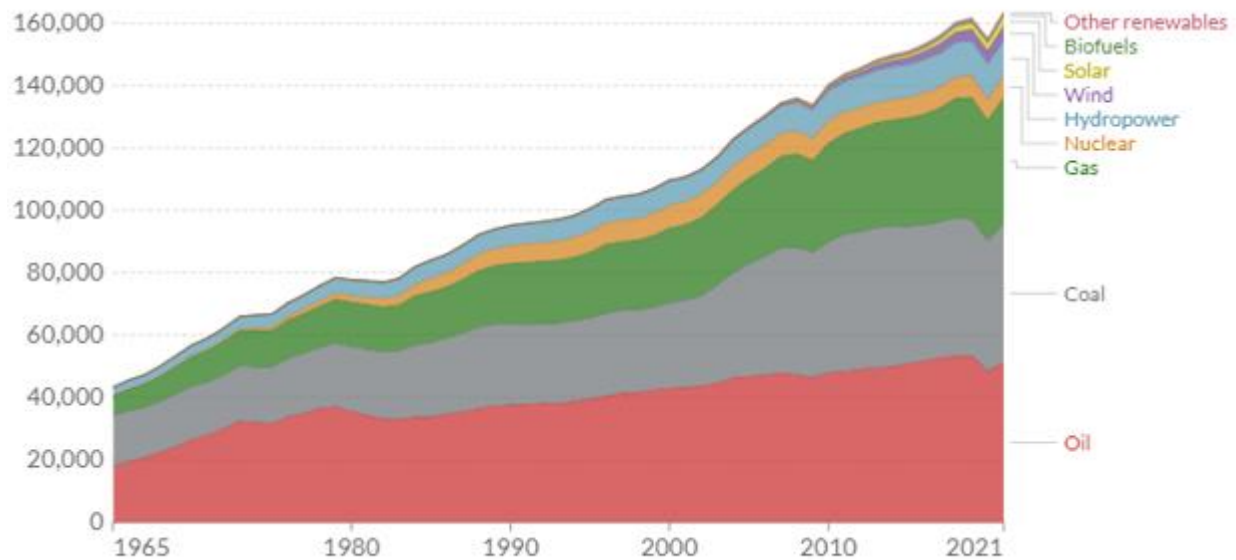


Figure 1-1: Global energy consumption by source. The unit measure for primary energy consumption is terawatt-hours (TWh) (Ritchie *et al.*, 2020).

1.2.3 National energy supply

The South African (SA) energy supply is also dominated by fossil fuels, which constituted 88.9% of the total energy supply, followed by nuclear and renewables with 5.6% and 5.5%, respectively. This is summarized in Figure 1-2 (Akinbami *et al.*, 2021: 5078).

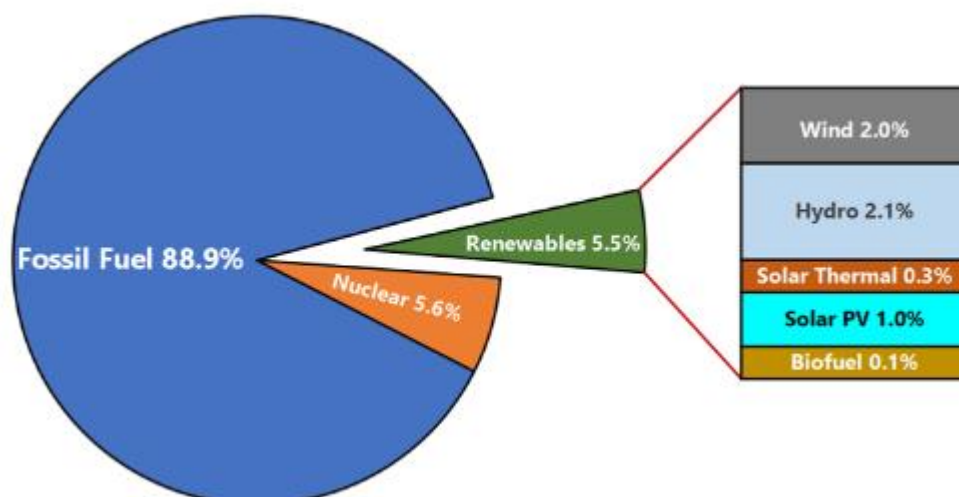


Figure 1-2: Total energy distribution in SA, 2016 (Akinbami *et al.*, 2021: 5078).

1.2.4 Fossil fuel impacts

The burning of fossil fuels causes adverse environmental impacts. Air pollution, acid rain and greenhouse effects are some of the environmental impacts caused by the production and consumption of fossil fuels (Sahin, 2004:503). According to Dincer and Acar (2015:585), 99.5% of global Green House Gas (GHG) emissions are caused by fossil fuel combustion, a likely contributor to global warming (Manieniyan *et al.*, 2009:3; Akinbami *et al.*, 2021:5077). A study by Akinbami *et al.* (2021:5078) also indicates that SA is the largest CO₂ and GHG emitter in Africa and the 14th largest CO₂ emitter globally. This is mainly attributed to its high dependence on electricity generated from coal.

1.3 Energy use in the mining industry

Energy plays a vital role in the economy of the mining industry. Despite the economic role it plays in the country, this industry is recognised as one of the most energy-intensive in the country and worldwide (Pretorius & Xia, ND:16-17). Its practices are mostly unsustainable and highly dependent on fossil fuels for use in many activities. Diesel, heavy oil fuels, and coal are some of the fossil fuels highly consumed by the industry (Igogo *et al.*, 2020:9).

The production and consumption of fossil-based energy in mining cause economic, social and environmental impacts such as depletion of natural resources, GHG and CO₂ emissions (Kusi-Sarpong, 2015:2; Dincer & Acar, 2015: 586; Hilson, 2001:27). To address the problems of overreliance on fossil fuels, increased energy demand and mitigate against the negative environmental, economic, and social impacts associated with production and consumption of fossil fuel energy, a transition to sustainable energy solutions such as clean energy is required to ensure a positive step towards environmental sustainability (Dincer & Acar, 2015: 586).

Economic and environmental factors mainly drive implementation of clean energy solutions by mining companies. According to Ryan (2014, 305-306), this is mostly driven by high electricity costs, the need to reduce reliance on electricity and to diversify energy sources. Other key drivers identified by this author include carbon tax liabilities and energy consumption and emission reduction targets that the companies have set for themselves. Also, economic feasibility and reliability are additional factors influencing the decisions of mining companies to invest in alternative energy sources.

Votteler and Brent (2016:1) also highlighted that the challenges of carbon emissions, high electricity costs, unreliable grid supply and other drivers mentioned influence the investigation of alternative electricity sources to diversify electricity sources to reduce electricity costs, reduce dependence on grid supply and reduce the organisation's carbon footprint. The positive aspect is the advancement of technological and economic development of clean energy sources for electricity generation in recent years, providing opportunities for South African mining houses to diversify electricity sources.

Another key reason for implementing clean energy by South Africa's mining companies, as highlighted by PWC (2020:16), is uncertainties regarding power availability and affordability. These challenges affecting the mining sector are expected to persist for some time, putting the sector under pressure to consider other options and transition to alternative energy sources such as self-generation and clean energy.

High costs of grid connection and the remote location of some mining operations where access to grid connection is not possible, are compelled to transition to self-generation to power their operations. However, of advantage is the availability of large, underutilized land by the mining sites suitable for renewable energy generation such as solar and wind (PWC, 2020: 16).

1.3.1 Energy use in the platinum mining industry

For platinum producers, another motivation to implement clean energy solutions are the need to reduce carbon emissions released by the platinum sector. The sustainability reports indicate the majority of platinum producers are highly dependent on electricity as a source of energy, consuming more than 70% electricity in their energy mix. This is also supported by Glaister and Mudd (2010:449), who is of the view that opportunities for the adoption of clean energy technologies exist for the platinum mining sector to reduce the GHG emissions. These platinum producers are dependent on electricity mainly sourced from the national utility supplier Eskom. This suggests that carbon emissions associated with platinum mining activities are high compared to other mining sectors, comprising 70% of energy (Ryan, 2014:299-303).

The main driver to implementing clean energy solutions by AAP, a case study selected for this research, is the desire to reduce carbon emissions from its activities. According to Figure 1-3, AAP2 (2021:58-60) reported an increase in total energy consumption and GHG emissions from 2022. In 2021, the organisation reported an increase in production, leading to an increase in the 2021 energy consumption of 20.81 million GJ, which was higher than the 2020 total consumption of 18 million GJ. In addition, 4.52 million tonnes of carbon emissions were generated directly from operational activities and carbon emissions incurred because of using electricity purchased by

Eskom for operational activities and were recorded as high, compared to 3.94 million tonnes CO₂ reported in 2020.

AAP recognises that these emissions contribute to climate change, which compels sustainable energy management. The platinum producer plans to achieve this through various measures such as optimising opportunities for its products to support clean and sustainable processes, reducing energy consumption and intensity and optimising renewable energy use (AAP2, 2021:58).

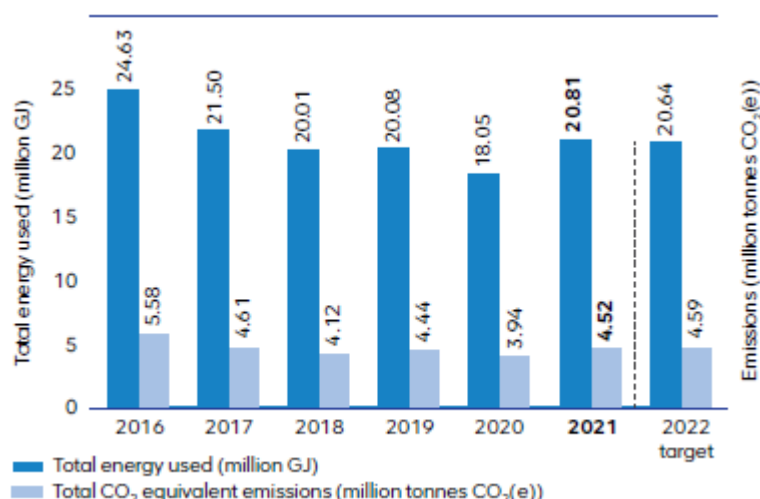


Figure 1-3: AAP energy consumption and GHG emissions (AAP2, 2021:60).

Another critical driver identified for AAP is the increase in carbon tax in South Africa and its implications on business costs. The AAP operations are liable to carbon tax because of direct CO₂ emissions emanating from fossil fuel use such as coal combustion. In this respect, the organisation is investing in solutions such as renewables and other initiatives to reduce reliance on electricity supplied by Eskom and off-set carbon tax liabilities (AAP2, 2021:58). Lastly, uncertainties of electricity supply and reliability are one of the risks experienced by the South African AAP operations. This is one of the motives for adopting alternative clean energy to substitute electricity supplied from the grid.

A transition to clean energy solutions by the mining companies can play a significant role in shaping the industry's future and reducing environmental impacts such as carbon emissions (Abbaspour & Abbaspour, 2022:2570). Sustainable mining practices are needed to reduce GHG emissions to prevent potential future energy shortages and reduce potential climate change risks. For platinum producers, sustainable energy management must form part of their business's key strategies (Ryan, 2014:299-306). Because the mining industry is one of the highest energy

consumers worldwide, they are expected to play a leading role in implementing sustainable practices, reduce dependence on energy derived from fossil fuels and transition to clean energy solutions (Igogo *et al.*, 2020:1).

To support the national policies and strategies on clean energy and investigate the apparent delay in implementing clean energy initiatives, this research aims to investigate the opportunities and challenges for implementing such initiatives in the mining industry using a platinum mining case study.

Clean energy will be defined in Chapter 2, followed by drivers for clean energy implementation and opportunities for implementing clean energy initiatives.

1.4 Rationale for the Study

This research aims to address a gap in the literature on the barriers that hinder the implementation of clean energy by South African platinum mines. This research also aims to prompt mining companies to be open mind on their assumptions regarding clean energy adoption, the associated benefits and long-term business sustainability. In addition, to ensure the credibility of the research outcomes, the researcher will obtain views from professionals with knowledge and experience in the energy management field.

A shift in energy management by the global industry is required to ensure sustainability. One way of achieving this is by substituting traditional fossil fuel-based technologies with sustainable clean energy innovations (Strupeit & Palm, 2015). As mentioned in section 1.2.4, using fossil fuels cause environmental impacts such as air pollution, acid rain and greenhouse gas effects. Fossil fuels are also limited in their availability, which motivates industries to use alternative sustainable energy sources (Sahin, 2004:503). Ryan (2014:300) reported that the environmental challenges related to climate change need to be addressed to ensure sustainability of the platinum sector. Various clean energy solutions are available for adoption by the mining industry to address the challenges of sustainability, climate change, energy security and high energy prices. The available options include energy efficiency, energy recovery, renewable energy, and carbon capture. The concept of clean energy is driven by factors such as climate change, the finite nature of fossil fuels, increase in energy demand, environmental degradation, job creation and others (Angwe, 2014:1). Clean energy sources are thereby recommended to effectively address the energy-related challenges facing the industry (Igogo *et al.*, 2020:1).

Despite the available options of clean energy, Igogo *et al.* (2021:11) are of the view that clean energy options are not widely explored across the mining sector. Hamilton (2016) argues that the adoption of clean energy initiatives by mining companies is low. In this respect, Votteler and Brent

(2016:17) realised that there is a need for further research in this field to enable mining companies to have access to information allowing them to make informed decisions. This research therefore aims at providing mining companies with concepts and benefits of clean energy and how it can contribute to addressing their specific needs and challenges.

Furthermore, to support the adoption of clean energy, the Kyoto Protocol, an international treaty adopted in December 1997, established mandatory targets for adoption by global countries to support the reduction of GHG emissions and fossil fuel consumption (Goldemberg *et al.*, 2005:2189).

To promote good energy management and assist the country's transition to a low carbon economy, the government adopted policies such as White Papers on Energy Policy (1998), Renewable Energy (2003), the National Climate Change Response (2011), an Integrated Energy Plan (2003), a National Integrated Resource Plan (2003/2004) and a National Energy Efficiency Strategy (2009). These policies, plans and strategies provide opportunities for various industries to improve energy efficiency and ensure responsible energy management (Angwe, 2014:3).

Most investors and companies aspire to achieve environmental, social and governance (ESG) business strategies (PWC, 2020: 16-19). To ensure businesses remain resilient in the volatile market environment, PWC is of the view that businesses are pressured to incorporate ESG issues into their strategies and decision making. Furthermore, the expectation from interested stakeholders is for businesses to also demonstrate transparency on ESG strategies and issues, including the development of energy transition strategies. In the context of mining, some of the key ESG focus areas identified by PWC that should be considered by this industry are climate related risks. According to PWC, this can enhance their social license to operate and contribute to a just transition economy.

To further expand on this, measuring impact relates to the ability of a business to measure and quantify the impacts associated with its activities and align them with the goals and strategies of other stakeholder expectations. This strategy will allow companies better understand the impact of their activities on the economy, society and the environment (PWC, 2020: 16-19). Climate risks, on the other hand, entail setting up systems to analyse the impacts associated with the climate change risks identifying necessary measures to address climate change. For example, some SA platinum mining companies have set goals to reduce GHG emissions improving energy efficiency. To mitigate against climate change risks, mining companies are encouraged to align their business strategies to applicable national policies and programmes on climate change. Furthermore, to mitigate against the effects of climate change on their businesses, these

companies are encouraged to invest in clean energy systems, including renewable energy, energy efficiency and low-carbon products and services and related (PWC, 2020: 16-19).

1.5 Research aim and objectives

Building on the problem statement above, this research aims to determine what barriers and opportunities may influence the implementation of clean energy initiatives in platinum mining.

The research aim will be addressed through the following objectives:

- Identifying and describing existing or proposed clean energy initiatives in the platinum mining case study (Anglo American Platinum (AAP)).
- Identifying and characterising the barriers to implementing clean energy initiatives in platinum mining.
- Identifying and evaluating opportunities for implementing clean energy initiatives in platinum mining.

1.6 Scope of the research

This research will use Anglo American Platinum operations as a case study. The scope is limited to AAP mining and process operations in Southern Africa and Zimbabwe, excluding all joint venture operations. All mining and process operations, concentrators, smelting and refineries, will be included. AAP was chosen as a case study due to its position as a world-class platinum producer, which has already implemented clean energy initiatives and investigated opportunities to improve and transition to cleaner technologies while improving environmental performance (AAP5, 2020).

1.7 Potential contribution of the research

The outcome of this research is expected to benefit other mining operations with similar activities wishing to adopt clean energy initiatives. Knowledge of the barriers that effect the implementation of clean energy initiatives will allow mining companies to make informed decisions. Furthermore, the research will provide mining companies with concepts and benefits of implementing clean energy systems and how they can contribute to addressing their specific needs and challenges.

However, it is acknowledged that the mining industry may not be homogenous, hence there's an opportunity for further research to explore the degree of uniformity and determine if the results of this research can be applicable to various mining sectors.

1.8 Structure and outline of the dissertation

This dissertation is structured into the following chapters:

Chapter 1: This section provides the structure and outline of the whole dissertation. It covers the introduction, background, problem statement and rationale for the research study, research aim and objectives, scope of research, limitations, and assumptions.

Chapter 2: This section covers the literature review that connects the research aim and objectives. This chapter summarises the literature review on clean energy initiatives, government, sectoral and corporate policies, and strategies that guide and inform the transition to clean energy within platinum mining, existing or proposed clean energy initiatives in the platinum mining case study, as well as challenges and opportunities related to the implementation of clean energy.

Chapter 3: This section outlines the methodology used in the research study. It covers the research design and data collection through document analysis and semi-structured interviews, and analysis of collected data.

Chapter 4: This chapter covers the analysis and interpretation of data collected in Chapter 3.

Chapter 5: This section summarises the research outcome's conclusion and recommendations.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter focuses on the review of literature pertaining to barriers and opportunities for implementing clean energy initiatives in the platinum mining industry. The review initially focuses on literature related to energy use in the mining sector, before reviewing the literature related to the concept of clean energy and its implementation status in the mining industry. The chapter then reviews the literature about generic drivers and benefits of implementing clean energy initiatives, as well as opportunities for integrating clean energy in mining. It also covers a review of the literature related to legal and corporate frameworks that guide the implementation of clean energy initiatives.

2.2 Overview of energy in the mining industry

The mining industry plays a significant role in the economic and social development of many countries (Levesque, 2015:1). Industries such as manufacturing, energy, construction, transportation and many other are mainly dependent on mining for supply of raw materials needed in their businesses (Igogo *et al.*, 2021:1).

In the mining context, different energy sources are used across the mining value chain (Levesque, 2015:4). According to Igogo *et al.* (2021:5), the mining process flow is energy intensive and generally comprises of processes such as ground drilling and blasting, excavation, loading, transportation, processing, smelting, and refining, all of which require energy. Sustainability reports indicate that most of the platinum producers are highly dependent on energy, mainly in the form of electricity, consuming more than 70% electricity in their energy mix (Ryan, 2014:299).

Despite its positive contribution to the economy, the mining industry is regarded as one of the highest consumers of energy in the world (Pretorius & Xia, ND:16-17; Ryan, 2014:299). According to the 2021 South African Energy Sector Report, the chemical and petrochemical industries are the highest energy consumers in the country, followed by iron and steel and mining and quarrying, which comprises 13% and 10% of the total energy demand, respectively. Of the total energy of 183 435TJ consumed by the South African mining industry, electricity accounts for 58%, followed by petroleum products and coal at 38% and 4%, respectively (Ratshomo & Nembahe, 2021:21-23). A breakdown of the country's total energy demand per industry is shown in Figure 2-1.

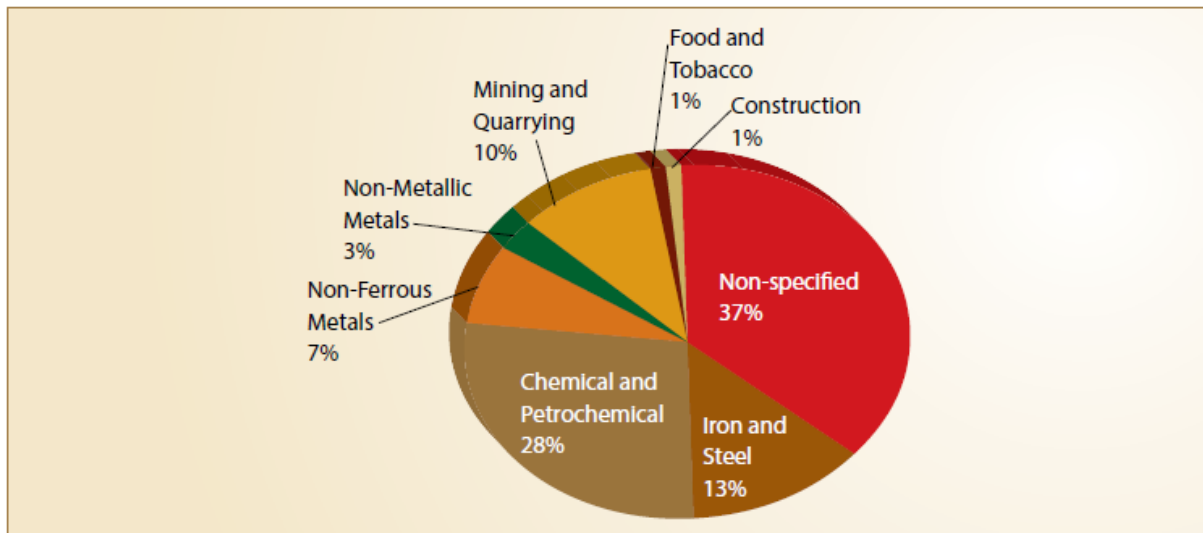


Figure 2-1: SA's energy distribution per industry (Ratshomo & Nembahe, 2021:22).

Igogo *et al.* (2021:1) is of the view that the global increase in energy demand is expected to persist due to increasing mineral demand and declining mineral ore grades. Ryan (2014:300) further adds, physical limitations on mining operation, socio economic factors, industrial and energy policy development, and the sustainability dimensions of mining are the barriers to improving energy management in the industry. In SA, one of the physical limitations faced by platinum mining are the geothermal gradient of the mine location and high mean rock temperatures which require ventilation and refrigeration that consumes high electricity. The type of ore grades also has an impact on the amount of energy required for certain activities, for example, mines with low grade ores require intense energy for crushing and milling activities. The other energy intensive activities identified by (Ryan, 2014:300) is smelting of chrome. Furthermore, socio-economic challenges are one of the energy management challenges facing the industry. Unfortunately, these labour and energy issues contribute to a decline in country's credit rating which subsequently affect investor confidence.

Various opportunities are available that mining companies can implement to address the energy-related challenges. Clean energy solutions such as renewable energy and energy efficiency are examples of non-fossil fuel energy options that can be adopted by various industries including mining (PAGE, 2017). These low carbon solutions have environmental, economic, and social benefits (Winkler *et al.*, 2005:36; Manieniyen *et al.*, 2009:3-4; Ryan, 2014:299).

Furthermore, Ward (2002:3-5) believes South Africa has one of the best solar resources in the world which provides many opportunities for solar energy use by many industries. However, a

combination of clean energy solutions is believed to be effective in addressing energy-related challenges facing the mining industry (Igogo *et al.*, 2020:1).

To realise the importance of clean energy implementation in South Africa, the government has passed policies and strategies to transition to a low carbon economy (Ratshomo & Nembahe, 2019:2; Owusu-Mante, 2020:1). Through the National Development Plan (NDP), government committed South Africa to reduce emissions and pollution by the year 2030. While promoting environmental sustainability, the country is also committed to transition to a low carbon economy, by increasing the contribution of renewable energy to the national energy mixture by the year 2030 (Ratshomo & Nembahe, 2019:2; Owusu-Mante, 2020:1).

It is evident from literature that this industry is one of the highest users of energy in the country as well as globally, therefore, a shift in energy management is imperative.

2.3 Clean energy

The use of clean energy sources is becoming widely common in industries and households compared to the traditional energy sources like fossil fuels. Clean energy sources play a significant role in achieving the strategies set out by the Sustainable Development Goals (SDG), Paris Agreement and other international treaties. This type of energy source is preferred because they are effective and environmentally friendly (Abbaspour & Abbaspour, 2022:569; Sahin, 2004:502). Industries experiencing environmental challenges such as greenhouse gas emissions can adopt clean energy initiatives to reduce emissions. Abbaspour & Abbaspour (2022:569) reported that the adoption of clean energy initiatives results in economic benefits, such as reduced cost of electricity generation compared to fossil fuel energy sources. In addition to the economic and environmental benefits, clean energy also has social benefits (DMRE, 2021:28). According to Dincer and Acar (2015:585-586), clean energy is a solution to achieving a sustainable future and in addressing challenges of increasing energy demands, dependence on fossil fuels and environmental degradation. Other benefits include a reduction in environmental pollution such as emissions, low energy input and increased system efficiencies (Dincer & Acar, 2015:585-586).

2.3.1 Clean energy defined

Clean energy refers to energy that comes from natural renewable sources or processes that are constantly replenished ([NRDC](#), 2023; Sahin, 2004:502). Solar, wind, hydropower, biomass, ocean and geothermal are some of the examples of renewable energy sources. Renewable energy sources are known to replenish through natural processes over short periods of time and do not release greenhouse gases and other harmful pollutants into the atmosphere when used (Abbasour & Abbaspour, 2022:569 & Iberdrola S.A., 2022). These renewable energy sources can

be harnessed through technology and other processes for use in heating, transportation, lighting and many other activities and processes ([NRDC](#), 2023). For example, solar energy can be captured through solar or photovoltaic (PV) cells to directly convert sunlight into electricity while wind energy can be harnessed by using wind turbines to generate wind energy (Sahin, 2004: 510; [NRDC](#), 2023).

In mining, clean energy can be integrated into various processes and activities such as extraction, processing, and refining. These activities, amongst others, include transportation, drilling, digging, loading, and electricity generation for the mining operations that are not connected to the grid (Igogo *et al.*, 2021:11).

Clean energy also refers to the use of technologies to improve energy efficiency, recover and store energy and capture pollutants such as carbon and others (Igogo *et al.*, 2021:1; NC Sustainable Energy Association, 2022; TWI, 2022). Unlike traditional energy sources such as fossil fuels, clean energy sources are favourable due to their environmental-friendly features and are known to play a significant role in environmental conservation and sustainable energy management (Abbasour & Abbaspour, 2022:569; Iberdrola S.A, 2022; Dincer *et al.*, 2015: v).

2.3.2 Global context of clean energy implementation in the mining industry

Mining is an energy intensive industry that is heavily dependent on fossil fuels as a source of energy (Levesque, 2015:41). The ever-increasing energy costs continue to become an issue faced by this industry (Zharan, 2016:1). Implementation of clean energy initiatives to substitute fossil energy sources is a challenge for many industries. Studies have shown that, increasing energy demand, fluctuating energy costs and ease of implementation are the reason behind the slow implementation (Zharan, 2016:1; Ryan, 2014:300; Abbaspour & Abbaspour, 2022:570). This statement is also supported by Igogo *et al.* (2020:3) who is of the opinion that energy is one of the highest expenses incurred by the mining industry, constituting an average of 15% - 40% of total operating costs.

Despite the technical and economic challenges faced by mining, this industry has in the last two decades deployed clean energy initiatives such as renewable energy (Abbaspour & Abbaspour (2022:570-571). In their research, these authors discovered that, 42 mining companies across the globe installed renewable energy technologies during the period 2003 to 2020.

The observation from the study conducted by Abbaspour and Abbaspour (2022:571) demonstrates that a combination of clean energy solutions was deployed, and in some cases a hybrid of technologies was adopted. The type of clean energy solutions installed by mining companies varied from geothermal, concentrated photovoltaics (CPV), hydropower system,

photovoltaic system (PV), battery storage, wind, gas, solar thermal, and concentrated solar power (CSP). The most common clean energy systems installed was found to be PV, wind, and battery storage.

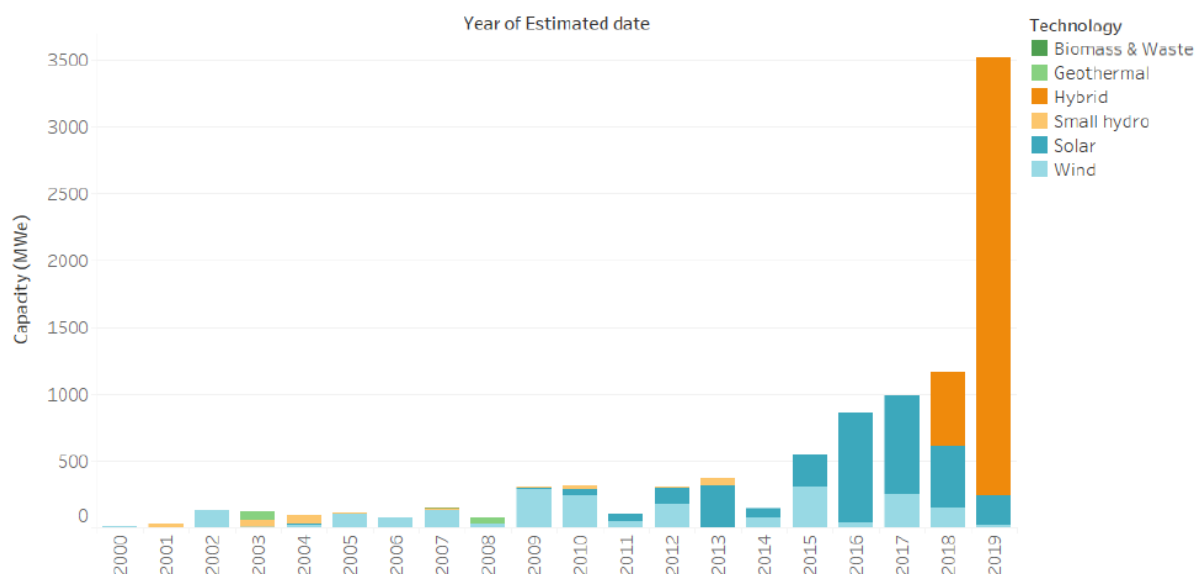


Figure 2-2: State of renewable energy implementation by global mining companies (Igogo *et al.*, 2020:8).

Figure 2-2 illustrates renewable energy systems implemented by mining companies across the world. The increase in renewable energy implementation was observed in 2019. The dominating systems adopted was hybrids i.e., a combination of other technologies such as wind, solar, energy storage, and others. Solar energy was observed as the highest energy technology adopted. The increase in the uptake of solar was observed in 2016, followed by wind (Igogo *et al.*, 2020:8).

2.3.3 State of clean energy implementation in SA mining industry

As previously mentioned, the mining industry is still reliant heavily on energy derived from fossil fuels, constituting 88.9% of the country's total energy supply, followed by nuclear and renewables with 5.6% and 5.5%, respectively (Akinbami *et al.*, (2021: 5078). The mining industry is one of the highest consumers of energy, mainly in the form of electricity and petroleum products (Ratshomo & Nembahane, 2021:23).

Unplanned power outages, high energy tariffs, energy shortages, ageing infrastructure and low investment in power infrastructure are some of the issues experienced by the SA energy industry,

affecting many other sectors in turn (Pollet *et al.*, 2015:16685). The observation from Ryan (2014:299) indicates that, increasing energy costs, future energy supply and climate change concerns and GHG emission targets are the motivation behind sustainable energy management in the country.

To address these challenges and reduce the load on the current grid, the SA government has rolled out and implemented several clean energy programmes and initiatives such as off-grid renewable energy solutions as well as energy sourced from hydrogen, oil and gas. An interest in renewable energy in the country started increasing in 2013, where most of the major construction started to install renewable energy technologies (Pollet *et al.*, 2015:16685). According to Pollet *et al.* (2015:16687), SA is recognised as one of the global leaders in renewable energy development. The favourable climate conditions including the vast availability of wind, solar and land resources present an opportunity for implementation of clean energy in the country (Gangazhe, 2016:8-10; Mail & Guardian, 2021).

Ryan (2014:300-302), who investigated the energy management of major South African platinum producers between the years 2008 and 2014, reported that the renewable energy market has been developing successfully since the establishment of the large-scale renewable energy independent power producer procurement programme (REIPPPP), a programme launched by the South African government in 2011. The main purpose of the REIPPPP is to supplement the national grid through private sector investment in renewable energy technologies such as wind, biomass, biogas, solar, photovoltaic (PV) and others (Pollet *et al.*, 2015:16687). Ryan (2014:300-302) notes, since the successful launch of this programme, the country has seen an increase in implementation of renewable energy projects and has since received attention from foreign nations who took interest in renewable energy investment. However, Ryan acknowledges that investment in clean energy development by South African platinum mining operations is lagging.

Ryan also discovered that most of the energy saving that were achieved were through energy efficiency initiatives. The author believes that cost benefits and the ease of implementation were the driving force behind these initiatives (Ryan, 2014:300-302).

2.4 Drivers for clean energy implementation

Previous studies reveal that various factors drive the motive towards the transition to clean energy by different sectors. Economic, environmental, and societal factors faced by the mining sector motivate a reconsideration of energy generation and consumption practices (Igogo *et al.*, 2021:1). These factors are said to influence the popularity of clean energy sources and delay its implementation (Abbaspour & Abbaspour, 2022: 577; Ryan, 2014:299).

In addition, the industrial revolution has brought about an increase in the use of non-clean energy resources. Because of the increased energy demand, these resources have become scarce and costly, raising concerns about energy security worldwide (von Hatzfeldt, 2013:201; Ward, 2002:3).

Research identified the main universal drivers influencing the decision to invest in alternative clean energy sources. They are summarised as global warming, dependency on finite resources, environmental impacts, energy security and energy demand and population growth (Rand & Dell, 2004:23; Ward, 2002:5; Aminjonov, 2021:2398).

In SA, one of the significant challenges that motivate the move towards clean energy is increasing electricity prices and poor reliability due to insufficient capacity during peak times, leading to blackouts. Mining is one of the industries highly affected by frequent electricity cuts (Hamilton, 2016). Pollet *et al.* (2015:16686) are of the view that this energy crisis is caused by failure to invest in the electricity sector properly.

Strazzabosco (2022:135) and Abbaspour and Abbaspour (2022:570), who looked at the contribution of clean energy systems in global mining companies, reported that the mining industry is energy intensive and relies mostly on electricity sourced from the grid. This statement is supported by Ryan (2014), who conducted a study investigating energy management approaches adopted by the major platinum houses in South Africa to mitigate the impact of rising electricity prices. These authors also noted that the mining industry is one of the highest GHG emitters that need to shift to alternative energy sources, such as clean energy, to ease the burden on the grid power capacity and transition to a low carbon economy. Investor and stakeholder expectations are another driver for implementing clean energy in the mining industry. Suppliers are pressurised to demonstrate sustainability across the value chain in relation to energy generation and consumption (Igogo *et al.*, 2020:3). One way of achieving this requirement is through the GHG emissions reduction and energy efficiency targets that most platinum mining companies have set for themselves. This also includes options to reduce the carbon tax cost liability. The social commitments for greenhouse gas emissions are another motivation for implementing clean energy solutions (Ryan, 2014:305).

According to Ryan (2014:299), sustainable energy management is driven by economic and environmental factors such as cost saving and reduction of greenhouse gas emissions. These companies have also established strategies to diversify energy sources to reduce reliance on energy derived from fossil fuels. Ryan (2014:299) also highlights that most platinum mining companies have identified the challenges of energy supply and reliability and high energy cost as business risks.

In the context of South African mining, Ryan (2014:299-305) identified three main drivers for implementing clean energy in the South African Platinum Mining industry. They are increasing competitiveness, increasing profitability, and increasing productivity. Environmental impacts, climate change risks, high electricity costs, future energy demands, voluntary emission reduction and energy use targets and economic feasibility and reliability are other important drivers influencing decisions to invest in alternative energy sources identified by Ryan.

The upcoming sub-section will further unpack the main drivers behind clean energy implementation by the mining sector.

2.4.1 Climate change risk

The National Climate Change Response White Paper defines Climate Change as the *“trend of changes in the earth’s general weather conditions as a result of an average rise in the temperature of the earth’s surface, often referred to as global warming”* (Smith, 2013:48; RSA1, 2011:1). Human activities together with other natural causes have over time, contributed to the climate change (Leggett, 2020:1). Activities such as burning of fossil fuels cause emission of harmful gases, which get trapped in the atmosphere, causing a greenhouse effect. These GHGs cause rising air temperatures near the planet’s surface, causing global climate change. This can be mitigated by putting measures in place to reduce emission of GHGs in the atmosphere, ultimately reduce the adverse effect of climate change on the environment (UN, 2006:16).

Environmental challenges, because of climate change need to be considered to secure the future sustainability of the platinum sector. The impact of climate change can negatively affect mining and operations through disturbances to infrastructure, changes in the supply chains and distribution routes, impacts on workers’ health and safety conditions, challenges to environmental management and mitigation, increased employee and community expectations, and restrictions on exploration and future growth (Ryan, 2014: 306).

2.4.2 Greenhouse gas emissions

Another driving factor towards the implementation of clean energy by the platinum producers is a need to reduce carbon emissions released by the platinum sector. Ryan reported that platinum producers are dependent on electricity sourced from Eskom. This suggests carbon emissions associated with platinum mining activities are high compared to other mining sectors, comprising 70% of energy (Ryan, 2014:303). Motivation to implement clean energy sources such as renewables by the platinum sector is not only driven by high electricity costs, environmental challenges, tax liability and risk but also by emission reduction and energy use targets that the companies have set for themselves and to enhance the companies’ licence/s to operate and

achieve compliance to environmental management and social commitments (Igogo *et al.*, 2021:1; Ryan, 2014: 300-305). This sector is further pressurised by stakeholders' expectations to demonstrate sustainability across the value chain regarding energy generation and consumption (Igogo *et al.*, 2020:3).

2.4.3 Energy security and demand

Mining is an energy-intensive industry that is heavily dependent on fossil fuels as a source of energy for use in their activities (Levesque, 2015:41). Fossil fuels are finite, making it difficult to keep up with the increasing energy demands (Dincer & Acar, 2015:585). This statement is supported by Ward (2002:3), who is of the view that the continuous use of fossil fuels results in depletion of natural resources, damaging the environment in the process. He further adds there is no balance between the supply of energy and demand in the global environment and the increase in energy demand continues to grow. This is exacerbated by population growth, coupled with urbanization and improved living standards (Al-Badia & AlMubarak, 2019:490).

Another issue is that fossil fuel reserves are now less accessible, and the available ones are quickly consumed, resulting in increasing costs of available reserves. Even though fossil fuels harm the environment, many industrialised countries still depend on this type of non-renewable energy to keep their economies running.

There is a high demand for energy in the mining industry. Most mining operations run throughout the clock and, as a result, require constant energy supply, which can be supplemented by clean energy sources (Igogo *et al.*, 2021:8).

Unequal energy distribution is a global concern, with energy resources concentrated in certain places (Ward, 2002:5; Goldemberg, 2005:2186-2187). The observation by Goldemberg (2005: 2185) indicates the distribution of energy is unequal among developed and undeveloped countries, with some countries consuming more than others. Developing countries are more advantaged, owning two-thirds of the world's fossil fuel reserves. Compared to other continents, Africa is less advantaged and has fewer fossil fuel reserves.

The type of energy resource available differs per country and geographical area. For example, solar energy is mostly prevalent in North Africa and North America. Hydropower energy is mainly found in mountainous environments where dams are constructed next to a natural flow of moving water, such as the river. Wind energy, on the other hand, is primarily installed in areas with high latitudes in the northern and southern hemispheres (Ward, 2005:5).

2.4.4 High electricity costs

The mining sector is one of the highest users of electricity in the country, accounting 58% of all the energy available to the sector in 2018 (Ratshomo & Nembahe, 2021:23). Mining operations require significant, reliable, and constant electricity supply to run the production processes (Igogo *et al.*, 2021:8). The source of electricity supply is mainly through on-site diesel generators and grid supply by Eskom (Votteler & Brent, 2016:1). The most common uses of electricity in the mining processes include refrigeration, ventilation, pumping and cooling (Altman *et al.*, 2008:44-45).

Electricity is regarded as a major component of the energy mix in the platinum sector, with the mineral processing and beneficiation stages of the production being the most energy-intensive (Votteler & Brent, 2016:2). According to these authors, electricity costs of a typical mining organisation comprise more than 10% of the total operating cost of a mine.

The South African mining corporation has seen a significant increase in electricity costs. DMRE (2021:6) reported that the increased electricity costs have a negative impact on mining operations. On the other hand, Votteler and Brent (2016:1) reported that rising electricity costs will negatively impact on the global competitiveness of these companies. Moreover, the unreliable grid supply and carbon emissions management also affect the possible future development of these companies.

Ryan (2014:303-304) is of the view that high electricity costs are one of the motivations to clean energy implementation by the platinum mining sector. In addition, increasing electricity costs is one of the business risks faced by this sector, which negatively influences the operating costs and energy intensity across the value chain. These electricity costs also result in extension of costs to downstream activities, which in turn affects the economic aspects related to production and profitability of the organisation.

Furthermore, Ryan (2014:303) argues that reliance on electricity suggests activities related to platinum production that contribute to high carbon emissions, which in turn give rise to an increase in carbon tax liabilities. The carbon emissions related to platinum mining, as opposed to other mining companies, are predominantly high, comprising approximately 70% of energy. The use of energy, such as electricity by this sector, is associated with high carbon tax cost implications, which will intensify the business costs associated with electricity consumption. In this regard, mining companies reconsider the shift towards alternative clean energy technologies such as renewables to reduce reliance on electricity supplied by the national utility supplier Eskom, subsequently off-setting carbon tax liabilities. Ryan (2014) also suggests that a reduction in

electricity use by industries will result in business cost savings and reduction of emissions. Companies can adopt the fiscal approach in a form of carbon credits as an incentive for implementing clean energy initiative such as efficiency projects and renewable energy.

According to Votteler and Brent (2016:1), the challenges facing this sector warrant for an investigation of alternative sources of electricity, such as renewables. This is expected to result in electricity costs reduction, create a sense of independence and reduce the carbon footprint of their operations. In addition, DMRE (2021:10) also encourages the mining house to explore other electricity generation alternatives, such as self-generation.

2.4.5 Unreliable grid supply

South Africa is experiencing challenges of unreliable electricity supply and frequent electricity cuts, affecting many sectors. Poor reliability due to insufficient capacity during peak times leads to blackouts. Mining is one of the industries that is highly affected by the frequent electricity cuts and unreliable grid supply (Hamilton, 2016; DMRE, 2021:6). As indicated, the platinum sector, which is heavily dependent on electricity sourced from Eskom is equally affected by this electricity crisis. These mining companies require a reliable and constant electricity supply to run their operations (Igogo *et al.*, 2021:8). Power cuts in mining can result in safety concerns and production losses, for example, power cuts can cause loss of ventilation and refrigeration and can result in people being trapped underground. In production, for example, electricity is required to keep the slurry rakes running to prevent thickening, which can cause damage to the rakes. Unfortunately, these uncertainties around power availability are expected to continue for some time into the future. These challenges faced by the mining operations act as a motivation to transition towards self-generation through clean energy solutions (PWC, 2020:24; Altman *et al.*, 2008:85).

Altman *et al.* (2008:8-15) identified several factors that contribute to the electricity crisis facing the country. Insufficient capacity to meet the peak demands is one of the dimensions of the electricity crisis. Another one is the lack of balance between power supply and demand, where the demand is higher than operational capacity. Lastly, the reserve margin between capacity and demand is inadequate to allow routine maintenance to prevent unplanned surges and to cope with unplanned down time. Furthermore, Eskom is experiencing challenges of constant supply of good quantities and quality of coal by suppliers. This electricity crisis calls for sectors to reduce their dependency on electricity supplied by Eskom and introduce alternative off-grid power or co-generation. Igogo *et al.* (2021:8) suggest that the only way to address the electricity challenges and ensure a reliable and uninterrupted supply of electricity is by adopting clean energy.

2.5 Benefits of clean energy implementation

Clean energy resources and their utilization positively contributes to sustainable development (Dincer, 2000:157). In developed and undeveloped countries, transition to clean energy sources can result in environmental, social and economic benefits. In addition, to other countries such as the United Arab Emirates, transition to clean energy sources can also mean gaining international prestige (Aminjonov, 2021:2400).

2.5.1 Environmental benefits

Another rationale behind the transition to clean energy is environmental benefits. Dincer (2000:173) highlights the main environmental problems associated with unsustainable use of energy sources as environmental degradation, stratospheric ozone depletion, and global climate change. In this regard, Dincer (2000) believes the move towards the use of clean energy is crucial. Also, DMRE (2021:27) in South Africa encourages the mining sector to reduce carbon emissions and transition from fossil fuel to low-carbon energy sources.

Sustainable energy practices can provide environmental benefits in both developed and undeveloped countries and across various sectors. To further emphasize this, the World Economic Forum encourages the mining industry to reduce its dependency on fossil fuel use and adopt clean energy systems to decarbonise the industry (DMRE, 2021:28).

2.5.2 Social benefits

Deployment of clean energy sources in both developed and undeveloped countries has a positive impact on the social outlook of the country. Clean energy sources contribute to sustainable development due to socio-economic benefits it brings. Some benefits include opportunities such as jobs and regional and rural development, and a variation in energy supply (Del Rio & Burguillo, 2009:1314). Aminjonov (2021:2400) further emphasizes that adopting clean energy sources create job opportunities. These job opportunities significantly contribute to the overall employment of the economy and bridge the gap of unequal access to energy (Yi, 2014:923; Goldemberg, 2005: 2188). In addition to job creation, other positive social benefits are reduction in environmental damage and emissions, subsequently contributing to reduced health impacts.

2.5.3 Economic benefits

Previous studies conclude that a correlation exists between an increase in the country's energy consumption and GDP growth. The transition to sustainable energy resources is therefore encouraged to realise future economic growth. Deployment of clean energy technologies and

efficient use of energy can generate extra revenue and savings on expenditures (Aminjonov, 2021:2400), thereby presenting an opportunity for mining companies to save costs.

To promote effective energy management and address harmful environmental emissions caused by burning fossil fuels, Levesque (2015:42) suggests imposition of carbon tax on mining companies is a positive move. Carbon tax is a fiscal-based instrument used to influence the behaviour of companies regarding energy management. This financial incentive is offered to companies that demonstrate good energy management. The primary aim of the carbon tax is to promote reduction of air emissions by various industries. In South Africa, a carbon tax on GHG emissions was enforced in June 2019 (DEFF, 2020:x).

2.6 Legal framework supporting the implementation of clean energy initiatives

To promote the implementation of clean energy and address universal concerns of climate change because of emission of GHGs and other harmful gases, command-and-control approaches have been established worldwide. These frameworks are fundamental in the transition to green economy and industrial development (DEFF, 2020:x). International and local frameworks supporting clean energy implementation are established. This section will outline the global and national frameworks in place and the role in driving and supporting the implementation of clean energy.

2.6.1 The role of legal frameworks

Legislative instruments, which can be a form of policies and legal frameworks, play an influential role in adopting and disseminating clean energy (Abdmouleh *et al.*, 2015:251). According to these authors, clear policies and legal frameworks are key in stimulating investor's interest in clean energy increasing their attractiveness. Legislative instruments also provide guaranteed support for the clean energy market. These instruments include, for example, legislative mechanisms that facilitate grid access and regulate the power purchase. They also reported that the complexities of clean energy and associated implementation costs, compared to conventional energy, threaten the financial viability of many clean energy initiatives. Therefore, this demonstrates the important role of legislative instruments in stimulating the clean energy market (Abdmouleh *et al.*, 2015:251).

2.6.2 The global legal framework supporting the implementation of clean energy initiatives

Climate change is a global concern caused by natural causes and unsustainable industrial activities. Activities such as burning harmful substances, cause emission of greenhouse gases which contribute to the earth's climate change (UN, 2006:16). This has led to the establishment

of frameworks in a form of policies, regulations, treaties, and other. These are further unpacked in the following section.

2.6.2.1 United Nations Framework Convention on Climate Change (UNFCCC)

United Nations Framework Convention on Climate Change (UNFCCC) is an international treaty aiming to address climate change. Its primary purpose is to "to stabilize greenhouse gas concentrations in the atmosphere at a level that will prevent dangerous human interference with the climate system, in a time frame which allows ecosystems to adapt naturally and enables sustainable development". Since 1992, this international treaty has been adopted by more than 172 countries (Leggett, 2020:1).

2.6.2.2 Kyoto Protocol & Paris Agreement

The Kyoto Protocol (KP) and the Paris Agreement (PA) are international treaties which are subsidiaries of the UNFCCC (Leggett, 2020:1). Aligning with the goals of sustainable development and poverty eradication, the PA aims to empower and support the global countries in their efforts to address the impacts caused by climate change (UN1, 2016:3). The PA provides an obligation for developed countries to provide financial support to the developing countries in their efforts to address issues of climate change (Leggett, 2020:1).

South Africa has endorsed the PA by embracing the view that economies and societies can develop while reducing adverse impacts on ecological systems (PAGE, 2017:18). The KP was the first subsidiary under the UNFCCC, which came to force in 2005. The KP which was drafted in Kyoto in December 1997, proposed that developed countries reduce their GHG emissions by 5% below their 1990 levels (Leggett, 2020:4; Dell & Rand, 2004:24). In other words, emissions should be reduced to levels that existed before industrialization. It was reported that over 50% of the global emissions originate from industrialized nations (Dell & Rand, 2004:24). Through this treaty, the developed countries are encouraged to reduce consumption of fossil fuels, primarily coal (Dell & Rand, 2004:24).

2.6.3 The South African legal framework supporting the implementation of clean energy initiatives

South African government has heeded the call to the universal crisis of global warming by establishing and adopting frameworks that support climate change mitigation (Smith, 2013:47). Because human and industrial activities result in emission of harmful gases and contribute to the changes in the climate (Leggett, 2020:1), SA has begun to implement measures to incorporate clean energy production into the national grid. These include regulatory instruments that support

the transition to a low-carbon and green economy. This commitment was evident through the ratification of the Paris Agreement and adoption of the 2030 Agenda on Sustainable Development, which was subsequently followed by a series of command-and-control instruments that support the transition to a low-carbon and green economy. The South African Government has passed on laws, policies and strategies such as the *National Energy Act* 34 of 2008, the National Development Plan, the White Paper on Energy Policy, White paper on Renewable Energy, Renewable Energy Independent Power Producer Procurement Programme, National Climate Change Response White Paper, Integrated Energy Plan, National Integrated Resource Plan and the National Energy Efficiency Strategy. These policies aim to improve energy security by introducing different energy sources and increasing capacity using clean energy sources such as renewables. Most policies target energy efficiency and renewable energy, specifically on large-scale projects SEA (2013:11).

This commitment to greening the economy is particularly displayed in the Green Economy Inventory for South Africa (GEISA), which summarizes the country's policy vision and green economy initiative implementation status across various sectors (PAGE, 2017:18). According to the GEISA, the country is progressing in its transition to decarbonizing and greening the economy. Further details on the regulatory frameworks and policies supporting the implementation of clean energy are outlined in this section. The AAP corporate policies and strategies that support the transition to clean energy are also summarised in the upcoming subsections.

2.6.3.1 The National Energy Act (2008)

This Act mainly focused on promoting diversification of energy supply and increasing renewable energy generation in the country. The *National Energy Act* 34 of 2008 mandates to the National Department of Energy. One of the key mandates is for the government to provide support by ensuring that diverse and sustainable energy resources are available at reasonable prices, considering, economic growth, poverty alleviation and environmental factors. In addition, the Act also makes provision for energy planning, increased generation, and consumption of renewable energy (SEA, 2013:4; DMRE1, 2020:20).

2.6.3.2 The National Development Plan (NDP)

The National Development Plan (NDP) is a national policy document that supports the transition to a green economy (DEFF, 2020:54). Through the National Development Plan (NDP), government committed SA to reduce emissions and pollution by the year 2030. While promoting environmental sustainability, the country is also committed to transitioning to a climate-resilient and low-carbon economy by increasing the contribution of clean energy to the national energy

mixture from 11% to 14% by the year 2030. This is anticipated to reduce fossil fuel use from 80% to 15% (Ratshomo & Nembahe, 2019; Owusu-Mante, 2020).

2.6.3.3 The White Paper on Energy Policy

The 1998 South African energy policy was drawn from the White Paper on Energy Policy. The primary objective of the white paper is to provide an overview of the energy sector's contribution to the country's overall Gross Domestic Product (GDP). The other objective is to enhance energy governance, improve access to affordable energy services, address environmental impacts caused by improper management of energy and improve energy security. In addition, the energy policy was supplemented by another White Paper on Renewable Energy, which was established to promote development of renewable and clean energy sources such as solar, wind and wind energy for electricity generation. This policy is orientated on establishing medium term targets. (Winkler *et al*, 2005:28-29; DME, 1998).

2.6.3.4 The White paper on Renewable Energy

The White Paper on Renewable Energy was published in 2003. The paper outlines the government's vision and goals for promoting and implementing renewable energy in the country. While acknowledging that the country relies on energy sourced from fossil fuels to meet its energy demands, through this paper, the government realises the importance of introducing renewable energy sources following a phased approach and strategy. Through this paper, the country was expected to produce 10 000 GWh of renewable energy by 2013. To achieve this target, the government must provide support by means of introducing measures such as command and control and fiscal instruments, building capacity and developing institutional infrastructure and technology. It further requires government to take advantage of the abundant renewable energy sources and develop a sustainable industry (SEA, 2013:4).

2.6.3.5 Renewable Energy Independent Power Producer Procurement Programme

South African Government has successfully integrated renewable energy production into the national grid using private sector investment. This is achieved through the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), which aims at supplementing the country's electricity system with renewable energy solutions such as photovoltaic, concentrated solar power (CSP), wind, biomass, and others (Ratshomo & Nembahe, 2021:19). REIPPPP was established in 2011 and has since progressed in transitioning to renewable energy in the country. Of the total power produced in 2018 by REIPPPP, 10 809 GWh of power, was produced from renewable sources, 60% was dominated by onshore wind power followed by photovoltaic and solar power at 30% and 10%, respectively (DEFF, 2020:20-39).

2.6.3.6 National Climate Change Response White Paper

The National Climate Change Response White Paper was established in response climate change concerns. It provides the short-term, medium-term, and long-term action plan to effectively ensure the transition to a low carbon and society economy while actively ensuring that activities resulting in GHGs are lowered to acceptable levels (Smith, 2013:47-48; RSA1, 2011). The National Climate Change Response White Paper supports the transition to clean energy, promoting the development and growth of renewable energy and energy efficiency initiatives and programmes (DEFF, 2020:11).

2.6.3.7 Integrated Energy Plan

The increase in economic activities is linked with the demand for energy by various sectors countrywide. In this regard, the Integrated Energy Plan (IEP) was drafted to address the imbalances and constraints of energy supply and demand. The IEP provides a guideline of the country's future energy landscape regarding energy infrastructure investments and policy development (DoE, 2016:11).

This is achieved by analysing the current energy consumption trends from various sectors, including mining, and the outcome used to determine the country's future energy requirements. The different types of energy sources and technologies are also analysed through the IEP to meet the energy needs efficiently (DoE, 2016:11-12). The IEP, therefore, supports the implementation of clean energy using command-and-control approaches and programmes (Angwe, 2014:3).

2.6.3.8 National Integrated Resource Plan

The Integrated Resource Plan (IRP) is a national policy document that focusses on addressing the country's energy needs challenges. It is the country's long-term electricity expansion plan introduced in 2011 (Pretorius & Xia, ND:51). Its primary objective is to develop electricity infrastructure in a cost-effective and environmentally sustainable manner (DMRE, 2021:7). In simple terms, it is a roadmap used for planning purposes by the energy sector and investors showing interest in the energy sector (Ratshomo & Nembahe, 2021:10). Parallel to this, the DMRE plans to prioritise the review and update of its regulatory frameworks that will support implementation of clean technologies. They plan to achieve this by creating enabling conditions for the industry to invest in self-generation through diversification of energy sources (DMRE1, 2020:6).

2.6.3.9 National Energy Efficiency Strategy

The 2005 National Energy Efficiency Strategy (NEES), which stems from the White Paper on Energy Policy (1998), supports the reduction of energy consumption through energy efficiency (Angwe, 2014:4). It promotes the development and implementation of energy efficiency initiatives and programmes. This strategy document provides a roadmap for implementation of energy-efficient programmes across various sectors. Since energy efficiency is regarded as a cost-effective and efficient way of using energy, NEES uses this opportunity to explore means of improving the country's energy utilization and reducing its intensity (DoE1, ND:3).

2.6.3.10 Carbon Tax

Carbon tax is a fiscal-based instrument used to influence the behaviour of companies regarding energy management. Igogo *et al.* (2021:4) define carbon tax as one of the enabling policies and regulation that the authority can use to enforce and promote the transition to clean energy by industries. In other words, the industries responsible for direct CO₂ emissions as a result of fossil fuel use are liable for the carbon tax (e.g. combustion of coal) (Ryan 2014: 303; DEFF, 2020:x; Levesque, 2015:42). According to DEFF, carbon tax in South Africa was enforced in June 2019 to promote the reduction of GHG air emissions by industries (DEFF, 2020:x).

Levesque (2015:42) reported that imposing carbon tax on mining companies is a positive step to ensuring good energy management and addressing harmful environmental emissions caused by burning of fossil fuels. Mining companies can achieve this through strict pollution controls and adherence to statutory reporting requirements (Igogo *et al.*, 2021:4).

To offset carbon tax liabilities, Ryan (2014:303) believes mining companies can invest in clean energy solutions to reduce reliance on energy sourced from fossil fuels. For example, carbon tax can be offset through the Clean Development Mechanism (CDM) of the Kyoto Protocol. CDM projects can be in the form of energy efficiency, cogeneration, and renewable energy initiatives by implementing CDM projects, mining companies can be incentivised through carbon credits for reducing emissions.

2.7 Corporate policies and strategies for the transition to clean energy in platinum mining

AAP has developed strategies and policies to respond to climate change concerns. As part of their sustainability goals and to support the Paris Agreement goals, the organisation has launched a climate change policy in 2021. Through this policy, the organisation endeavours to address the causes of climate change and protect its employees, assets, local communities and the

environment against climate change impacts (AAP2:5). The organisation also supports this agreement through established GHG emissions and energy intensity reduction targets.

The organisation endeavours to achieve carbon neutrality by 2040 by reducing carbon emissions generated directly from operational activities and carbon emissions incurred using electricity purchased by Eskom for operational activities across its operations. A carbon neutrality roadmap has been developed in this regard, which includes set targets. The organisation has also appointed a Safety and Sustainability Development committee whose mandate is to manage issues related to climate change within the organisation.

In line with the United Nations (United Nations) Sustainable Development Goals (SDG), AAP has developed a Sustainable Mining Plan (SMP) made up of several stretch goals. The SMP is based on three sustainability pillars, of which one is a commitment to building a healthy environment by creating carbon neutral mines. The SMP includes stretch targets to improve energy efficiency by 30% and a 30% net reduction of GHG emissions by 2030 (AAP6, 2018:11). Coupled with that is the organisation's participation in the Task Force on Climate-related Financial Disclosures (TCFD). TCFD is a framework established by the Financial Stability Board (FSB) in 2015 voluntary assist organizations in disclosing their climate-related impacts, including risks and opportunities. AAP has complied with the TCFD recommendations, which are summarised in the AAP Integrated Annual Reports (AAP3, 2021:30; AAP12:40). In addition, the organisation has also publicised climate-related disclosures through the Sustainability Reports, Integrated Annual Reports and Climate Change Reports (AAP, 12:40).

2.8 Barriers to implementing clean energy initiatives in mining

Previous studies show that several barriers affecting the implementation of clean energy solutions in the mining industry exist. They show that the mining industry has an interest in investing in alternative energy sources however, there are hindrances to achieving this. These barriers, which vary per country or region, can be defined as factors that negatively affect the adoption and implementation of clean energy initiatives and can be categorised as Economical & Financial, Awareness & Information, Behavioural and Political & Regulatory, Technical and Ecological and Geographical (Luthra *et al.*, 2015:763-764; Moorthy *et al.*, 2019:1, Yagoot *et al.*, 2016:478). According to Moorthy *et al.* (2019:1), the most common barriers that influence the deployment of alternative clean energy solutions relate to social, technical, and regulatory barriers.

Meanwhile, Ryan (2014:299-305) conducted a study to assess energy management by platinum mining companies in SA. The revelations from this study concluded that this industry is energy-intensive, especially when it comes to electricity consumption. The author suggested that this

industry invests in alternative energy sources, such as renewables, to supplement electricity supplied by the national utility supplier, Eskom. The author believed this mitigation strategy would, amongst others, reduce electricity costs, which the author highlighted as a challenge faced by this industry. The author also acknowledged that opportunities and efforts to transition to alternative energy sources by this industry were in place however, the implementation was seen to be immature. Increasing competitiveness, profitability and productivity within the industry were identified as the main drivers for the transition to clean energy in the mining sector. Other key factors that affect good energy management in this sector, as described in Section 2.2, are physical limitations on the mining operation, economic development and labour concerns, industrial and energy policy development, and the sustainability aspects of mining (Ryan 2014:230).

Understanding the barriers that hinder the implementation of clean technology provide insights to industries that wish to adopt clean energy initiatives. It can also play an important role in guiding and informing the policy makers responsible for developing and reviewing policies and strategies on sustainable energy and associated technologies (Luthra *et al.*, 2015:763). The following section provides a review of some of the literature on the barriers that hinder the implementation of clean energy initiatives.

2.8.1 Technical barriers

Previous studies identified technical factors as one of the critical barriers that delay the adoption and implementation of clean energy technologies in various sectors (Luthra *et al.*, 2015:762; Moorthy *et al.*, 2019:7). Technical barriers generally refer to the technical performance and reliability of clean energy technologies (Luthra *et al.*, 2015:762). According to Moorthy *et al.* (2019:17), technical barriers prevent clean energy from being efficient and cost-effective.

Technical barriers also involve barriers related to inadequate and intermittent renewable energy resources; inappropriate and inadequate technology design (Yagoot *et al.*, 2016:479). These authors also highlighted that lack of skilled expertise in design and development, manufacturing, installation, operation and maintenance of clean energy technologies are some of the important technical barriers to the successful dissemination of clean energy technologies. Moorthy *et al.* (2019:7) also reported that very little is invested in research and development of clean energy technology by both the private and public sectors. This reluctance prevents clean energy from thriving economically like fossil fuel energy.

2.8.1.1 Intermittency of renewable resources

The intermittency of renewable resources such as solar and wind has been widely identified as a technical complexity that hinders the implementation of clean energy initiatives. Despite the finite nature of renewable energy sources such as wind and solar, they are not consistently available to produce the energy required by many sectors. Wind, solar and biomass energy resources are generally known to have low energy flux compared to traditional energy sources, thus putting clean energy sources at a disadvantage compared to fossil fuel technologies (Yagoot *et al.*, 2016:478-479).

2.8.1.2 Accessibility of spares and equipment

The complexities associated with clean technologies act as a hindrance to the adoption of clean energy initiatives (Luthra *et al.*, 2015:767). According to Moorthy *et al.* (2019:7), ease of access to clean energy technologies may challenge most companies and industries. Furthermore, technological infrastructures, components and spares are mostly purchased from technologically advanced international countries, thus posing logistical challenges for countries that are not technologically advanced. Understanding the operational procedures for clean energy technologies and maintenance thereof is another complication associated with this type of technology (Moorthy *et al.*, 2019:7).

2.8.1.3 Inadequate systems

Technological risks associated with the development of clean energy, such as renewables, are another barrier to investment in research and development of clean energy technologies (Moorthy *et al.*, 2019:7). The author argues that Research and Development (R&D) of renewable energy technologies is still in its infancy, thereby resulting in inadequate systems such as technical standards, guidelines, and procedures. This observation puts fossil fuels in a commercially competitive state compared to clean energy. It was reported that the regulators and other industries are reluctant to invest in R&D while in its development stage because of the technological risks associated with this technology type (Moorthy *et al.*, 2019:7).

2.8.1.4 Poor reliability and inappropriate technology

Inappropriate and inadequate technology design and operation were identified as one of the critical barriers affecting the implementation of clean energy technologies. Yagoot *et al.* (2016:479) argue that the lack of success and unreliability of clean energy technologies affects the implementation of clean energy initiatives.

2.8.1.5 Lack of technical expertise

Inadequate expertise required to design, maintain, and operate clean energy technologies is another barrier to the greater adoption of clean energy initiatives identified by Yagoot *et al.* (2016:479). According to Sen and Ganguly (2017:1175), this is a major barrier in developing countries. Luthra *et al.* (2015: 767), in their study, also observed that skilled, experienced, and trained human resources required for the development and application of sustainable energy technologies were lacking. In addition, Hamilton (2016) reported that there is reluctance to adopt renewable energy by the mining industry due to lack of in-house skilled expertise and perceptions that it is unproven technology.

2.8.2 Economic and financial barriers

2.8.2.1 Access to funding

Economic and financial barriers to the implementation of clean energy initiatives are identified in several studies. These barriers include high start-up capital, unavailability of subsidies and unavailability of funding from investors and institutions (von Hatzfeldt, 2013:204; Luthra *et al.*, 2015:765). Luthra *et al.* (2015:765) reported that sustainable energy technologies imported from technologically advanced countries are efficient, but the purchasing costs are normally expensive and resulting in high start-up capital costs.

Luthra *et al.* (2015:765), on the other hand have explored barriers that influence the adoption of renewable/sustainable energy technologies in India. The findings from Luthra's study suggest there are insufficient incentives provided by the government to encourage and lure the industries and other sectors to adopt clean energy systems.

Another barrier identified in an article by Hamilton (2016) is that the lifespan of some mining operations is shorter than the payback period and life of renewable energy technologies, such as solar, wind and geothermal. The Ontario Mining Association's Energy Committee also acknowledged this as a barrier in a study conducted by Levesque (2015:35).

Furthermore, the study by Levesque (2015:35) identified several other barriers impeding the adoption and implementation of clean energy in the mining industry. Their findings reveal that environmental conservation was not seen as a business priority as opposed to production, thus making deployment of clean energy less prioritised. The absence of financial incentives linked to energy conservation in the key performance indicators of the production personnel was also identified as a barrier. The research findings also highlighted the financial risk associated with investing in projects needing major technological changes (Levesque, 2015:35).

2.8.2.2 High start-up capital costs

Hamilton (2016) mentioned a study by a non-profit organisation called Carbon War Room (CWR) to determine the barriers behind the slow investments in renewable energy solutions in the mining industry. The purpose of the study was to assist the industry in transitioning to renewable energy solutions in a cost-effective way and subsequently reduce emission of greenhouse gases caused by the industry. The CWR findings attributed the slow investment in renewable energy technologies by the mining industry to market related obstacles, such as high financing and implementation costs.

2.8.2.3 Fossil fuel abundance, accessibility and affordability

The prominent use of fossil fuels continues to act as a competitor to clean energy. Many industries still dependent on conventional energy resources such as coal due to its abundance, accessibility, and affordability (Moorthy *et al.*, 2019:5-9). Abdmouleh (2015: 251) reported that low capital cost gives conventional energy sources such as fossil fuels a competitive advantage compared to renewable energy projects.

2.8.2.4 High land acquisition costs

Moorthy *et al.* (2019:5-9) reported that prohibitive costs are involved in establishing and running renewable energy projects. Moorthy *et al.* (2019:5-9-) further indicated that renewable energy projects normally require large areas of land to develop to produce the same amount of energy that traditional technologies can produce within a small space. According to the author, significant financial capital is often required to acquire land that is suitable to develop and operate renewable energy projects.

2.8.2.5 High technology importation costs

Another significant factor is the inability to manufacture clean energy technology in the local space, which becomes a costly exercise of importing equipment from technologically advanced countries (Luthra *et al.*, 2015:765).

2.8.3 Institutional barriers

2.8.3.1 Inefficient government policies, inadequate incentives, and unrealistic targets

Institutional aspects in the form of administration, policy and regulatory, and infrastructure for research institutions and design were widely identified as barriers that have a strong influence on the adoption and dissemination of clean energy initiatives (Yaqoot *et al.*, 2016: 483-484; Moorthy

et al., 2019:7). According to these authors, the absence or inefficient government policies, lack of or inadequate incentives, lack of standards and unrealistic targets and certification also hinder the deployment of clean energy initiatives. Moorthy *et al.* (2019:7) reported that very little is invested in research and development of renewable energy by both the private and public sectors. This reluctance prevents clean energy from thriving economically like fossil fuel energy.

In China, industrial companies believe that a lack of a strong policy framework is a barrier to the successful implementation of clean energy initiatives (Liu, 2012:5). Gangazhe, (2016:33) also pointed out that a lack of robust, supportive, and practical policy framework can hinder adoption of clean energy solutions. To draw the attention of investors, it is essential for legal frameworks and policy strategies supporting clean energy implementation to provide a clear direction.

Lack of institutional, financial, and technical structures to promote the adoption of clean energy initiatives is identified as another barrier in this barrier category (Yaqoot *et al.*, 2016: 483). These authors also identified lack of infrastructure such as institutions for research and design purposes as a barrier. The authors also reported that another barrier is the limited availability of spare parts needed by industries for maintenance purposes. Institutional support is required to ensure industries have easy access to spare parts needed for effective maintenance of clean energy technologies.

2.8.3.2 Bureaucratic complexities and permit acquisition constraints

Bureaucratic complexities, such as tedious administrative procedures, poor project planning and coordination among various stakeholders are also identified as an institutional barrier. This barrier is reported to have a negative effect on the investment and deployment of clean energy initiatives, which can contribute to delays in project implementation (Moorthy *et al.*, 2019:7-8). One of the permit acquisition constraints experienced by industries is delays in obtaining environmental permits required for developing clean energy technologies (Abdmouleh *et al.*, 2015:256). Similarly, a study by Eleftheriadis and Anagnostopoulou (2015:153), also reveals that delays in issuing building permits were an important barrier that inhibited the implementation of renewable energy sources.

2.8.4 Awareness and information barriers

2.8.4.1 Lack of information and knowledge

Uncertainties on the lack of information, knowledge and environmental benefits and financial feasibility of implementing clean energy projects is a barrier to the deployment of clean energy initiatives (Moorthy *et al.*, 2019:4). Igogo *et al.* (2020:9) also reported that the government and

regulators in many countries do not have sufficient knowledge and experience to integrate renewable technologies into their power system, thereby limiting the mining companies to access renewable energy through processes such as power purchase contracts. These authors also believe that the industry is not adequately equipped with the necessary skills, knowledge and expertise related to renewable energy to inform mine planning and design. Lack of knowledge of the operation of clean energy technologies is highlighted as a hindrance to its adoption (Luthra *et al.*, 2015:766).

2.8.4.2 Inadequate research and development

Moorthy *et al.* (2019:7) also reported that Research and Development (R&D) of renewable energy technologies is still in its infancy, thereby resulting in limited information and knowledge on the technical standards, guidelines, and procedures.

2.8.4.3 Lack of consumer awareness

In addition to the lack of knowledge and information, Igogo *et al.* (2020:9) reported that the lack of awareness of clean energy by interested and affected parties in both private and public sectors has an important influence in the implementation of clean energy initiatives. A lack of consumer awareness of clean energy technologies may cause a lack of interest and commitment to promoting them (Luthra *et al.*, 2015:766)

2.8.5 Land constraints barriers

2.8.5.1 Land availability

Moorthy *et al.* (2019:5-9-) reported that renewable energy projects require relatively large areas of land. Finding suitable land for construction of renewable technology is a constraint faced by the mining industry (Igogo *et al.*, 2020:30). Although the footprint of the mining operations may be perceived to be large, these authors reported that the challenge has always been the availability of land that is of less mineral value and suitable in terms of land grade and cover to accommodate renewable energy technologies, such as PV solar and wind turbines. Li *et al.* (2022:1280) also reported that land availability is a barrier to the implementation of large-scale renewable energy technologies in Singapore.

2.8.5.2 Land use constraints

Martin and Rice (2012:125) conducted a study to investigate the barriers that impede the development of renewable energy supply in Queensland. The authors discovered that land access and land use constraints are barriers to implementing clean energy technologies.

Hilson (2002:65) also reported that land-use conflict is an important barrier facing both mining companies and their host communities. The author reported that mining impacts the environment, poor communication with the communities and environmental accidents cause disputes over land use between the mines and surrounding communities. These disputes over land use between mining organizations and surrounding communities make it difficult for the two parties to coexist.

2.9 Opportunities for integrating clean energy in mining

Several considerations exist for integrating clean energy sources into mining operations (Abbaspour & Abbaspour, 2022: 572). Unlike fossil fuel energy, these clean energy sources are generally preferred because of their environmentally friendly nature and can continually replenish through natural resources such as wind, rain, sunlight, wave and tides and others (Luthra *et al.*, 2015:764; Rand & Dell, 2004:23; Dufey, 2010:1; Dincer & Acar, 2015:588). The literature review identified several main areas that provide mining companies with opportunities to implement clean energy initiatives. Previous studies indicated that clean technologies such as wind and solar are the cheapest source of energy available for adoption by most industries. This presents a good opportunity for the industry because of the declining start-up capital costs that have been reported to be declining over the years (Igogo *et al.*, 2021:5).

Igogo *et al.* (2021) further reported that clean energy offers mining companies the opportunity to decarbonize their operations, which is expected to increase the operating margins and improve risks associated with fossil fuel market volatility. These authors also highlighted that mining operations located in geographical areas where resources such as wind and solar are available and abundant are more advantaged and can integrate renewable energy into their organizations.

Ryan (2014:303) reported that mining companies can implement renewable energy through power purchasing agreements instead of incurring the cost of generating electricity upon themselves. This approach is preferred by the mining industry because renewable energy is not their core business.

The introduction of clean energy initiatives by mining companies can offer socio-economic opportunities for the communities around the mines. Igogo *et al.* (2021:6) reported that communities located nearby mining operations are generally rural and agricultural by nature. According to Hilson (2002: 65), large-scale mining sites mostly find it difficult to co-exist with the host communities, which often causes social and political instabilities. To overcome these challenges, mining companies that operate in this type of environment can contribute towards social development by improving their relationship with surrounding communities by involving them in clean energy related projects (Igogo *et al.*, 2021:16).

These authors also believe these initiatives can provide socio-economic opportunities, enhancing the social license to operate, create shared value and local economic development. For example, the mine can share the surplus renewable energy produced with the nearby communities and involve them in the non-technical aspects of the project and others. This will present opportunities for job creation and consequently promote social and political stability.

2.10 Replacing fossil fuels by integrating renewable energy sources in mining processes and transportation to reduce GHG emissions

2.10.1 Replacing fossil fuels with clean energy in mining processes and transportation

Most mining activities rely on energy mainly generated from fossil fuels, such as heavy oil fuels, diesel, and coal (Levesque, 2015:41; Akinbami *et al.*, 2021:5078). Generation and consumption of these fossil fuels are unsustainable and cause environmental degradation and pollution such as GHGs emissions and others (Ryan, 2014:299-306).

The mining activities mainly consume energy in the form of electricity for use in many processes and activities, including heating (Ratshomo & Nembahane 2021:23; Ryan, 2014:299; Igogo *et al.*, 2014:5). Because the heating activities generally consumes a lot of energy, Igogo *et al.* (2021:5) believes that mining companies can reduce fossil fuel usage by targeting the processes and activities that generate heat. Other uses of energy in the industry include powering equipment used for ventilation, hauling and on-site transportation with clean energy sources. For transport activities for example, diesel powered trucks can be displaced with battery, biodiesel and hydrogen technologies in trucks and haulage.

2.10.2 Integrating renewable energy to meet electricity demand and reduce GHG emissions

Renewable energy sources have been identified as a solution to bridge the gap between energy supply and demand and addressing concerns GHG emissions caused by fossil fuel burning (Abdmouleh *et al.*, 2015:250; Abbaspour & Abbaspour, (2022: 572).

Igogo *et al.* (2021:5-9) reported that renewable energy can be used as enablers to meet the mining operation's energy demands and provide power to both on and off-grid mining operations. Observations from Levesque (2015:32) indicate that wind, solar and geothermal are the most preferred energy sources in the mining industry. On the contrary, a recent study by Strazzabosco *et al.* (2022:138) shows that solar PV is the most preferred and adopted technology to power mining operations.

Meanwhile, an article by Labuschagne (2020) illustrates that most South African mining companies are pulling their weight in their quest to ensure sustainable energy management. They

have acknowledged that their operations are highly dependent on electricity supplied from the national power producer Eskom and that alternative electricity sources are required to achieve sustainability. They also recognise the electricity supply challenges faced by Eskom.

During the 2020 Mining Indaba, mining houses welcomed the call from the Department of Minerals and Energy to allow mining companies generate their own power through renewable energy technologies (Labuschagne, 2020). In Labuschagne's article, the Minerals Council indicated that several South African mining companies are developing renewable energy projects to generate their own power and supplement electricity sourced from Eskom. These initiatives, which are summarised in Table 2-1, are, *inter alia*, expected to collectively generate approximately 609MW of electricity from various technologies, including renewables.

In addition, the South African government encourages all sectors to maximise the abundant sun as a source of energy to produce electricity through solar technologies. Industries, including mining, are encouraged to install roof-top solar panels, which can be connected to the grid. To enable a larger uptake, government plans to incentivise commercial and residential solar installations through feed-in-tariffs, allowing electricity generators to sell surplus power to Eskom (RSA2, 2022).

2.10.3 Types of renewable energy sources for integration in mining processes and activities

This section discusses the types of renewable energy sources available for integration in mining operations. These renewable energy types come from natural resources or processes that are naturally replenished. They vary from biomass, solar, hydropower and wind (NRDC, 2022).

2.10.4 Biomass

Biomass is a naturally occurring energy source that can be used to replace the conventional fossil fuel energy sources. It is the only energy source of an organic nature that comes from renewable sources such as wood, animal, and plant wastes which is rich in carbon and available in abundance (Balat & Ayar, 2005:931). Biomass energy is mostly prevalent in the rural domestic sector and used primarily by industries such as forestry and paper for heat generation (DME, 1998:3). The activities associated with its generation have negative impacts such as environmental pollution and risk to conservation areas. A balanced approach is therefore required when using biomass energy (Field *et al.*, 2007:65). Abbaspour & Abbaspour (2022:571) indicates that biomass energy use and generation in the mining industry is not common, as most mining companies adopted solar and wind as their preferred alternative energy sources.

Although this energy source is not common in the mining industry, some mining operations have established initiatives to reduce the load from the grid by powering hostels and some mining residential compounds with electricity generated from bio-energy plants and PV cells (Altman *et al.*, 2008: 45).

2.10.5 Hydropower

Hydropower is a renewable source of energy recognized worldwide that uses the natural flow of moving water to generate electricity (Barta *et al.*, 2011:37; Iberdrola S.A., 2022). It is a sustainable means of generating electricity which can be used to substitute fossil fuel energy (Luthra *et al.*, 2015:764). Hydropower as a large-scale energy is also efficient and can store energy in hydroelectric pumping stations (Iberdrola S.A., 2022).

In countries such as Europe, hydropower energy is widely adopted and contributes to achieving climate and renewable energy policies and targets (Farmaki *et al.*, 2021:3). Although hydropower generates cheaper energy, these authors reported that its development is extensive, with the infrastructure such as dams requiring a large footprint area for development which has a negative impact on biodiversity, river flows and social impacts.

The article by Barta *et al.* (2011:38) reported that the development of hydropower has the potential for growth globally. Furthermore, the authors reported that it has the same potential in Africa, however, it is reported that energy generated from hydropower is yet to thrive, contributing about 6% of its capability. These authors mentioned that development of hydropower in South Africa is moving at a slow pace. The authors also indicated that most of the hydropower projects installed in South Africa do not operate according to design capacity, while others are poorly maintained and many others out of operation. He also looked at hydropower use by the South African mining operations, his observations reveal that the deep mines are the primary users of hydropower, where large quantities of water are used to supply energy in hydropower drills and for cooling purposes.

2.10.6 Wind

Wind energy is a renewable energy that is naturally replenishing (Luthra *et al.*, 2015:764). Wind energy is generated when kinetic energy is transformed from the wind using turbines and windmills (Iberdrola S.A, 2022; Sahin 2004: 503). According to Iberdrola S.A (2022), wind energy can be found in two forms, namely, on-shore and off-shore. On-shore wind energy utilizes air currents produced on land, whereas off-shore utilizes the wind that blows on the high seas. It was reported that over 200 000 wind turbines are constructed worldwide to generate electricity. This

energy type is well received by society and industries because it is clean, practical to implement, economical and environmentally friendly (Sahin, 2004:501-503; Luthra *et al.*, 2015:764).

Levesque (2015:33) reported that wind energy is used by mining companies worldwide. For example, Rio Tinto's Diavik Mine located in a remote area in Canada with no access to grid electricity supply, constructed a wind farm in 2012 to supplement electricity generated by diesel generators. This project was expected to contribute to a reduction of the mine's diesel consumption by 10% and in the process, reduce GHG emissions.

South African mining operations located in high-wind areas can potentially deploy wind energy. Votteler and Brent (2016:1) reported that several small to utility-scale wind farms were established in the country, which can supplement the grid supply. In addition, the REIPPPP plans to supplement the country's electricity infrastructure with wind energy (Pollet *et al.*, 2015:16688).

2.10.7 Solar

Solar is a renewable energy source that converts sunlight into electricity and replenishes it through natural processes (NRDC, 2022; Dincer & Acar, 2015:588; Iberdrola S.A., 2022). Photovoltaic (PV) and concentrating solar power (CSP) are examples of solar technologies that can be used to convert sunlight into electricity (Pollet *et al.*, 2015:16688; Iberdrola S.A., 2022). Pollet *et al.* (2015) further mentioned that there has been an increase in the installation of solar PV and CSP technologies by both private and public sectors in South Africa.

According to Ward (2002:3-5), South Africa has one of the best solar resources in the world, which provides opportunities for mining and other industries to adopt solar technologies (Ward, 2002:3-5). This creates an opportunity for mining operations, especially those situated in remote areas with little to no access to grid connection, and with ample underutilised land to adopt this type of technology for power generation (PWC, 2020:24).

Previous studies have shown that solar energy is the most preferred and adopted energy technology for power mining companies, followed by wind energy (Igogo *et al.*, 2020:8; Strazzabosco, 2022:135). This statement aligns with observations by Strazzabosco (2022:135), who looked at the evolution of renewable energy adoption by Australian mining operations. His findings show that solar PV was the most adopted and preferred renewable energy technology, with 92% of the 27 Australian mining companies installing or planning to install solar photovoltaic technology compared to other renewable energy technologies.

Another study that shows the popularity of solar technology in the mining industry was conducted by Abbaspour & Abbaspour (2022:571), who investigated the state of renewable energy

implementation by global mining companies. Of the 42 mining companies that were investigated during 2003 and 2020, 64% installed solar PV technology. An article by Labuschagne (2020) also reveals that about 90% of the renewable projects developed/planned by South African mining companies since the year 2020 were solar PV installations (Table 2-1).

Table 2-1: Potential renewable electricity projects in South African mining companies (Labuschagne, 2020).

Mining Company	Power Capacity (MW)	Potential renewable energy project type
Sibanye Stillwater	200	PV
Goldfields South Deep Mine	40	PV
Orion	38	PV
Harmony	30	PV
Exxaro	3	PV
Vedanta	200	PV
Anglo American	75	PV

2.11 Hybrid energy systems

As a way of ensuring consistency in energy supply, most mining companies prefer to operate hybrid systems (Strazzabosco *et al.*, 2022:142). These hybrid systems can be a combination of technologies or energy generated from renewable sources and fossil fuels. For economic purposes, most mining companies can adopt hybrid systems which can supplement between 30% and 40% of the operation's total electricity demand through renewable energy technologies (Igogo *et al.*, 2020:8). Electricity generated through hybrid systems reduces the fossil fuel use but not entirely. Some of the common hybrid systems used in this industry are wind-battery-diesel hybrid systems, solar PV-battery-diesel hybrid systems and solar-wind battery-diesel systems (Igogo *et al.*, 2020:8).

2.12 Hydrogen production through renewable energy

Mining companies that have installed renewable energy technologies can use excess electricity generated from these renewables to produce hydrogen. Hydrogen can be produced using electricity generated from renewable energy such as solar, wind and nuclear. Hydrogen is produced when water is split by electricity to produce hydrogen and water (Miller *et al.*, 2012: 533-540). The use of hydrogen produced from renewable energy is environmentally friendly and results in zero environmental emissions, thus providing opportunities to companies that want to

decarbonise their operations (Iberdrola S.A., 2022). In addition to environmental benefits, this energy type is cost-effective and reliable. Strazzabosco *et al.* (2022:138) reported that reducing diesel consumption at the point of consumption through renewable energy systems has proven to be effective in reducing costs related to energy production and in increasing power supply reliability.

On the other hand, PWC (2020:20) reported that hydrogen power is starting to receive attention in the mining space due to the anticipated decline in renewable hydrogen production costs, which is expected to reduce by over 60 % in the coming decade. According to PWC, hydrogen is one of the recommended options to meet the energy needs of a mining operation and can be used in various forms. For example, hydrogen can be used to supply electricity to the mine and heat on-site industrial processes (Igogo *et al.*, 2021:6).

Hydrogen can also be used in other mining activities, such as providing power to mining fleets and displacing diesel. This option is reported to improve the energy efficiency of haulage materials such as trucks and is expected to result in zero environmental emissions (Miller *et al.*, 2012: 533-540; PWC, 2020:20; Igogo *et al.*, 2021:11). Some platinum mining companies have started introducing hydrogen technologies in their operations through various initiatives. For example, Impala Platinum Mine Springs Refinery rolled out its first hydrogen fuel cell forklift in 2016 while AAP Mogalakwena Mine tested its first hydrogen-fuelled haul truck in the first quarter of 2022 (RSA3, 2016; AAP2, 2021:63).

2.13 Potential opportunities and actions taken to address the clean energy implementation barriers in the mining

A review of a study by Moorthy *et al.* (2019:1) has revealed that barriers such as institutional, behavioural, technical, economic and financial are the most common barriers that act as a hindrance to the adoption and implementation of clean energy initiatives.

Implementation of clean energy solutions can only be achieved by addressing the barriers that exists (Gangazhe, 2016:33). Bridging the gap caused by barriers to promote the adoption of clean energy will assist countries to meet their energy demands and address concerns of climate change. By so doing, social, environmental, and economic benefits will also be realized (Byrnes *et al.*, 2013:720).

The following section describes the potential opportunities and actions already implemented by previous studies to overcome the barriers affecting the deployment of clean energy initiatives in mining.

2.13.1 Addressing technical barriers

Several technical barriers that affect the implementation of clean energy initiatives in mining are summarised in section 2.8.1. Some of the common and critical technical barriers identified include intermittency of renewable resources; inappropriate technology design and operation; unavailability of spare parts; lack of expertise required to design, maintain, and operate equipment. Various measures that can address the technical barriers to the implementation of clean energy systems have been identified in previous studies.

2.13.1.1 Intermittent nature of renewable resources

One of the critical barriers, the intermittent nature of renewable energy resources, can be mitigated by developing and utilizing energy storage devices such as large batteries to store energy for use when the sun is unavailable or insufficient or when there are power supply interruptions. The energy storage device ensures a consistent power supply to the operations (Yagoot *et al.*, 2016:478-479; Moorthy *et al.*, 2019:7).

2.13.1.2 Inappropriate technology

The inappropriate and inadequate technology design, installation and performance barriers can be addressed by mines through Research and Development (R&D), cooperating with equipment manufacturers and procuring durable and easy-to-maintain renewable energy technologies (Yagoot *et al.*, 2016:478-480).

2.13.1.3 Lack of skilled expertise

Sen and Ganguly (2017:1175) are of the view that awareness and training can be used to address this barrier. Lack of technical expertise was also identified as a barrier by Igogo *et al.* (2021:10), who indicated that the mining industry is not adequately equipped with the necessary skills and expertise required to handle clean energy technologies. According to these authors, this knowledge gap can be bridged by developing educational programs at higher learning educational institutions which will contribute to an increase in the skill set in the industry.

2.13.2 Addressing economic and financial barriers

The economic and financial barriers can be overcome through financial incentives such as capital subsidies which can be in the form of capital grants and subsidies for research and development. Other fiscal incentives include tax exemption for investing in renewable energy, tax holiday on generation income and market-based incentives such as feed-in tariffs, regulated energy reduction targets and competitive tendering (Gangazhe, 2016:34; Abdmouleh, 2015: 259-261).

2.13.2.1 Public funding and Research and Development

Von Hatzfeldt (2013:206) is of the view that financial incentives barrier should be given attention in both the private and public sectors. The public funding of both sectors needs to be improved and extended to research and development in clean energy, pre-investment studies and project start-up. To overcome the barrier of inadequate public funding, this author suggests that mining and other energy-intensive industries form consortiums to fund innovative technological projects. This can also be used as an opportunity to overcome the high land acquisition costs barrier.

Likewise, Igogo *et al.* (2020:31) believe more R&D is required to incrementally advance past today's barriers to integrating renewables into mining operations. R&D will increase the attractiveness of renewable energy and as a result many organizations will be encouraged to invest in developing advanced technologies that can optimize usage of renewable energy (Moorthy *et al.*, 2019:18).

Igogo *et al.* (2020:31) also reported that the mining industry needs cost-effective solutions for scaling renewable use, or for using renewable sources to produce high-temperature heat, or for low-cost energy storage with longer durations. There are also R&D opportunities for other emerging solutions such as green hydrogen production as alternative low-emissions feedstocks in their activities and processes. For example, the mines can introduce eco-friendly and efficient haulage of material/equipment which can substitute diesel with clean energy (Igogo *et al.*, 2020:31).

2.13.3 Addressing institutional barriers

2.13.3.1 Practical policy and conducive regulatory frameworks

According to Liu (2012:5), a clear policy framework and political guidance can positively influence the industry's behaviour towards good carbon management. It was also noted that a fit-for-purpose policy design is key in addressing specific barriers identified. Byrnes *et al.* (2013:711) also believe the success of breaking barriers can be achieved by implementing practical policies and regulatory frameworks which can be used to alter the behaviour of industries in their efforts to deploy clean energy.

As mentioned before, inefficient government policies and procedures is one of the biggest obstacles affecting the deployment of clean energy initiatives (Yaqoot *et al.*, 2016: 483-484; Moorthy *et al.*, 2019:7). This barrier can be overcome by streamlining policies and developing user-friendly procedures (Abdmouleh *et al.*, 2015:256- 257). The authors also mentioned that a conducive legal, regulatory framework is key to successfully implementing renewable energy. In

other words, the regulations related to permit acquisitions of renewable energy must be clear and simplified to support implementation by industries. Moorthy *et al.* (2019:9) also supported this statement and emphasized the importance of having well-established regulatory framework. The author is of the view that this will attract investors and entrepreneurs interested in implementing clean energy initiatives. It was proven from previous studies that countries that have well-established legal framework in place and a strong political support have a high dissemination of renewable energy (Huang *et al.*, 2013:4466; Abdmouleh *et al.*, 2015:257).

2.13.3.2 Addressing bureaucratic complexities and poor coordination in SA

In the South African context, government has acknowledged that bureaucratic complexities and poor coordination of the application processes for energy projects that require approvals from various government entities, which is a challenge faced by many applicants from various industries (RSA2, 2022). Government is also aware of the lengthy licensing and permit requirement processes and red tape required for energy project applications (RSA2, 2022). To mitigate against these barriers, government has recently removed the licensing threshold for new embedded generation projects (related to electricity generation or storage plants connected to a distribution network) from 1 MW to 100 MW, which gave the private sector the opportunity to generate their own electricity to an increased capacity of up to 100MW. To support clean energy projects, government also removed the licensing requirement for generation projects up to 100 MW that are connected to the grid (RSA22, 2022).

To overcome the bureaucratic complexity barrier, Winkler *et al.* (2005:27) believe that the success of these policies requires enabling activities and funding to promote the adoption of clean energy. In addition, a robust policy approach is required to positively influence the behaviour of mining companies in promoting clean energy, which will also play a role in achieving environmental goals. Industrial companies in China believe that a robust policy framework can mitigate this barrier. Incentives are another institutional tool that can be used to overcome the economic and financial barrier (Liu, 2012:5).

To address concerns about poor coordination of the application processes for energy projects, the SA government plans to establish a single point of entry for all energy project applications, which will streamline the approval processes across various government institutions and entities (RSA2, 2022). In addition, government also committed itself to reviewing the timelines required to process the energy projects applications with the aim of expediting the applications (RSA22, 2022).

According to Winkler *et al.* (2005:30-32), the majority of South Africa's electricity supply still comes from non-renewable energy sources. There are several policy and regulatory instruments in place that the government can consider in promoting the implementation of clean energy on a larger scale, for example, policies that regulate the quantity of renewable energy. Section 2.6.3 covers the energy policies that are in place that promote clean energy in the country, with the 1998 Energy White Paper setting the framework for most of the energy objectives.

Private sector participation, integration of renewable energy policies with developmental programmes, conducive legal framework and long-term policies for all stakeholders are some of the measures recommended by Yaqoot *et al.*, (2016:477-884) to increase the dissemination of clean energy initiatives. Also, to attract investment in renewable energy technologies, these authors suggest that renewable energy policies include incentives for renewable energy utilization.

In an assessment conducted by Asante *et al.* (2020:111478), political and regulatory barriers were ranked the highest among six other categories. To overcome these barriers, the authors recommend the development of specific renewable energy standards, user friendly certification procedures and grid connection quotas. Also, to support sustainability and inclusiveness, the authors advocate a bottom-up approach when establishing renewable energy policies. Similar barriers were identified by von Hatzfeldt (2013:207), who is of the view that government can demonstrate a strong political commitment to introduce robust reforms that will improve the legal framework and incentive structure and establish serious penalty systems. Hatzfeldt also mentioned that setting realistic targets for renewable electricity generation such as the contribution of renewable energy over a specific period and fixing prices through energy tariff regulation, can be used as an approach to achieve this barrier.

Other instruments that can be adopted that can contribute to achieving the renewable energy target are by setting a price for renewable electricity through feed-in tariffs where different tariffs are set per technology type and setting the quantity of renewable electricity through renewable electricity portfolio standard (Gangazhe, 2016: 34; Winkler *et al.*, 2005:30-32). Unlike other funding types, such as subsidies and grants, these authors reported that feed-in tariffs are more reliable and better preferred by investors. Igogo *et al.* (2021;11), on the hand, is of the view that a review of government policies and strategies such as tax exemptions and subsidies that apply to fossil fuel purchases is required. These instruments can be used as opportunities to innovate green hydrogen technologies, enhance commercial demand, develop infrastructure, and introduce funding mechanisms to reduce high capital costs (Igogo *et al.*, 2021;11).

The outcome of a study conducted by Hilson (200:714) reveals that legislative issues are barriers preventing the implementation of cleaner technologies in a few mining companies in America. Hilson suggests government can also play a supportive role to mining companies by means of awareness, information sharing and training to empower the industry in implementing these sustainable solutions.

2.13.4 Addressing awareness and information barriers

Lack of knowledge and awareness of clean energy can be addressed through research and educational programs that provide information on resource studies and renewable technology options. This can also be achieved through training and information sessions related to government incentives and available support systems (Luthra *et al.*, 2015:766).

Moorthy *et al.* (2019:18) believe that investment in research and development can address the awareness and information barrier. The authors believe addressing this barrier will increase the organization's understanding of the environmental and financial benefits of implementing clean energy. This will also increase the attractiveness of clean energy and enhance investment in advanced technologies.

2.13.5 Addressing land constraint barriers

To address the barriers of land constraint faced by mining operations, Igogo *et al.* (2021: 11) suggests that individual or groups of mining operations collaborate to develop a renewable energy system or microgrid that will supply electricity to themselves and the communities in need. These authors are also of the view that this pooling of resources can address the land constraints barriers facing the mining industry. Alternatively, services can be procured from the IPP and developers.

2.13.5.1 Land availability constraints

To minimize the land use constraint of large portions of land for the construction of solar farms when land availability is limited, Aman *et al.* (2015:1200) suggested increasing the efficiency of solar panels or constructing the cells on structures such as rooftops. In Singapore, developers installed solar PV systems on rooftops, such as top of Keppel Bay Tower, to address the land constraint barrier in a dense urban environment (Li *et al.*, 2022:1274).

2.13.5.2 Land use constraints

To overcome the land access and land use constraint barrier in Queensland, the Queensland government amended the Land Act (1994) to enable the landowners to grant sub-lease access

to renewable energy supply firms and developers (Martin & Rice, 2012:125). This approach can be adopted by other authorities to create an enabling environment for industries experiencing similar challenges.

2.14 Chapter summary

This chapter reviewed the literature on the implementation of clean energy initiatives in the platinum mining sector, focussing specifically on the barriers to such implementation, as well as potential opportunities to address the barriers to implementing clean energy initiatives.

A literature review demonstrates that different energy sources are used in various mining processes and activities. It is clearly observed that this industry, including platinum, is energy-intensive, and uses energy mainly in the form of electricity. In addition, this industry is still highly dependent on energy sourced from fossil fuels.

The industry is experiencing challenges in adopting clean energy solutions to substitute fossil fuels. As mentioned in section 2.3.1, clean energy is defined as energy that comes from natural renewable sources or processes that are constantly replenished. These renewable energy sources can be harnessed through technology and other processes for use in many mining activities and processes. Increasing energy demand, fluctuating energy costs and ease of implementation are contributing factors to the slow implementation of clean energy initiatives in the mining sector.

Despite the technical and economic challenges faced by mining, review of literature illustrates that this industry, has in the last two decades, increased its efforts in adopting clean energy initiatives. This increase in clean energy implementation was observed in 2019.

Observations from previous studies reveal the types of clean energy solutions adopted by mining companies. A combination of clean energy solutions was adopted, which in some cases include a hybrid of clean technologies and fossil fuels such as wind-battery-diesel hybrid systems, solar PV-battery-diesel hybrid systems and solar-wind battery-diesel systems. Geothermal, concentrated photovoltaics (CPV), hydropower systems, photovoltaic system (PV), battery storage, wind, gas, solar thermal, and concentrated solar power are examples of clean energy technologies implemented. Hybrid systems and solar energy were seen as the most common clean energy adopted in this industry.

Economic, environmental, and societal factors were recognised to influence the deployment of clean energy initiatives in the global mining sector. The main drivers identified include global warming, dependency on finite resources, environmental impacts, energy security and demand

and population growth. In SA, the transition to clean energy is mainly driven by increasing electricity prices and poor reliability due to insufficient capacity during peak times, which causes frequent blackouts.

Adopting clean energy initiatives will result in environmental benefits. This will also enhance the social outlook of the country through job creation, rural development, and a variation of energy supply. In addition, a fiscal-based system, such as carbon-tax, can be used as a financial incentive to influence the behaviour of air emitters, which is offered to companies that demonstrate good energy management. The primary aim of this fiscal system is to promote reduction of air emissions by industries.

The legal framework supporting the implementation of clean energy initiatives was also discussed in this chapter. The unsustainable industrial activities and climate change because of GHG emissions caused by burning harmful substances have led to the development of frameworks such as policies, regulations and treaties. The global frameworks to address climate change concerns include the United Nations Framework Convention on Climate Change, the Kyoto Protocol and the Paris Agreement.

Subsequently, the South African Government passed laws, policies and strategies to support the transition to a low-carbon and green economy. These include the National Energy Act 34 of 2008, National Development Plan, the White Paper on Energy Policy, White paper on Renewable Energy, Renewable Energy Independent Power Producer Procurement Programme, National Climate Change Response White Paper, Integrated Energy Plan, National Integrated Resource Plan and the National Energy Efficiency Strategy. These policies were established to improve energy security by introducing a variety of energy sources and increase capacity through clean energy sources. The policies also provide energy efficiency and renewable energy targets for large-scale projects.

In support of the Paris Agreement goals, AAP has developed strategies and policies to respond to climate change concerns. These corporate frameworks guide the implementation of clean energy technologies in the organization. The organization has developed a carbon neutrality roadmap, which includes GHG emissions and energy intensity reduction targets. This carbon neutrality is endeavoured to be achieved by 2040 to reduce carbon emissions generated directly from operational activities and carbon emissions incurred because of using electricity purchased Eskom for operational activities across its operations.

Several barriers that hinder the adoption of clean energy initiatives were identified, namely, technical barriers, economic and financial barriers, institutional barriers, awareness and

information barrier and land constraints barrier. Intermittence of renewable energy, complexities associated with clean energy technologies, technological risks, technology design and operation complexities and inadequate technical expertise are some of the technical barriers that influence the adoption of clean energy initiatives in mining.

With regard to the economic and financial barriers, the common barriers identified include high start-up capital costs caused by high financing and implementation costs. Abundance, accessibility, and affordability of fossil fuels are another barrier identified in this category caused by the prominent use of fossil fuels. It was reported that the prominent use of fossil fuels continues as a competitor to clean energy.

Renewable energy projects normally require large areas of land to develop, resulting in high land acquisition costs. Observations from review of the literature indicate that significant financial capital is often required to acquire land suitable for the development of clean energy projects. It was also observed that incentives provided by the government to encourage and lure industries and other sectors to adopt clean energy initiatives are inadequate. Another economic and financial barrier is the inability to manufacture clean energy technology in the local space, resulting in high equipment importation costs from technologically advanced countries.

Administrative complexities, such as tedious administrative procedures, poor project planning and coordination among various stakeholders, were recognised as important institutional barriers in various studies. Lack of institutional, financial, and technical structures to promote adoption of clean energy initiatives is another barrier identified in the institutional barrier category.

Uncertainties on the lack of information, knowledge and environmental benefits and financial feasibility of implementing clean energy projects is an awareness and information barrier reported to negatively influence the implementation of clean energy initiatives. This also includes a lack of consumer awareness regarding clean energy technologies, which may result in lack of interest and commitment by stakeholders in promoting them.

The availability of land that is of less mineral value and suitable in terms of land grade for construction of large-scale renewable energy technology was highlighted as a barrier to adopting these technologies. Furthermore, disputes over land use between mining organizations and surrounding communities are an important barrier affecting the mining industry's ability to implement clean energy initiatives.

Several opportunities for integrating clean energy initiatives in mining were identified in this chapter. These opportunities aim to replace fossil fuels with clean energy in mining processes and transportation, and to also meet the electricity demand and reduce GHG emissions. Biomass,

solar, hydropower and wind are the types of renewable energy available for adoption by mining companies. Other opportunities include hybrid systems, which are a combination of technologies or energy generated from renewable sources and fossil fuels. Excess electricity generated from these renewables can be used to produce hydrogen energy for use in mining activities such as mining fleet to displace diesel energy. This option is reported to improve the energy efficiency of haulage material such as trucks and is expected to cause zero environmental emissions. To ensure consistency in energy supply, it was evident in this chapter that most mining companies prefer to operate hybrid systems. Some of the common hybrid systems used that can be adopted in this industry are wind-battery-diesel hybrid systems, solar PV-battery-diesel hybrid systems and solar-wind battery-diesel systems.

To overcome the barriers influencing the implementation of clean energy initiatives, potential solutions were identified. To address the intermittency of renewable sources technical barrier, previous studies recommended using storage devices, such as batteries, to store energy when the sun is unavailable or during power supply interruptions. Investing in Research and Development by the mines is a measure proposed to overcome the barriers of inappropriate and inadequate technology design, installation, and performance. Cooperating with equipment manufacturers by procuring durable and easy to maintain renewable energy technologies is another solution proposed to address this technical barrier. The lack of skilled expertise required to operate and maintain renewable energy technologies was identified as a technical barrier. This can be achieved through training to increase the skill set of employees responsible for the operation and maintenance of these technologies.

Inadequate public funding is an economic barrier identified by several authors. Proposed solutions to address this barrier include improved public funding for public and private sector initiatives, including research and development in clean energy initiatives, pre-investment studies and project start-ups. This approach is reported to increase the attractiveness of clean energy. Previous studies have also shown that this barrier can be addressed by pooling resources to develop shared renewable energy systems, which can be procured from the Independent Power Producers. This pooling of resources can also be used to address land constraints and economic barriers facing the mining industry.

Providing incentives for clean energy utilization through energy policies is a measure identified to attract investment in clean energy technologies and overcome institutional and economic barriers. Efficient and simplified policies, regulations and procedures, clear and streamlined government approval and authorisation processes, are some of the proposed measures to address the institutional barrier experienced by many industries.

Lastly, to address the barriers associated with land unavailability and land-use constraints, renewable energy systems such as solar panels can be constructed on top of existing structures such as rooftops.

CHAPTER 3 METHODOLOGY

3.1 Introduction

The aim of the research was to identify opportunities and barriers that influence the implementation of clean energy initiatives in the South African mining industry. This chapter describes the research design adopted for the study and provides methods used to answer the research question. The structure of this section includes the research design, followed by a description of data collection processes and analytical methods.

3.2 Research design

The research methodology adopted in this research is based on a case study approach using qualitative methods. Qualitative research involves the collection, analysis and interpretation of data that are not easy to quantify (Anderson, 2010:1). According to Tenny *et al.* (2017:1), qualitative methodologies explore and provide deeper insights into real-life problems and involve gathering the views and perceptions of the participants based their experiences.

The research approach followed in this study involves the adoption of existing theory applied to a specific case study. Because this research started with general principles of barriers and opportunities influencing the implementation of clean energy initiatives applied to a platinum mining case study, Saunders *et al.* (2019:153) refers to this research approach as deductive.

3.2.1 Research case study

Yin (2009:2) recognises the use of case studies in conducting research. The author believes case studies can be used to answer research questions.

Anglo American Platinum is an organisation that includes mining (open cast and underground) and metallurgical process activities, namely, concentrators, smelting and refineries. This organisation was chosen as a case study due to its position as a world-class platinum producer, which has already implemented clean energy initiatives and investigated opportunities to improve and transition to cleaner technologies while improving environmental performance (AAP5, 2020).

According to Malisa *et al.* (2018), Crowe *et al.* (2011:8) and Van Breda (2019), the use of a case study approach provides an in-depth and holistic understanding of an issue in its real-life context. The case study approach was used in this study to examine the issue of barriers influencing the implementation of clean energy initiatives through real-life contexts. The case study thus focuses on the clean energy initiatives implementation in the context of platinum mining operations.

Furthermore, a successful research design should define the boundaries of the case study in question (Yin, 2009:33). In this case, the boundaries of the case study were limited to the South African AAP operations, including Operations in Zimbabwe.

In this case study approach, the research will cover the following AAP operations - opencast and underground mines, concentrators, smelters and refinery activities. The outcome of the case study's barriers and opportunities related to its clean energy implementation approach can be useful to a typical mine or industry with similar metallurgical activities.

3.3 Sampling methodology

Creswell and Poth (2016:123) reported that data collection involves the purposeful identification of the study operation/s and individuals.

3.3.1 Sampling size

According to Israel (1992:2), a review of previous literature of a similar nature can be used as guidance for selecting the sample size required for data collection. A total of 15 individuals from various operations were interviewed. This sample size aligns with the sample size used by Ganghazhe (2016), who selected a homogenous sample size of 10 in a similar study that explored barriers to greater adoption of renewable energy by South African mining companies. The key role players in this study have experience in energy management and clean energy initiatives in the mining environment.

3.3.2 Selection of participants

The participants interviewed in this study were selected using purposeful sampling methodology. According to Palinkas *et al.* (2015: 33-536), purposeful sampling is used in research to obtain an in-depth understanding of the subject of interest. It involves the identification and selection of individuals or groups of individuals who are experienced subject matter experts (Palinkas *et al.*, 2015: 534-536). In this regard, the participants who formed part of the interview were selected based on their background knowledge and experience in energy and their involvement in the implementation of clean energy initiatives. They were therefore deemed to be able to contribute toward answering the research question and meeting the research objectives. Through this sampling technique, the researcher aims to ensure that an adequate number of key participants provide accurate data.

All the participants interviewed are AAP appointed employees who are based in different operations and have experience in the mining industry. To protect the anonymity of the participants, information such as participant names and operation names were not disclosed.

A total of 15 individuals were interviewed, representing more than 70% of potential participants (Table 3-1).

Table 3-1: Summary of the key participants interviewed.

Role	Number of participants	Total number of potential participants
Electrical & energy engineer (Appointed Energy Champions for mines, concentrators, smelters & refineries) -	4	6
Electrical Engineering Specialists	8	11
Energy Specialists	3	4
Total	15	21

The key individuals that participated in the research included the energy specialists, electrical engineering specialists and operational energy champion leads, who are also electrical and engineering specialists. These individuals were included in the because of the role they play in the investment decisions related to clean energy initiatives and their involvement in the planning and execution of such initiatives. These individuals are also involved in coordinating energy projects across AAP operations, by managing and coordinating energy costs, energy efficiency, energy consumption and GHG emissions management. They are also responsible for investigating alternative energy sources, energy security and the sustainability of the operations.

The energy champions and electrical engineering specialists are responsible for the implementation and operation of clean energy and energy efficiency initiatives and good energy management in the operations. The energy champions and electrical engineering specialists that were targeted to take part in this research are those that have implemented or are in the process of implementing clean energy initiatives in their operations. The specialists that are not involved in these initiatives were excluded from this study. This includes specialists whose operations did not implement clean energy initiatives.

The energy specialists include the Head of Energy, Energy Projects Principal and the Energy Projects Principal. They are involved in the planning and implementing clean energy initiatives across the AAP operations. They are also responsible for the development of clean energy projects and providing support to the operations.

3.3.3 Selection and identification of the study operations

3.3.3.1 Selection of study operations

During the selection of research operations, the researcher identified the AAP operations that have implemented or planning to implement clean energy initiatives to form part of the research.

The researcher specifically targeted the participants whose operations were implemented, planned or in the process of implementing clean energy initiatives, irrespective of whether the initiatives were successful or not. Furthermore, the operations that were selected included both open-cast and underground mines, concentrators, smelters, and refineries. The outcome of the study can therefore apply to metallurgical-related activities in platinum mining and other industries with similar activities.

3.3.3.2 Location and type of case study operations

AAP mining operations consist of operations located in the Bushveld complex in South Africa and include a mining complex located in the Great Dyke region of Zimbabwe (AAP1: 2022). There are two non-managed joint operations with other companies which are excluded from the scope of this research. Figure 3-1 shows the geographical location of all the AAP operations in South Africa, including the joint operations, while Table 3-2 only includes the operations that formed part of this research.

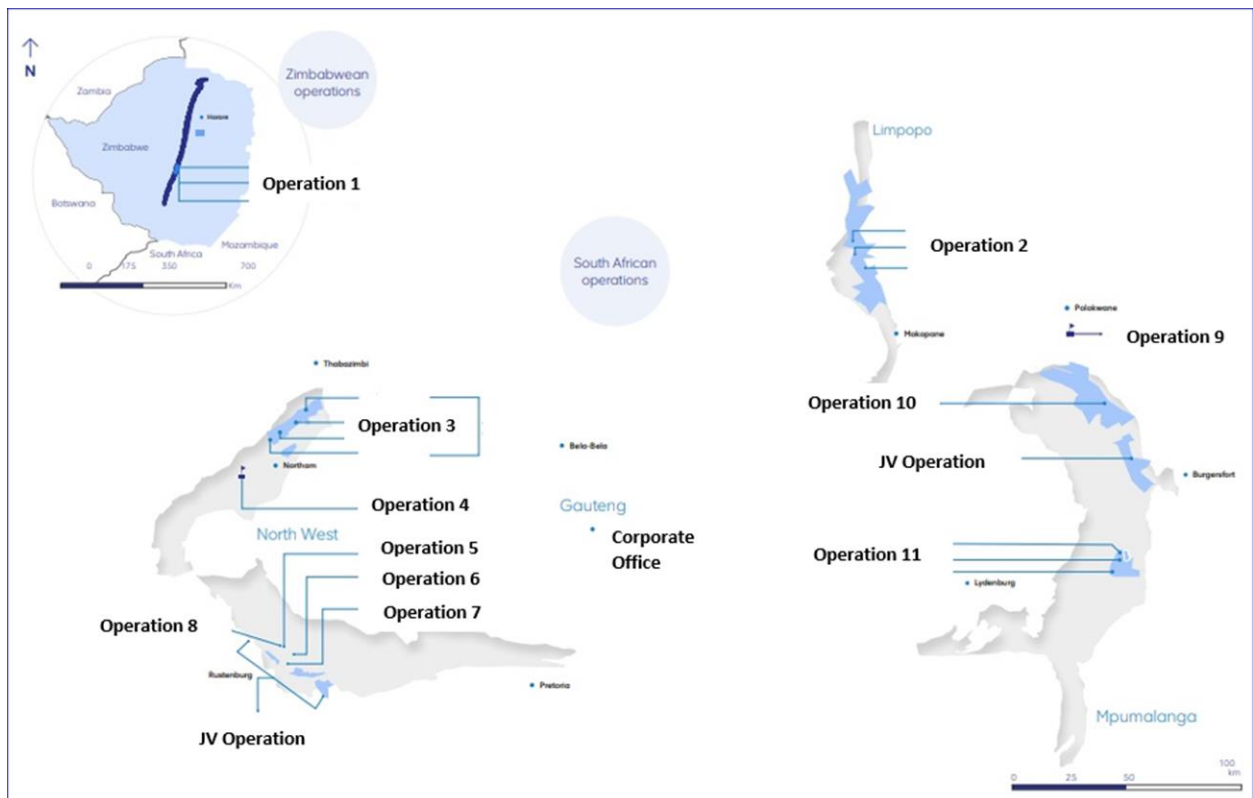


Figure 3-1: Geographical location of AAP operations in South Africa that formed part of the study (AAP11, 2021:3).

Table 3-2: List of operations that was included in the case study.

Operation Number	Operation type	Included in research scope? (Yes/No)
Operation 1	Mines, concentrators and smelter	Yes
Operation 2	Mines and concentrators	Yes
Operation 3	Mines and concentrators	Yes
Operation 4	Smelter	Yes
Operation 5	Acid convertor plant	Yes
Operation 6:	Base metals refinery	Yes
Operation 7	Precious metals refinery & distribution centre	Yes

3.4 Data Collection

Data on the case study operations was collected by means of document analysis and semi-structured interviews. The research identified barriers and opportunities that may influence the implementation of clean energy initiatives in platinum mining by reviewing and evaluating printed and electronic documents and by interviewing individuals who are involved in the implementation of clean energy initiatives in the target organisation.

3.4.1 Document analysis

Document analysis is one of the methods that can be employed to collect data from existing documents. Document analysis is a systematic way of reviewing or evaluating documents, which may be in a printed or electronic format (Bowen, 2009:27). According to this author, some of the advantages of collecting data through document analysis is that documents can be easily accessed. In addition, the process is efficient and cost-effective and provides the specific information required. Hall and Rist (1999:302) argued that data collection through document analysis can provide researchers with a wealth of information. These authors believe this method is unobstructed and will not result in selective memory and social bias. Like other methods, document analysis has weaknesses associated with it. Ahmed (2010:10) and Bowen (2009:27)

reported that document analysis is restricted by the availability of material, which may result in inaccuracies in the original material.

Policies and strategies from the government, sustainability reports from mining and corporate spheres, as well as scientific articles, were used during the document analysis. Data was also collected by searching credible electronic sources available through Google Scholar, government websites, online libraries, and other databases. In addition, internal corporate documents related to the case study operations that have undergone the necessary assurance checks by the accredited auditors before publication was obtained from electronic organisation databases.

3.4.2 Interviews

Semi-structured interviews were conducted with the key role players who are experts in the fields of energy management and who provide support to the AAP operations. These individuals are also involved in the implementation of clean energy initiatives in the case study operations. The researcher aimed to obtain their perspectives on the opportunities and barriers to the implementation of clean energy initiatives in platinum mining. In addition, it was expected that the research would gather a variety of insights from participants who were likely to have different views and experiences.

3.4.2.1 Interview methodology

Because the researcher and the identified participants were based in different geographical areas, the interviews were conducted using Microsoft Teams, a virtual communication platform that allows individuals to connect, record and hold discussions through video or audio. This method of communication has been popular since the start of the Covid-19 pandemic. The use of this communication tool is supported by Sah (2020:1104), who found that it was an alternative to face-to-face interviews which is viable, cost-effective and saves travelling time. It is also convenient, as it allows both the researcher and participants the opportunity to mutually agree on a suitable time to conduct interviews.

3.4.2.2 Design of the interview questionnaire

A guiding questionnaire was used for the interviews (Annexure A). The interview questionnaire consisted of three sections, as discussed below.

General information:

This section of the interview questionnaire provided a brief description of the research background, as well as research aims and objectives. This section also collected general

demographic information about the participants, including role and experience of the participants in the mining industry and clean energy field. Data was collected on the name of the operation, current designation, current role and job description, qualification, the number of years in the mining industry and role and experience with clean energy initiatives. Lastly, this section included generic open-ended questions about the participant's view on clean energy initiatives in the entire mining industry.

Consent form

The interview questionnaire was accompanied by a consent form, which participants had to complete before participating in the research. The purpose of the consent form was to ensure that individuals made an informed choice on whether to participate in the research or not, without being subjected to penalties. In the form, the researcher briefly introduced the nature of the research, the expected duration of the interview, potential risks and benefits associated with the study, confidentiality information and contact persons. The participants were made aware that participation is voluntary and that they may choose to withdraw from the study at any moment without incurring any penalties. It also requested permission to record the interview sessions on MS Teams. All participants consented to participate before commencing with the interviews.

Barrier categories and opportunities:

This section of the interview questionnaire was structured to obtain the view of the participants on the barriers that influence the implementation of clean energy initiatives in platinum mining. The actions taken and potential opportunities required to achieve implementation of clean energy initiatives were also included in this section.

The barriers were structured into categories that were derived from the literature review. The barriers were classified into technical, economic and financial, institutional, awareness and information and land constraint categories.

The researcher first defined the barrier category and then, through closed-ended questions, gave the participants the opportunity to identify the barriers that could be applicable to the mining industry. Where the participants could not identify the barriers under each category, the interviewer suggested examples of such barriers that were identified from the literature review that could be applicable to the mining industry. From the list of examples provided in the questionnaire, each participant was required to select the top two barriers per barrier category that according, to them, influenced the implementation of clean energy initiatives. For each of the top two barriers identified, the participants needed to provide a motivation for their choice based on their experience in existing or planned clean energy initiatives.

Through open-ended questions, the participants were further asked to identify and describe the possible opportunities that could be taken to overcome the specific barrier and facilitate the implementation of clean energy initiatives. The participants' responses to the open-ended questions were furthermore used to stimulate further discussions through targeted questions.

This approach allowed the researcher to obtain detailed data about the barriers and opportunities to the implementation of clean energy in the mining industry. Davies and Hughes (2014:28) argued that this approach can provide the researcher with opportunities for new ideas and/or additional initiatives that may have been missed.

Closing questions:

This was the last section of the interview questionnaire, which was designed to give the participants another chance to identify additional barriers and opportunities not mentioned before. Information on the clean energy initiatives implemented by other mining companies that might be replicated in other operations was also collected.

3.4.2.3 Pilot interview

The interview questionnaire was first piloted before it was used in the interviews. The purpose of the pilot interview was to help the researcher identify any flaws or limitations within the interview design and allow modifications to be made to the research study where required. (Majid *et.al.*, 2017:1074). In this study, the pilot interview was conducted via MS Teams with one of the energy experts who is responsible for the implementation of clean energy initiatives in AAP. The exercise was valuable as it allowed the researcher to identify shortcomings and modify the interview questionnaire where required.

3.5 Data analysis

Data analysis is an important step in research studies. According to McNabb (2010:287), data collected from various sources and methods provides meaningful value when analysed, processed, and interpreted by the researcher.

In this study, data analysis was undertaken through content analysis, a research tool that identified words or phrases from text and extrapolated them into themes or concepts based on their presence or repetition (Babbie, 2021:327; Hsieh & Shannon, 2005:1277). Creswell and Creswell (2017) argued that the method of using a coding process to generate themes or categories is best suited for case studies, thereby rendering it suitable for this research.

The coding categories were developed deductively, using key factors or barriers and questions that formed part of the interview questionnaire. The coding categories represented five key factors that may play a role in the implementation of clean energy initiatives. This information was used to develop the interview questionnaire. Hsieh and Shannon (2005:1281) denote this approach as directed content analysis, which aims at validating or expanding a specific concept or theory.

Notes and recordings were analysed manually, using the MS Teams interview recordings to determine the appropriate barrier coding categories they fall under. From the predetermined codes, the participants were requested to identify the barriers they experienced during the implementation of clean energy initiatives at their operations. They were also asked to provide potential opportunities that may be taken and actions that have already been taken to address the barriers related to each identified category. In this way, the researcher identified new barriers and opportunities during the data analysis process that were not identified during literature review. These were also allocated to previously identified categories or sub-categories.

3.5.1 Determining the importance ranking of the top barriers

The overall importance ranking of the barriers identified by participants was achieved using the calculated weighted average calculation method from the data set. According to Ganti (2023), this method is used to determine the importance of the numbers in a data set. The author believes this method can yield more accuracy compared to a simple average in which all numbers in a data set are assigned an identical weight.

The weighted average was calculated as follows from the data sets for the identification of all and top two barriers:

1. The number of participants that identified a specific barrier was used to allocate a rank to the barriers. The highest number of participants that identified a lack of technical expertise for both datasets was 10, which meant that this barrier was ranked as 1. The second highest number of participants in the all barriers dataset that identified the intermittency of renewable resources was 9, which meant that this barrier was ranked 2. Similarly, the third highest number of participants in the all barriers dataset that identified fossil fuel abundance, accessibility and affordability was 8, which meant that this barrier was ranked as 3. The same logic was applied to the ranking of the other barriers in each of the two datasets.
2. A total weighted score was calculated by multiplying the number of participants that identified a barrier by the rank of that barrier for each of the datasets and summing the values for the two datasets.

3. The barrier with the lowest weighted score was ranked as the most important overall, with the second lowest value as the second most important barrier. The same logic was followed for calculating the overall importance of all barriers.

Through this method, the overall importance ranking of the top 11 barriers, based on the results of the identification of all barriers, and the top two barriers was determined.

3.6 Ethical considerations

The process of obtaining ethics clearance was followed prior to the commencement of the study. The North-West University Senate Committee for Research Ethics (NWU-SCRE) declared the study to have minimal ethical risk and granted permission to proceed with the research under ethics number N W U - 0 1 2 1 7 - 2 2 - A 9.

To ensure that the participants made an informed decision, they were required to complete a consent form, as discussed under section 3.4.2.2, prior to the engagements taking place. To ensure anonymity, all personal information, such as names on the interview transcripts, was hidden by using pseudonyms, generic descriptors or similar. The research results were presented in aggregate, and the participants were not linked with the findings or views expressed.

3.7 Methodological assumptions and limitations

This section identifies the assumptions and limitations of the chosen research methodology. Although it can be assumed that the mining industry is generally homogenous, with shared characteristics, common obstacles and comparable prospects, this study is confined to a specific case study and excludes other industries and mining companies. As indicated in section 3.2, the case study was limited to South African AAP mining and process operations, which included underground and open-cast mines, concentrators, smelters and refineries. Therefore, the outcome of the results on barriers and opportunities influencing the implementation of clean energy initiatives is only applicable to mining and process operations with similar metallurgical activities and processes.

One of the limitations of the data collection was that the research only involved a small number of participants. To address this limitation, the research participants were specifically selected to only include professionals who are actively involved in the planning and implementation of clean energy projects across the operations. They were purposefully selected with the assumption that their experience will ensure that the research question could be answered and/or research objectives could be achieved.

Another limitation of the data-gathering methods is that only electronic documents were used during the document analysis process. In this regard, Hall and Rist (1999:302) warn that some documents used in the document analysis process may be more credible and trustworthy than others. To address this limitation, all documents were accessed from credible sources such as Google Scholar, the NWU online library, Anglo American website, South African Government websites and others. The scientific document searches were limited to peer-reviewed publications, while documents related to the case study were obtained from sources which were subjected to necessary assurance checks by independent auditors before being published.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Introduction

This chapter provides the results of the data analysis and interpretation from document analysis and semi-structured interviews regarding clean energy implementation barriers, opportunities and actions proposed to address the barriers.

4.2 Demographic data of the participants

The data in Table 4-1 summarise the demographic characteristics of the participants obtained during the interviews.

Table 4-1: Demographic data of the participants interviewed.

No.	Qualification/ background	Role/position	Clean energy experience (years)	Mining experience (years)
1	Electrical Engineering	Electrical engineering specialist & operational energy champion	1	18
2	Electrical Engineering	Energy specialist	10	1
3	Mechanical Engineering	Energy specialist	3	10
4	Electrical Engineering	Electrical & energy engineer & operational energy champion	8	15
5	Electrical Engineering	Electrical & energy engineer & operational energy champion	9	3
6	Electrical Engineering	Electrical engineering specialist	5	7
7	Electrical Engineering	Electrical & energy engineer & operational energy champion	4	23
8	Electrical Engineering	Electrical engineering specialist	2	27
9	Electrical Engineering	Electrical & energy engineer & operational energy champion	2	6
10	Electrical Engineering	Electrical engineering specialist	2	20
11	Electrical Engineering	Electrical engineering specialist	4	3
12	Mechanical Engineering	Energy specialist	10	15

13	Electrical Engineering	Electrical engineering specialist	10	20
14	Electrical Engineering	Electrical engineering specialist	4	4
15	Electrical Engineering	Electrical engineering specialist	<1	4

All 15 participants that were interviewed hold an engineering qualification. Thirteen of the participants hold an electrical engineering qualification, while two hold a mechanical engineering qualification. All the participants have work experience in the mining industry. The participants' work experience in the mining industry ranged from one to 27 years, with an average of 12 years' work experience. Five participants had less than five years mining experience, five had 6-15 years' experience, while five had more than 15 years' mining experience.

All 15 participants interviewed were currently involved with the clean energy initiatives. Their experience in clean energy initiatives ranged from one to ten years, with an average of five years. Only five participants had more than 5 years' experience of clean energy initiatives, reflecting the recency of this trend in the mining industry.

4.3 Existing and proposed clean energy initiatives in the platinum mining case study

The identification and description of existing or proposed clean energy initiatives in the platinum mining case study, was achieved through document analysis and interviews.

The platinum mining case study is known as one of the largest Platinum Group Metals (PGM) producers globally, that invested in implementing renewable energy technologies across various of its operations (AAP4, 2021:17). Like many other industries in South Africa, the case study experiences climate change concerns, electricity supply interruptions, energy security and cost increases. To respond to this energy crisis, the case study operations have implemented measures to reduce their energy intensities and introduce low carbon emission technologies and systems in their energy mixes (AAP5, 2020: 42).

According to PWC (2020:20), one of the driving factors to clean energy implementation by the mining industry, including platinum producers, is the need to decarbonise the industry through renewables and other clean energy solutions. PWC reveal that there are various renewable energy opportunities and solutions for the adoption by mining companies to reduce carbon emissions associated with their activities.

The platinum mining case study organisation has committed itself to decarbonising its operations and transition to a low carbon-economy, through decarbonised energy and transport initiatives.

The case study organisation has implemented several initiatives to displace the use of fossil-based energy and reduce dependency on grid supplied electricity (AAP2 2021:58). In response to climate change concerns and support of the Paris Agreement goals, the case study organisation has developed a carbon neutrality roadmap (Figure 4-1) and has committed itself to achieving carbon neutrality across its operations by 2040. Through this commitment, to reduce its carbon dioxide emissions against the 2016 baseline, the organization aims to reduce carbon emissions generated directly from operational activities and indirectly for operational activities that use electricity purchased from the National Electricity Utility, Eskom (AAP5, 2020:38-45).

To meet the case study operation's electricity demands and support SA in its decarbonization efforts, the case study organisation has recently also partnered with EDF Renewables to develop a regional renewable energy ecosystem (RREE) in South Africa. EDF is a global leading independent power producer that specialises in renewable energy production. Through this partnership, the case study organisation aims to supply 100% renewable electricity to its operations by 2030 (AAP7:2022).

Operations carbon neutral by 2040

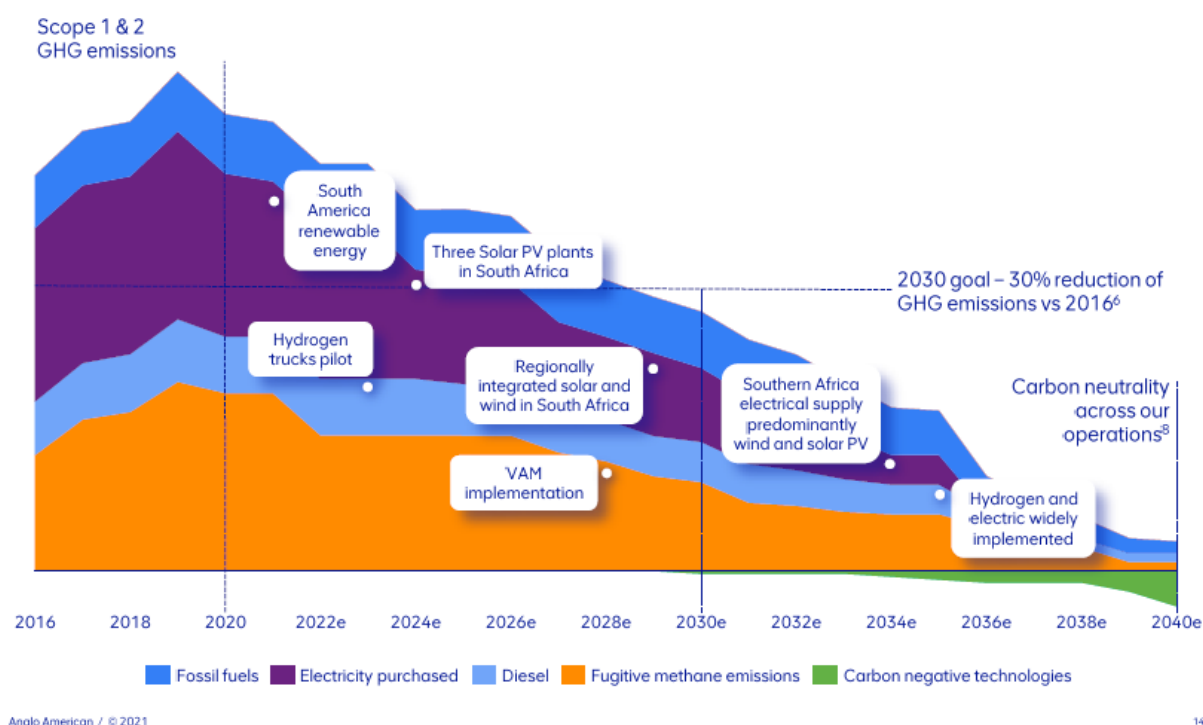


Figure 4-1: Carbon neutral roadmap for Anglo American (AAP4 2021:14).

The case study organisation endeavours to achieve carbon neutrality through various clean energy initiatives, such as improving energy efficiency, clean energy, and adoption of green hydrogen fuel-cells AAP (AAP4, 2021:22; AAP2 2021:58). In addition, the case study

organisation, including individual operations, established carbon-neutrality roadmaps and are in the process of executing project pipelines (AAP2, 2021:58). Clean energy initiatives, such as renewable energy projects and renewable energy storage facilities are some of the implemented or planned initiatives. These clean initiatives which, are shown in Table 4-2, aim to reduce 20% to 30% CO₂ emissions. The case study organisation also plans to reduce 20% to 25% CO₂ emissions by reducing energy intensity through steam reticulation optimisation projects.

In addition, the case study organisation plans to decarbonise the mine fleet by rolling-out approximately 40 hydrogen fuel-cell electric mine haul truck trucks in one of their mines situated in the Limpopo Province, to replace diesel fired trucks and reduce diesel consumption. Reducing carbon emissions in mining and related activities through this initiative, PWC (2020:20) indicated that the cost for renewable hydrogen implementation is anticipated to decline by 60% over the coming decade, thus presenting opportunities to extend this initiative to other AAP mining operation's fleet (AAP, 5:44).

Hydrogen will be produced by the electricity generated from the large-scale solar PV plant project that is in the process of being implemented. This ground-breaking initiative was launched in early 2022 and is anticipated to reduce the companies CO₂ emissions by 10% to 15%. The combination of renewable energy and hydrogen powered haul trucks is expected to result in a reduction of carbon emissions by 50% to 70%. This will apply for emissions generated directly from the operational activities and carbon emissions incurred because of the use of electricity purchased from Eskom for operational activities.

Another initiative that contributes to a reduction in energy consumption is the AAP Future Smart Mining programme, where a reduction in energy intensity is achieved through various technological advancements, which involves process and equipment modifications (AAP5,2020:43-45). Table 4-2 summarises the existing and planned clean energy initiatives across various AAP operations.

Table 4-2: Clean energy initiatives implemented/planned by AAP (AAP12:2022:17-18; AAP2, 2021:58-63; AAP4, 2020:57; AAP8, 2012; AAP9, 2014; AAP10, 2015).

AAP Operation	Initiative	Progress
SA AAP operations	AAP has signed a memorandum of understanding with EDF Renewables, a global leader in renewable energy and independent power producer to develop a regional renewable energy ecosystem ("RREE") in South Africa, consisting of a network of on-site and off-site solar and	The renewable energy ecosystem will be designed to meet all SA AAP's operational electricity requirements from renewable sources by 2030.

AAP Operation	Initiative	Progress
	wind farms to provide AAP operations with renewable energy.	
Operation 2, Mokopane, Limpopo Province	100MW Solar PV plant to power the mining complex and produce green hydrogen. This will support the constant operation of the hydrogen powered haul trucks.	Construction planned for 2024.
Operation 2, Mokopane, Limpopo Province	Electric mine haul trucks powered by zero-emission hydrogen fuel-cells replacing the diesel-powered haul trucks.	First truck launched in Quarter 1 2022. Plan is to replace all diesel trucks with hydrogen trucks from 2024.
Operation 2, Mokopane, Limpopo Province	Constructed a 3.5 MW Solar PV plant as part of a hydrogen production, storage, and refuelling system, replacing diesel.	Design and build of infrastructure completed in 2020.
Operation 7a, Rustenburg, Northwest Province	Constructed 350 kWp solar PV plant to supply electricity to the distribution centre.	Commissioning in progress. Plant expected to operate by end of 2023.
Operation 7b, Rustenburg, Northwest Province	1MWp carport Solar PV plant. To be mounted on parking structures which will be connected to high efficiency inverters to generate clean energy.	To be commissioned in 2023
Operation 6, Rustenburg, Northwest Province	1 MWp carport Solar PV plant mounted on parking structures to generate clean energy.	To be commissioned in 2023
Operation 3, Thabazimbi Limpopo Province	200 kWp carport solar PV plant mounted on parking structures to generate clean energy.	Commissioned in 2022
Operation 3, Thabazimbi Limpopo Province	100 kWp roof-top change-house solar PV plant to supply electricity to the new change house.	In progress
Operation 1, 3 and 7, Shurugwi, Midlands	Feasibility studies for large scale solar PV plants that will supply electricity to the operations. Similar implementation model to Operation 2 solar PV plant will be adopted for these operations.	In progress

AAP Operation	Initiative	Progress
Province (Zimbabwe), Limpopo Province (Thabazimbi & Northam) and Northwest Province (Rustenburg)		
Operation 1, Shurugwi, Midlands Province Zimbabwe	150 m ³ biogas digester project generates biogas through the treatment of biodegradable food waste and sewage from the camps and offices. The biogas will be used to sustain the daily average 70m ³ /day cooking energy demands in the on-site kitchens.	Launched in 2020 & ongoing
Villages around Operations 2, 10 & 11, Limpopo Province	Solar streetlights installed in 10 villages around these operations, employing more than 100 young people to maintain the lights and benefitting about 50 000 community members.	Completed (Commission date not publicized)
Operation 3, Limpopo Province	Operation 3 is planning to install water covers with floating solar panels on their pollution control dams to save energy and reduce evaporation losses. Concept study has been completed.	In progress
Various locations, Limpopo Province	Hydrogen powered fuel cell locomotives for underground use.	Launched in 2012 & ongoing
Various business units, (location unspecified)	ECO2MAN: An energy and carbon dioxide management strategy programme established in 2010. It focuses on understanding the way in which energy is used across the business units and investigates the energy saving opportunities and other potential positive impacts. Example of energy saving opportunity is moving power demand for use in off-peak periods to benefit from the low tariff-rates.	Launched in 2010 and ongoing.
Underground mines (specific operation and province not disclosed)	Introduced energy efficient electrohydraulic rock-drill technology to replace pneumatic rock drills	Completed in recent years (completion date not available)

AAP Operation	Initiative	Progress
Operation 8, Rustenburg, Northwest Province	Clean energy power plant with a capacity of 5MW developed at Operation 8 to generate electricity from waste heat recovered from Operation 5. The plant has an installed capacity of 5MW of which 4.3MW is available to the grid thus reducing AAPs capacity bought from Eskom.	Launched and in progress
Smelters & Others	Investigating renewable technology options for smelters, as well as clean alternatives to coal energy for steam generation	Investigations underway

Operation 2 plans to develop a 100MW solar PV for electricity generation (AAP2, 2021:63). Electricity generated from the solar plant will supply power to the complex and produce green hydrogen through the recently installed electrolyser. The operation plans to decarbonize their fleet by introducing hydrogen fired haul truck that will displace the use of diesel. These trucks will use hydrogen generated from renewable energy. This initiative will unlock many opportunities for the surrounding communities, who will benefit through community ownership, land lease rentals, job creation and skills development. There will also be opportunities to boost the local market by involving small, medium and micro local enterprises in the project (AAP5, 2020:44; AAP2, 2021:63).

An initiative implemented by Operation 1, is the development of a 150 m³ biogas digester to generate biogas. Biogas will be produced by treating biodegradable waste generated from food waste and sewage from the camps and offices. This creates an opportunity for operations with canteen facilities to generate biogas from food waste, which can be used to meet other energy demands within the operation.

One focus area for AAP identified during document analysis, is the reduction of energy consumption and improving energy efficiency. The organisation's 2030 target is to improve energy efficiency by 30%. According to Igogo *et al.* (2021:11), increase in energy efficiency measures, translates to savings in energy costs, which AAP can realize through these initiatives. The steam reticulation optimisation is an initiative to reduce energy efficiency (AAP2, 2021:59). Replacing pneumatic rock drills with energy efficient electrohydraulic rock-drill technology, is another initiative implemented by Operation 3 (AAP5, 2020:42).

In Operation 2, hydrogen will be used to power mining fleet and displace diesel. This option is believed to improve the energy efficiency of haulage material of trucks (Miller *et al.*, 2012: 533-540; PWC, 2020:20; Igogo *et al.*, 2021:11). An observation made during document analysis and

interviews, and as mentioned in section 2.10, is the partnership in place between AAP and EDF to supply SA operations with 24-hour renewable energy. Through this partnership, Participant 2 indicated that: “AAP has been aggressive and bold in terms of clean energy”. The document analysis demonstrates that many opportunities will be unlocked in the region through this partnership, which includes prospects to develop new economic sectors, local production, and supply chains. In addition to economic opportunities, the partnership plans to involve local Black Economic Empowerment (BEE) partner in their regional renewable ecosystem to ensure shared value and participation by the host communities (AAP7, 2022).

4.4 Barriers to the implementation of clean energy initiatives identified in the case study

A total of 22 barriers were identified by the participants during the interviews based on the identification of all barriers (Figures 4-2) and a total of 20 barriers were identified based on the identification of the top two barriers by the participants (Figure 4-3). Twenty-one of these barriers were also identified during literature review, while two new barriers were identified during the interviews (Table 4-3).

Table 4-3: Total number of barriers identified during literature review and interviews.

Barrier category	No. of barriers identified during literature review	No. of barriers identified during interviews	No. of new barriers identified during interviews
Technical	6	6	1
Economic & financial	5	4	1
Institutional	5	5	
Awareness & information	3	3	
Land constraints	2	2	
Total	21	20	2

Figure 4-2 shows the most important barriers selected by participants, based on the identification of all barriers, whereas Figure 4-3 outlines the most important barriers based on the identification of the top two barriers by participants.

4.4.1 Most important barriers based on the identification of all barriers by participants.

Figure 4-2 provides an overview of the most important barriers based on the identification of all barriers by participants.

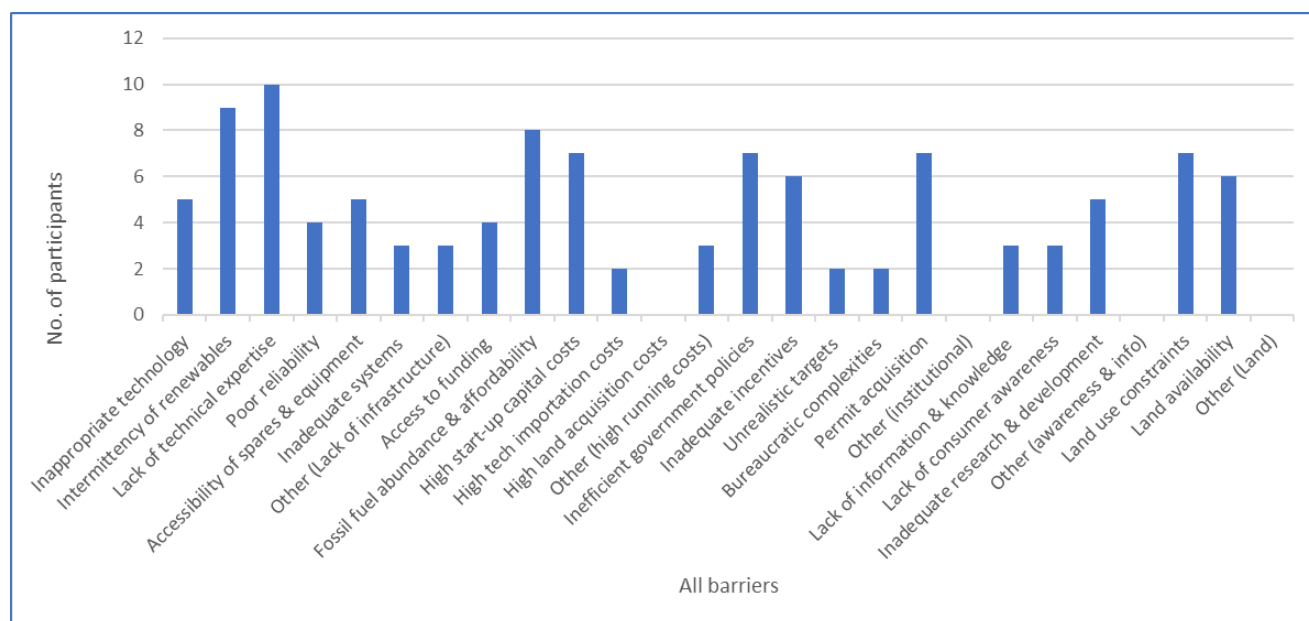


Figure 4-2: Most important barriers based on the identification of all barriers by participants.

Based on the total number of participants who identified specific barriers in the all-barrier results (Figure 4-2), a lack of technical expertise and intermittency of renewable resources were the most important barriers identified by the highest number of participants. Interestingly, both are technical barriers. Similarly, high start-up capital costs and fossil fuel abundance, accessibility and affordability were the most important economic and financial barriers identified, while inefficient government policies, inadequate incentives and permit acquisition were the most important institutional barriers identified. Barriers related to land use constraints and land availability for construction of clean energy technologies were deemed the most important land constraints barriers. One new technical barrier related to a lack of infrastructure support and one economic and financial barrier related to high running costs were identified during the interviews.

Based on the identification of all barriers by participants, the least important barriers were inappropriate technology, poor reliability, inadequate systems and other-lack of infrastructure (technical barriers), access to funding, high land acquisition costs, high running costs, high technology importation costs (economic and financial barriers), bureaucratic complexities and unrealistic targets, other-institutional (institutional barriers) lack of information and knowledge and lack of consumer awareness and inadequate research and development, other-awareness and information (awareness and information barriers) as well as other- land (land constraints barrier).

4.4.2 Most important barriers based on the identification of the top two barriers by participants.

Figure 4-3 summarises the top two barriers identified by the participants through interviews.

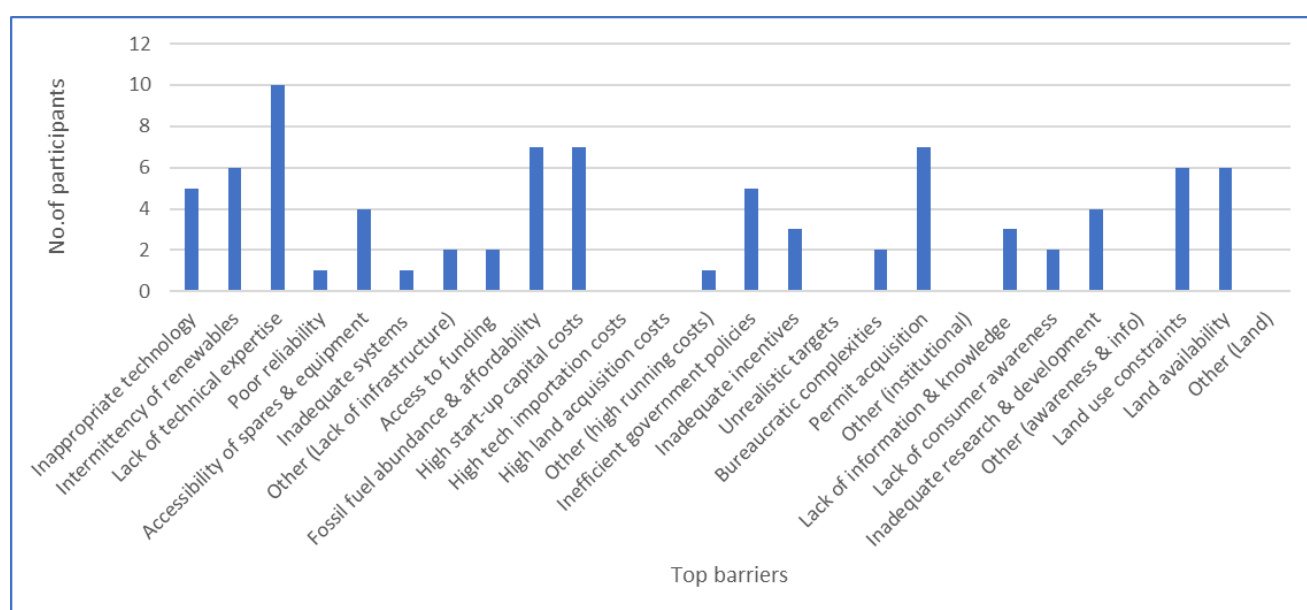


Figure 4-3: Most important barriers based on the identification of the top two barriers by participants.

A technical barrier, a lack of technical expertise, was identified as the most important barrier to the implementation of clean energy initiatives, based on the identification of the top two barriers by 10 participants. Three more barriers were identified as second most important barriers, identified by seven participants as one of the top two barriers. These included two economic and financial barriers of high start-up capital costs and fossil fuel abundance, accessibility and affordability, and one institutional barrier of permit acquisition constraints. Three more barriers were identified as third most important barriers, based on the identification of the top two barriers by six participants. These included one technical barrier of intermittency of renewable resources and two land constraints barriers of land use constraints and land availability.

Lack of infrastructure support, poor reliability of clean energy technologies, inadequate systems (technical barriers), access to funding, high technology importation costs, high land acquisition costs, other- high running costs (economic and financial barriers), unrealistic targets, bureaucratic complexities, other institutional (Institutional barriers), lack of information and knowledge and lack of consumer awareness on clean energy (Awareness and information barriers) initiatives were viewed as the least important barriers based on the identification of the top two barriers by participants.

Nearly 50% of the identified 22 barriers were identified as least important to the implementation of clean energy initiatives. Four barriers were not identified as one of the top two barriers by any participant, another three barriers were only identified as one of the top two by one participant, while four more barriers were only identified as one of the top two barriers by two participants.

4.4.3 Most important barriers to the implementation of clean energy initiatives

The overall importance of the top eleven barriers, is summarised in Table 4-3 based on the results of the identification of all barriers and the top two barriers. Since the last three barriers included in the table have the same importance ranking necessitated the inclusion of 11 barriers and not only the top 10.

Table 4-4: Overall importance ranking of the top 11 barriers, based on the results of the identification of all barriers and the top two barriers.

Barrier	Barrier category	All barriers dataset		Top two barriers dataset		Total weighted score	Overall importance ranking
		Number of participants	Rank	Number of participants	Rank		
Lack of technical expertise	Technical	10	1	10	1	20	1
Intermittency of renewable resources	Technical	9	2	6	3	36	2
Fossil fuel abundance, accessibility and affordability	Economic and financial	8	3	7	2	38	3
High start-up capital costs	Economic and financial	7	4	7	2	42	4

Barrier	Barrier category	All barriers dataset		Top two barriers dataset		Total weighted score	Overall importance ranking
		Number of participants	Rank	Number of participants	Rank		
Permit acquisition constraints	Institutional	7	4	7	2	42	4
Land use constraints	Land constraints	7	4	6	3	46	5
Inefficient government policies	Institutional	7	4	5	4	48	6
Land availability	Land constraints	6	5	6	3	48	6
Inadequate incentives	Institutional	6	5	5	4	50	7
Inappropriate technology	Technical	5	6	5	4	50	7
Inadequate research and development	Awareness & information	5	6	4	5	50	7

When comparing the results for the identification of all barriers with the results for the identification of the top two barriers, the most important barrier to the implementation of clean energy initiatives is a lack of technical expertise, a technical barrier.

Leading barriers are in the technical, economic and financial and institutional barrier categories, namely, lack of technical expertise, fossil fuel abundance, accessibility and affordability, high start-up capital costs and permit acquisition constraints. Intermittency of renewable resources was the second highest barrier identified in the results for all the barriers (Figure 4-2) after lack of technical expertise. However, in the results of the top two barriers (Figure 4-3), fossil fuel abundance, accessibility and affordability, high-start-up capital costs and permit acquisition constraints barriers were the leading barriers identified.

Lack of technical expertise, high start-up capital costs, permit acquisition, inappropriate technology, and land availability for construction of clean energy technologies barriers were equally identified by the participants in the all barrier and top two results (Figure 4-2 & Figure 4-3).

Inefficient government policies, inadequate incentives and inadequate research and development were leading in the results for all barriers (Figure 4-2) but lagging in the results of the top two barriers (Figure 4-3). Based on the results of the identification of all barriers and the top two barriers, inadequate incentives, inappropriate technology and inadequate research and development have the same overall importance ranking and were also viewed as the least important top 11 barriers (Table 4-3).

4.4.4 Technical barriers

4.4.4.1 Lack of technical expertise

Ten of the 15 participants identified lack of technical expertise as a top barrier in the technical barrier category. This barrier was also viewed as the most important barrier overall, from the overall barrier results (Figure 4-2) and the top two barrier results (Figure 4-3).

All the participants, who identified the technical barriers, are involved in the day-to-day implementation and maintenance of clean energy initiatives at the case study operations. However, only one of the three participants, that provide support services to the operations, experienced this barrier. This clearly indicates this barrier is more important to the operational teams than it is to the support services.

Several participants pointed out that the implementation of renewable energy initiatives requires specialised skills, which was highlighted to be lacking. The participants mentioned that the lack of skills required to handle the technical aspects relating to the operation and maintenance of clean energy technologies, negatively influences the optimal operation and maintenance of new technologies.

Two participants indicated that the suppliers of the renewable energy technologies reluctantly share the technical knowledge related to the operation and maintenance of these technologies, making it difficult to independently maintain the equipment and attend to breakdowns timeously and effectively. One participant expressed a view that: *“skill set development is an issue, we are just basing the implementation on electrical engineering knowledge”*. This clearly indicates a knowledge gap that can negatively affect the implementation of clean energy initiatives.

Another observation highlighted in the case study that is linked to a lack of technical expertise, is the fact that most clean energy technology equipment, spares and components are manufactured by international companies. As a result, during equipment breakdowns or failure, a lack of in-house expertise required to repair or replace the equipment/parts becomes a challenge.

The research results are similar to those of Hamilton (2016) who also found that one of the barriers to implementing renewable energy in mining, is a lack of in-house skilled expertise. The case study results also align with findings by Yagoot *et al.* (2016:479) and Luthra *et al.* (2015: 767), who discovered that skilled, experienced, and trained human resources required to design, maintain, and operate sustainable energy technologies were, lacking and were a barrier to adoption. Igogo *et al.* (2020:30) also identified similar findings in which the authors found that the mining industry lacks the proper skill sets required for successful implementation of clean energy technologies. This gap which is supported by Moorthy *et al.* (2019:7), created complications for the operations when it comes to operating and maintaining these technologies because of lack of understanding of the operational procedures.

4.4.4.2 Accessibility of spares and equipment

Five of the 15 participants identified the accessibility of spares and equipment barrier in the all barrier category, while four identified this barrier in the top two barrier category. This barrier was not viewed as the most important barrier overall, from the overall barrier results (Figure 4-2) and the top two barrier results (Figure 4-3).

Availability of these equipment, spares and components locally is another technical barrier identified in this category. One participant mentioned that the energy recovery plant installed in their operation was handed over to the operational staff by the OEM supplier without supplying any spares for the equipment. The operation was only provided with a list of critical spares which they experienced difficulties in accessing them in the local market. In this regard, the operation was forced to order the equipment in the overseas market and in some cases, they discovered that the desired equipment or spares was discontinued in the market. Another participant raised concerns on the affordability of spares in the local market. Because most equipment is imported, many operations depend on the supply of equipment or spares from the international market, which often comes at a high cost due to the associated import and logistical costs. Although some of the equipment may be available locally, the operations found that the prices are higher and sometimes the available equipment and spares do not meet the OEM specifications.

4.4.4.3 Intermittency of renewable resources

Nine participants identified intermittency of renewable resources as a technical barrier in the all barrier results (Figure 4-2), while six participants identified this barrier in the top two barrier results (Figure 4-3). Intermittency of renewable resources was the second highest barrier identified in the results for all the barriers. This barrier viewed as the second most important barrier overall, from the overall barrier results (Table 4-3).

A common barrier identified by the participants that are based at the operations and those providing support to the operations, is the inconsistent and unreliable supply of renewable energy technologies because of their intermittent nature. They highlighted that energy sources such as solar and wind does not supply constant electricity that meet the maximum electricity demand required by the operations. In other words, renewable energy will not be able to provide the required base load power without being supplemented by other systems. Eight participants highlighted a need for adequate backup energy supply, such as battery storage when using renewable energy such as solar energy.

Furthermore, Participant 4 indicated that most of the AAP operation's electricity consumption is constant and require continual and reliable power supply to keep them running. This observation confirms a report by Strazzabosco *et al.* (2022:142), who reported that most mining companies operate around the clock and thus require reliable and consistent electricity supply to avoid detrimental operational consequences. The observation from the case study further aligns with the findings identified under section 2.8.1 of literature review in which Yagoot *et al.*, (2016:478-479) reported that renewable energy sources like wind, solar and biomass have low energy flux compared to traditional energy sources and may not adequately meet the required energy demands without being augmented by other systems.

The results of the case study show that solar energy is the most practical and suitable type of renewable energy to implement by the operations. However, the findings reveal this is dependent on the type of solar technology and the geographical location. Clean energy technologies such as wind were deemed unsuitable for adoption due to uneven and insufficient renewable resources in most of the case study operations. Similar barriers were identified by Luthra *et al.* (2015:767), who discovered that in India, amongst others, geographical and weather conditions had an impact on the adoption and implementation of renewable energy initiatives because of the intermittency of solar and wind and the uneven distribution of these resources.

4.4.4.4 Inappropriate technology

Inappropriate technology was also identified as a technical barrier by five participants in both the all barrier results (Figure 4-2) and the top two barrier results (Figure 4-3). When comparing the results for the identification of all barriers with the results the top two barrier results, inappropriate technology was viewed as one of the least important barriers (Table 4-3).

The common trend identified by eight participants is the fact that renewable energy technologies are relatively new and evolving compared to conventional energy sources. Participant 9 mentioned that uncertainties of introducing different and constantly changing technologies

manufactured by different OEMs might affect the efficacy of the final product. There are further uncertainties that the application of different technological models of different manufacturers will work in a single system. Hamilton (2016) also found that one of the barriers that contributes to delays in the adoption and implementation of clean energy technologies in the mining environment, is because of perceptions that it is unproven technology. This was further supported by Moorthy *et al.* (2019:7) under subsection 2.8.1, who reported that renewable energy technologies are still developing and have insufficient research and development, resulting in inadequate systems.

Five participants that were involved in the operation and maintenance of clean energy technologies experienced inappropriate technology as a barrier. One of the operations that installed solar panels to power access gates discovered that the technology design was insufficient for its purpose even after receiving assurance from the OEM that the technology was designed to specification. Participant 1 indicated that their operation often experienced irregular interruptions on the solar boom gates, due to insufficient battery storage capacity, especially in days when there is insufficient sunlight. Because of these challenges, Participant 1 indicated that inadequate and inappropriate technology may result in reluctance in replicating these types of technologies to other operational activities and/or processes.

4.4.4.5 Lack of infrastructure support

A new barrier identified during the case study is the unavailability of infrastructure to support and enable operations adopt and implement certain clean energy technologies. Only three participants identified this technical barrier in the overall barrier results (Figure 4-2) while two identified it in the top two barrier results (Figure 4-3). One of the operations that explored various technology types to replace coal used for steam generation with hydrogen gas, discovered that the absence of established gas lines in the area to enable reliable gas supply to the operations, became a hindrance to implementation of clean technologies. They discovered that other gas supply alternatives to the operation would be by means of vehicle transportation, but this option was not viewed to be feasible as it would not be adequate to meet the required daily energy demands of the operation. Also, it may not be reliable when unforeseen circumstances such as truck breakdown, protest action and others arise.

The findings of the case study reveal most operations are reluctant to fully implement initiatives without conducting trials first to test and confirm the efficacy and sustainability of these technologies. This was evident in the hydrogen fuel cell haul truck project developed in Mogalakwena Mine, which was reported to undergo testing and validation before expanding the scale of the project (AAP5, 2020:44).

4.4.4.6 Least important technical barriers

The remaining technical barriers (poor reliability & inadequate systems) will not be discussed in detail in this section because they were viewed as the least important technical barriers, identified by less than five participants in the overall barrier and top two barrier results. Although a lack of infrastructure support barrier was not viewed as an important barrier based on the results of the identification of all-barriers and the top two barriers (by less than five participants), it was important to include this barrier in the discussion because it is a new technical barrier that was not previously identified during literature review.

4.4.5 Economic and financial barriers

4.4.5.1 Fossil fuel abundance, accessibility and affordability

The fossil fuel abundance, accessibility and affordability barrier were identified as the second most important barrier in the case study. Eight participants identified this economic and financial barrier in the all barrier results, while seven participants identified it in the top two barrier results. When comparing the results for the identification of all barriers with the results of the top two barriers, fossil fuel abundance, accessibility and affordability was viewed as the second most important barrier (Table 4-3). The participants emphasized that the availability and affordability of fossil fuels, such as coal, puts clean energy at a disadvantage. They further mentioned the difficulties of motivating funding for the implementation of clean energy projects when cheaper alternatives are available.

A common theme observed from the case study operations, is the inability of some of the clean energy projects to provide a good business case when compared to fossil fuel energy systems. Most of the participants highlighted that fossil fuel-based projects provided a good business case compared to clean energy. Interestingly, this barrier was mostly identified by the participants based in the operations and only one participant from the support services identified it as a barrier. This suggests that this barrier is more important to the teams that are involved in the day-to-day implementation of clean energy initiatives as opposed to the support services team.

Participant 15 mentioned that: *“it’s a challenge when you’re trying to justify implementation of clean energy when there is a cheaper alternative”*. This observation is supported by Moorthy *et al.* (2019:5) in section 2.8.2 of the literature review, who is of the view that fossil fuels are a competitor to renewable energy and are prominently used due to their abundance, accessibility, and affordability.

Apart from providing environmental benefits, the participants highlighted that projects of this nature are difficult to motivate for funding because of the lack of economic benefit. Although these projects do not necessarily provide a good business case, they indicated that the rising pressures from the investors, and the organisation's ambitions to decarbonise the business, are also a motivating factor to implementing some of the clean energy options that are not necessarily the cheapest. However, this approach was seen to be pursued when all other possible options are explored.

Participant 9 reported that their operation uses coal in their process, which are already set up in terms of harnessing it. Its affordability and accessibility make it a barrier to implementation, and in this case, changing to a new technology would require high capital input. Similar to the view of Participant 15, Participant 9 also indicated that: *"it's a barrier having to weigh to move to another type of energy when you have a cheaper option to get the same energy"*. This statement proves that motivating a business case for clean energy initiatives when there's a cheaper fossil fuel option, may be challenging.

4.4.5.2 High start-up capital costs

High start-up capital cost barrier is one of the highest barriers identified in the case study following the lack of technical expertise and fossil fuel abundance, accessibility and affordability. This barrier was identified by seven participants in the all barrier results, who equally identified it in the top two barrier results in the economic and financial barrier category.

The common trend observed is the capital constraints experienced, related to electricity back-up systems, infrastructure and technology modification costs, that would be required when introducing some of the clean energy technologies into the operations. Participant 9 mentioned that their experience with solar technology for example, is the high start-up capital costs needed for energy storage equipment, which are mostly imported from international markets. This observation is also supported by participant 4, 11 & 15, who mentioned that battery storage equipment is one of the expensive components in terms of renewable energy implementation. They indicated that solar energy is impractical to implement if the electricity backup or storage systems are not available or sufficient during power supply interruption. Participants from Operation 1 indicated that some of their financial constraints are because most solar equipment including storage, are not manufactured locally, thereby resulting in dependency on the international market for supply. These findings align with the observations by Luthra *et al.* (2015:765) in section 2.8.2.5 of the literature review, who argues that clean energy technologies imported from technologically advanced countries are efficient, but the initial start-up costs associated with these technologies is normally high.

4.4.5.3 High running costs

Three participants identified a new barrier of high running costs in the all barrier results, while one participant identified it in the top two barrier results. The participants expressed concerns about the high running costs for certain clean energy technologies, which influence their implementation negatively. Ideally, the participants preferred to spend on capital costs for technology that will work and provide free energy without incurring significant operational and maintenance costs. The following view was expressed by Participant 4: *“some of the running costs do not give a good business case”*. Participant 2 also shared similar views by saying *“ultimately, as a business, the financial numbers need to be healthy, otherwise, we won’t survive as a business”*. As an example, one of the operations considered to replace coal with hydrogen energy technology to generate steam from the boilers, however it was found that the initial capital and running costs associated with this technology would be significant and therefore not make good business sense. They discovered that using coal would be economically viable because it is easily accessible and cheaper to generate steam. A similar observation was identified by Abdmouleh (2015: 251), who reported that the use of fossil fuel energy is still preferred by many industries because of the low capital cost requirements associated with it as opposed to renewable energy systems.

4.4.5.4 Least important economic and financial barriers

The remaining economic and financial barriers (access to funding, high technology importation costs and high land acquisition costs) will not be discussed in detail in this section because they were viewed as the least important economic and financial barriers, identified by less than five participants in the all barrier and top two barrier results. High land acquisition costs, previously identified as an economic and financial barrier during literature review, was not identified by any participant in both the all barrier and the top two barrier results.

Although high running costs barrier was not viewed as an important barrier based on the results of the identification of all barriers and the top two barriers by less than five participants, it was important to include it in the discussion because it’s a new economic and financial barrier that was not previously identified during the literature review.

4.4.6 Institutional barriers

4.4.6.1 Permit acquisition constraints

Institutional aspects have been identified by previous studies as one of the significant barriers that impede progress towards implementing clean energy initiatives. Permit acquisition constraints was the highest institutional barrier, identified by seven participants in both the all

barrier and top two barrier results. Like fossil fuel abundance, accessibility, affordability, high start-up capital costs and permit acquisition constraints, came out as one of the leading barriers in the case study and institutional barrier category. The major concern raised by both groups of participants, who provide project support to the operations and those actively based in the operations, is the timelines to acquire permits that is required for development of clean energy projects. In their experience, the permit acquisition processes are lengthy and onerous, thus becoming a burden to project implementation. The time required to get necessary permits and approvals in place often takes longer than the regulated timeframes. Another concern raised is the lengthy time taken by the authorities to update the energy policies to allow the mining industry to develop their own renewable energy plants.

4.4.6.2 Bureaucratic complexities

The participants highlighted that the biggest issue that causes major delays is the process of obtaining approvals from various licensing authorities. According to the participants, the licensing requirements are poorly coordinated with different approvals required from various government institutions and/or licensing authorities. Participant 9 shared their view as follows “*poor coordination, we have to deal with a number of agencies to obtain permits*”. The observations from the case study align with findings from the literature review (Moorthy *et al.*, 2019:7-8) in section 2.8.3, which states that bureaucratic complexities such as poor planning and coordination are a barrier to project implementation and causes project delays. These findings from the case study suggests that the administrative bureaucracies cause frustrations for the applicants and negatively affect project implementation progress.

4.4.6.3 Inefficient government policies

Similar to permit acquisition barrier, inefficient government policies were viewed as another leading institutional barrier based on the identification of all barrier results by seven participants and the second highest institutional barrier based on the identification of the top two barrier results by five participants. This barrier was regarded as the sixth most important barrier of the top 11 barriers (Table 4-3). Although the South African government is making efforts to improve the policies, the participants emphasized that progress to improve and implement these policies is slow and that the efforts to enforce them is inadequate. Similar sentiments were echoed by Participant 15, who pointed out that: “*they lack in terms of oversight and enforcement of those regulations*”. The lack of enforcement of regulations is observed to cause complacency in terms of adoption and implementation of clean initiatives. Moorthy *et al.* (2019:7-8) in section 2.8.3 of literature review also confirmed that regulatory barriers such as inefficient or the lack of government policies, have a strong influence on the deployment of renewable energy.

4.4.6.4 Inadequate incentives

Six out of 15 participants identified inadequate incentives as an institutional barrier in the all barrier results, while three identified it in the top two barrier results. When comparing the all barrier results with the top two barrier results, inadequate incentives was viewed as one of the least important barriers of the top 11 barriers (Table 4-3). Some of the participants are of the view that government is not subsidising clean energy initiatives enough to make them affordable and attractive. They believe that there is a lack of supportive policies that promotes the adoption and implementation of clean energy initiatives. This observation aligns with the findings by Luthra *et al.* (2015:765), who explored barriers that influences the adoption of renewable/sustainable energy technologies in India. The author's findings revealed that insufficient incentives by the government can negatively influence industries and other sectors to adopt and implement clean energy.

4.4.6.5 Least important institutional barriers

The remaining institutional barrier (unrealistic targets) will not be discussed in detail in this section because it was viewed as the least important institutional barrier, identified by less than five participants in the overall barrier and top two barrier results.

4.4.7 Awareness and information barriers

Awareness and information barriers came out as the least identified barrier category in the case study. In this category, lack of information and knowledge is one of the least identified barriers, identified by three participants in both the all barrier and the top two barrier results. This barrier was also not viewed as an important barrier of the top 11 barriers (Table 4-3). In addition, this barrier was barely identified by the population from the support services, only one participant from that group could relate.

4.4.7.1 Inadequate research and development

Five out of 15 participants identified inadequate research and development as a barrier in the all barrier results, while four identified it in the top two barrier results. When comparing the all barrier results with the top two barrier results, inadequate research and development came out as a leading barrier in the awareness and information barrier category. It was also viewed as an important barrier of the top 11 barriers (Table 4-3).

Lack of consumer knowledge regarding clean energy technologies was a common theme observed, in which the participants indicated that clean energy in general is still evolving and lacks R&D, which affects its implementation. This observation is like the findings identified by Luthra *et*

al. (2015:767), who identified lack of R&D as one of the major barriers impeding the implementation of renewable energy in India.

The case study observation reveals inadequacies in the amount of research and trials conducted in the entire mining industry to enable companies, that wish to implement similar technologies, to learn and replicate clean energy initiatives based on the trial-and-error learnings and research studies conducted. They also highlighted that this gap causes reluctancy and uncertainties to implement new clean energy technologies that have not been adequately trialled and tested. The participants highlighted that AAP is the front-runner regarding some of the clean energy initiatives, however, they noted that the disadvantage is that there is nowhere to go to see if the technology is working as a way of promoting adoption. Some participants mentioned that there is a need for more R&D work before implementing projects on a larger scale. Participants 4 & 6, for example, highlighted the need for more R&D on battery storage technology before it can be adopted as a final solution in the industry.

Another observation which can be linked to the barrier of lack of technical expertise, as identified in the technical barrier category above, is insufficient R&D within AAP. Some of the participants acknowledge that the organisation is investing in R&D on clean energy, however in their experience, development of skills of the workforce is lacking. They also highlighted that most of the project studies are conducted by 3rd parties, who rarely impart the skills and knowledge to the on-site teams that are responsible for operation and maintenance of these systems. For example, some of the challenges experienced by some operations regarding maintenance of the solar powered access gates and the fuel cell locomotives that were tested for underground use in one of the operations, is because of the lack of technical expertise and insufficient R&D. They indicated that the workforce was not adequately trained to maintain these technologies. In comparison with findings from literature review in section 2.8.4, Moorthy *et al.* (2019:7) found that investment in research and development in renewable energy in both the public and private space, is insufficient and negatively affects its implementation. As a result, this gap results in operations being sceptical to implement and replicate similar technology.

4.4.7.2 Least important awareness and information barriers

The remaining awareness and information barriers (lack of information & knowledge and lack of consumer awareness) will not be discussed in detail in this section because they were viewed as the least important awareness and information barriers, identified by less than five participants in both the overall barrier and top two barrier results.

4.4.8 Land constraints barriers

4.4.8.1 Land use constraints

Seven participants from both the support group and the operations identified land use constraints in the all barrier results, while six participants identified it in the top two barrier results. When comparing the all barrier results with the top two barrier results, land use constraints were regarded as the fifth most important barrier of the top 11 barriers (Table 4-3). Although not all operations experienced this barrier, the participants who identified this barrier believe it has the potential to become a “*showstopper*” when it comes to implementation of clean energy initiatives, especially when it comes to renewable energy projects that require a large footprint for development.

Observations from the case study indicate that land use challenges are linked to social aspects. For example, land use constraints were observed as a common theme in this category. This barrier is faced by some operations, especially in cases where land near the mining operations is owned by government, communities, tribal authorities etc. Few participants mentioned that clean energy initiatives are difficult to implement if land is not owned by the organisation. Lengthy land acquisition processes, such as lease agreements and other requirements that needs to be in place before project development can commence, are some of the concerns raised by the participants, which contribute to delays in project implementation. Similar findings were identified during the literature review in section 2.8.5 by Martin and Rice (2012:125) who also discovered that in Queensland, constraints related to land acquisition can hinder the implementation of renewable energy systems.

4.4.8.2 Land availability

Unavailability of land that is suitable for construction of clean energy technologies was identified by six participants from various operations in the all barrier and the top two barrier results. When comparing the all barrier results with the top two barrier results, land availability was regarded as the sixth most important barrier of the top 11 barriers (Table 4-3). Participant 5 specified that the adoption of technologies such as wind energy were considered as an option by some operations, however, limitations of climate and geographical conditions became a hindrance to implementation. They found that renewable energy resources where most of the operations are located, were insufficient to accommodate these types of technologies. Intermittency of renewable resources, and the potential biodiversity impacts are some of the limitations affecting the implementation of clean energy initiatives in those geographical areas. The case study findings are similar to the findings by Gangazhe (2016:68), who is of the view that the location of

mining operations plays an important role in adoption and implementation of renewable energy. Gangazhe acknowledges that most mining companies are not located in areas where a variety of renewable energy resources are abundant (Gangazhe, 2016:25).

Furthermore, the availability of land that is big enough to construct enough solar panels needed to meet the operation's energy demand, is a barrier experienced by some of the operations. In section 2.8.5, Li *et al.* (2022:1280) also discovered that land constraints can impede development of large-scale renewable energy technologies. The study also show that climate conditions can hinder the implementation of large-scale clean energy technologies such as wind and hydropower.

4.4.8.3 Land use constraints

Another theme identified in the case study is conflicting land uses, and land use limitations on large-scale renewable energy project development by mining operations as well as land use by the host communities. Land use constraints were identified by seven participants in the all barrier results and six participants in the top two barrier results.

Land invasions by the host communities were raised as a major concern in this barrier category. The participants indicated that local communities often encroach on the land where the solar panels are planned to be built for agricultural or residential purposes with the hope of benefiting from the project. Participant 10 narrated his experience as follows: *"100ha of land was identified for solar field, communities started to see that the mine is erecting the plant, they started building shacks"*. As a result, major implementation delays due to onerous land use negotiations that needs to be undertaken between the organization and communities, were experienced by the operations.

Participants 11 and 15 experienced land use challenges wherein the host communities encroached on a mine leased area to use the land earmarked for development of large-scale solar farm for residential and social activities. Participant 12 shared similar concerns as the participants above, by stating that most of the clean energy projects, such as renewables, require large areas for development. In the participant's view, this is a barrier to implementation because of the challenges experienced with land limitations. In the experience of the participant, land around mining complexes is very limited because of invasions by communities: *"Land constraint is a barrier, the major barrier is for mining houses to try and build these projects because the mining footprint is always encroached on by communities and ever-increasing communities"*. These social issues cause project delays because of the negotiations that must take place with the communities prior to implementation.

Another conflicting situation raised by three participants are challenges of permit acquisition and approvals of renewable energy projects applications in cases where social and environmental aspects compete with proposed projects. Participant 7 and 15 indicated that this affects acquisition of permits especially where large tracks of land is required. The conflicting issues of having to conserve the land for the environment and communities, or for construction of clean energy technologies, can result in project delays and in some cases non-implementation. Similar findings were also observed during the literature review in Chapter 2 by Hilson (2002: 65), who identified land-use conflict as one of the challenges experienced by both the mining companies and their host communities.

4.4.8.3.1 Security constraints

An interesting observation identified during the case study, which came out as another common theme in this category, was concerns about the safety of equipment of renewable technologies. Because of the high crime stats in SA, the participants noted concerns about possible theft of solar panels when installed on land outside the boundaries of the operations. Land availability within the boundaries of the operation is often limited in size to accommodate large scale renewable energy development. Participant 11 who was involved in the implementation of a solar PV plant project, experienced the same challenge and expressed his view as follows: *“the outside space was not an option due to safety and theft issues”*. As a result, this situation often leaves the operations with no choice but to consider alternative plans for project development. For example, Operation 7 explored the possibility of building solar panels on top of existing structures within the operation, however, this option was not practical because some of the structures were not adequately reinforced to carry the weight of the solar panels, which can cause safety implications. Modification of the current structure was considered a solution, but was not feasible, due to safety and high-cost implications. The participants indicated that this barrier influenced the implementation of existing and planned projects negatively.

This observation from the case study was not identified as a barrier in Chapter 2 during the literature review, however, Akinboro *et al.* (2012:80) and Ikejemba and Schuur (2018: 1) in their study, discovered that theft and vandalism of renewable energy technologies is a common problem facing the solar energy utilization. Ikejemba and Schuur (2018: 1-4) in their study reported that in several Sub-Saharan African countries, including SA, numerous cases of theft of solar panels and other renewable energy-related infrastructure from the renewable energy project operations were reported. According to the author, ineffectiveness and failures of government to effectively create jobs and other social securities were some of the contributing factors to committing these crimes by the communities.

Furthermore, survival and non-inclusivity of communities in the implementation of these projects is another major cause of these crimes (Ikejemba & Schuur, 2018: 1-4). These authors believe failure to involve the communities in renewable energy projects, leads to unsustainable management, theft, and vandalism of renewable energy related infrastructures in the Sub-Saharan Africa. They further reported that these social issues can negatively influence the dissemination and sustainability of renewable energy development in the Sub-Saharan Africa.

4.5 Opportunities for the implementation of clean energy initiatives identified in the case study

During the document analysis and semi-structured interviews, it became clear that most clean energy projects in the case study operations are still in the development phase, with solar PV technologies being the most dominant and preferred clean energy technology adopted for implementation by the case study operations. This section will cover the actions proposed by participants to overcome the barriers that influence the implementation of clean energy initiatives in the case study operations.

Figure 4-4 summarises the opportunities proposed by the case study operations to overcome the identified barriers. Skills development is viewed as the most important action identified by the case study operations to address the barrier of a lack of technical expertise. Adopting a hybrid of technologies to address the intermittency of renewable resources barrier, was the second most important opportunity identified by the case study operations. This was followed by various clean energy initiatives proposed by the participants in which the case study operations can involve and empower the host communities. The recent policy and regulation changes in South Africa were seen as an important solution to unlock opportunities to increase the electricity generation capacity in the industry. Introducing stringent targets and law enforcement, streamlining permit acquisition processes, infrastructure development, building solar energy technologies on top of structures, and establishing consortiums to develop funds and address other challenges related to clean energy were regarded as the least important opportunities to drive the implementation of clean energy initiatives.

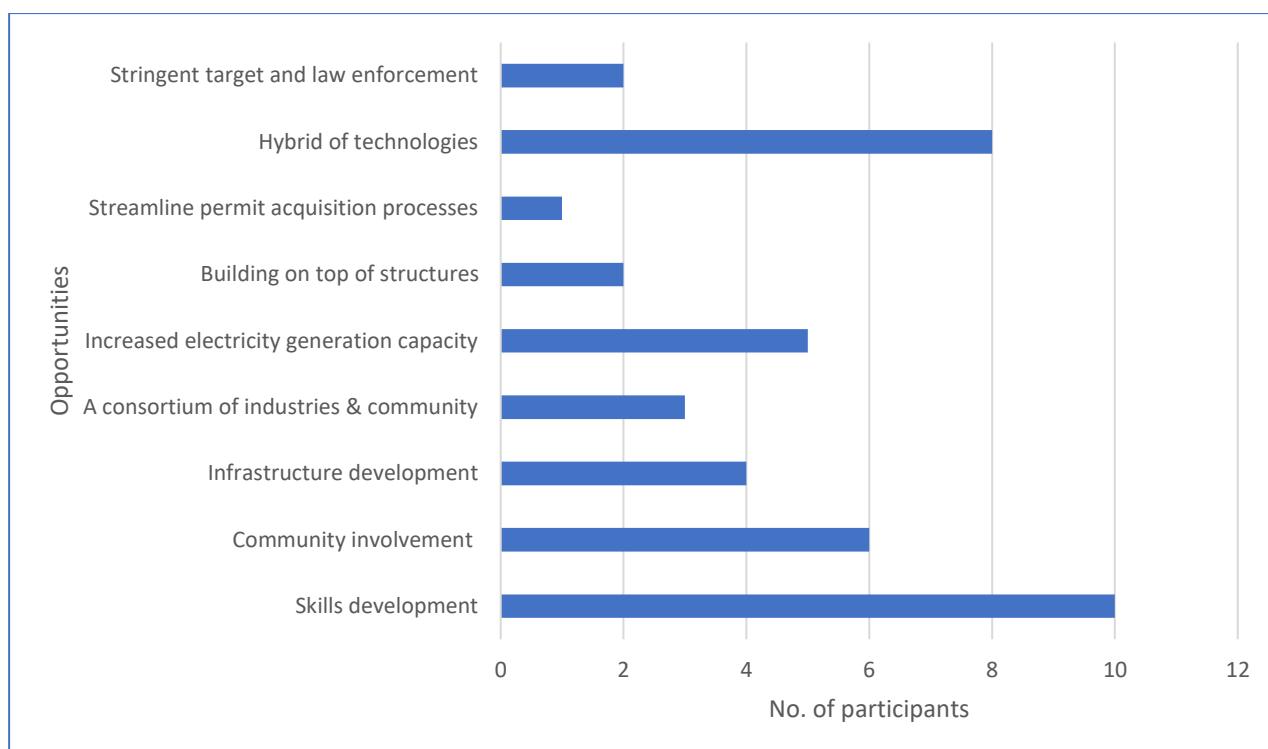


Figure 4-4: Opportunities identified by the case study operations to address the barriers.

4.5.1 Technical opportunities

4.5.1.1 Hybrid of energy technologies

Technical factors were identified in the case study as opportunities to drive the implementation of clean energy initiatives. Referring to Figure 4-4, eight participants suggested that intermittency of renewable resources barrier can be overcome by employing a mixture of technologies to guarantee constant energy supply required to meet the case study operation's energy demands. Examples of the hybrid mixes suggested, include the use of solar energy and molten salt to absorb energy during the day and release at night. Others includes a combination of fossil fuel-based energy with renewables, and a hybrid of solar energy with utility supply and battery storage. Participant 4 and 3 suggested another hybrid mix, which involves wheeling electricity from different areas for use in the case study operations. For example, solar technologies can be used by the case study operations during times when the sun is available, and wheel electricity from the existing transmission networks during the night or daytime when solar energy is unavailable or interrupted.

4.5.1.2 Battery storage

A hybrid system identified in the case study, aimed at ensuring uninterrupted energy supply is the use of battery storage units, that are integrated with renewable energy systems. For example, solar energy can be used during daytime when the sun is available and surplus energy stored in the battery storage units for use at night-time or when the sun is unavailable. Five participants indicated that this type of storage can be used as backup during electricity supply interruption. In line with the case study's findings, Strazzabosco *et al.* (2022:142) support the use of hybrid systems to address the barrier of intermittent renewable energy. Through this approach, the author believes the reliability of power supply to the operations, will increase. Furthermore, these authors believe that no stand-alone renewable energy systems exist, because of the intermittent nature of renewable energy systems. Instead, they suggested that most renewable energy systems can be operated in hybrid configurations with diesel and gas engines.

The study by Strazzabosco *et al.* (2022:142) reported that the cost of battery storage units is decreasing and is expected to decrease even further in the coming years. They also indicated that new renewable energy technologies, that are being manufactured, have battery storage incorporated in the design and is expected to be a norm in the future systems from the year 2021 and beyond. On this point, the mining industry can make use of the purchasing cost reduction opportunities to implement similar technology designs.

4.5.1.3 Infrastructure development

The case study operations also welcomed the SA government's efforts to relax the licensing requirements, which will allow industries to increase their electricity generation capacity. The government's policy and regulation changes will unlock opportunities to increase renewable energy in the industry. Infrastructure development is an opportunity identified by four participants during the case study to enable the adoption and implementation of clean energy initiatives. On this point, the changes proposed by the government will enable the operations to upgrade their infrastructure and increase the capacity to accommodate clean energy technology. For example, certain types of technologies have specific energy requirements, in this case, infrastructure can be developed and upgraded to allow specialised equipment to fit in with the current set-up.

Furthermore, the development of infrastructure to allow transportation of other types of energy, such as hydrogen via pipelines to the end-users, is one more need identified in the case study that will motivate industries to implement clean energy initiatives. This gap presents an opportunity for mining companies to collaborate with government and other industries to develop

such infrastructure to overcome this barrier. There is also an opportunity for research and development in this area.

4.5.1.4 Training and development programmes

As previously mentioned in section 4.3.1, a lack of technical expertise is the highest technical barrier identified in the case study. To address this barrier, the participants emphasized that the implementation of clean energy technologies such as renewables require technical expertise because of the evolving nature of these technologies. Upskilling the workforce responsible for the day-to-day running of these technologies within the operations is identified as an important approach to expand their capabilities and contribute to a smooth implementation of those initiatives. This approach is supported by Sen and Ganguly (2017:1175) as indicated in section 2.10.1 of the literature review, who reported that lack of skilled expertise to operate and maintain renewable energy technologies can deter implementation of these initiatives. Educating the workforce involved in the operation and maintenance of clean energy technologies will also be key in ensuring that the technical challenges associated with these technologies are immediately attended to without having to outsource the services from external service providers. It was further recommended that the technical resources and the workforce responsible for maintenance and operation also form part of the design and feasibility studies. This will add value by reducing downtimes and costs in the case study operations.

Additionally, nine participants believe a lack of skills and expertise barrier can be achieved by means of training and development programmes. This will ensure that the appropriate skill set is in place for the workforce responsible for implementation, including maintenance. The proposed actions align with the solutions noted by Igogo *et al.* (2021:10) in 2.8.4 in which the authors reported that developing educational programs at higher learning educational institutions can be a solution to address the knowledge gap. The same training programmes can be outsourced by the operations to upskill the workforce. The participants further highlighted a need for development of a dedicated Technical team (in addition to the current Energy team), that will provide support to different operations regarding implementation and maintenance of clean energy initiatives.

4.5.1.5 Subsidizing and developing clean energy learning programmes

The participants further indicated, that to transition from fossil fuel usage to clean energy, the government needs to show intent by developing and subsidizing clean energy programs for learning and upskilling labour from the industries that intend to implement clean energy initiatives.

4.5.1.6 Redesigning clean energy technologies

Concerns about theft of solar panels that are developed or planned to be developed outside the boundaries of the mining operations, were raised by several participants. Taking into consideration the crime concerns in the country, this barrier can be overcome by designing these technologies in a manner that incorporates security systems to prevent ease of access and theft. Alternatively, the case study finding suggests building of solar panels on top of buildings or structures.

4.5.2 Economic and financial opportunities

4.5.2.1 Public funding and incentives

Fossil fuel abundance, accessibility and affordability is the highest barrier identified in this barrier category. The fact that fossil fuels energy is still available, abundant, and cheap makes it difficult for the operations to adopt other alternatives. The following remarks were made by Participant 1: *“fossil fuel options are available, if there were no other options, clean technology would have been installed long ago”*. The observations made from the case study suggests that measures be put in place by government to make adoption attractive, for example, by subsidizing clean energy technologies to make them affordable.

The observations from opportunities identified in section 2.10.2 to address the economic and financial barrier suggests a need to improve the public funding system, especially in the R&D regarding clean energy, project start-up and pre-feasibility studies. Yaqoot *et al.* (2016:477-884) believe clean energy policies should include incentives for renewable energy utilization to attract investment.

4.5.2.2 Phased approach project implementation

High start-up capital cost came out as the second highest economic and financial barrier in the case study. This barrier was reported to cause financial constraints to the business, which will subsequently affect implementation of clean energy initiatives. Participant 9 proposed that this barrier can be addressed by implementing these projects in phases. In this way, capital costs can be allocated and distributed in stages over a couple of years. Another suggestion by Participant 6 is the adoption of hybrid systems by mining companies and avoid going off the grid entirely. They can start off with developing small units, which can be increased gradually over the years, while supplementing with the national electricity grid supply. By adopting this approach, Participants 6 and 9 believes it will offset the high start-up capital barrier.

4.5.2.3 Upskilling the workforce

As mentioned above, the case study observations show that solar PV is the most preferred and adopted technology by operations. Participant 2 indicated that solar technology is implemented because of the associated financial benefits. In the participants view: *“the cost of electricity generated from solar is significantly low “*. This statement is confirmed by Igogo et al. (2021:11), who indicated that the savings realised through clean technologies, such as wind and solar can be used as incentives, which can subsequently be used to expand the scope of renewables in the operations. Participant 10, whose operation is planning to develop a large-scale solar farm, mentioned that solar energy technology is cost effective, and its savings can be used to benefit the communities. Linked to a lack of technical expertise barrier identified in 4.4.4.1, a few participants mentioned that their operations generally outsource external providers for maintenance and other specialist services related to clean energy technologies.

According to the participants, this approach is a costly exercise. To off-set the cost constraints caused by outsourcing these services, a few participants proposed training be provided to the workforce responsible for the implementation and maintenance of these initiatives.

4.5.2.4 Working in a consortium

Another means of overcoming the barrier of high start-up capital cost proposed by the participants is for mining companies and similar industries to collaborate and request government to provide subsidies, incentives and land to develop large scale renewable energy technologies, such as solar PVs. Participants 2, 3 and 5 mentioned that working in a consortium will be cost effective and can result in cost savings. Participant 3 also shared their view by stating that: *“working in a consortium will be cheaper because of the economies of scale, the bigger you build the cheaper it becomes, they can save money and create jobs and supply communities when there is surplus”*. This indicates that not only the organization will benefit, but the communities as well. Similar recommendations were made by von Hatzfeldt (2013:206) in which the author suggested that mining and other energy intensive industries can form a consortium to develop a fund which can be used to develop innovative technological projects and use the platform to address other challenges. Surplus electricity generated through these projects can be supplied to host communities. Not only will this close the gap of capital constraints, but it will also open opportunities for employment, benefit the local communities and unlock other benefits.

4.5.3 Institutional opportunities

4.5.3.1 Review of sectoral policies and regulations

Participants 6 and 12 identified a need for a proper revision of the sectoral policies and regulations. They mentioned that the IRP, which provides a framework for the roll out of energy in the country, need to be revised to include clean energy and to give direction on the current generation capacity, renewable energy and all the other technology options and how they will be integrated to provide a full view of the long-term energy plans the country.

4.5.3.2 Enforcing policies and regulations

Another common trend identified by the participants to address this barrier is for the government to enforce the policies and regulations and intensify punitive measures for excessive consumption of fossil fuel energy. A comment by Participant 13 and 15 emphasised that enforcing the policies and regulations can contribute to closing this gap: *“they lack in terms of oversight and enforcement of those regulations. So that's when you realize that people will tend to relax and stay in the lane or possible fields rather than trying to develop initiatives for cleaner energy. Measures in place are not strict against fossil fuels”*. Participants 1 and 9 further added that incentives should be made available to the mining industry by the public sector to drive and enhance the implementation of clean energy initiatives.

4.5.3.3 Streamlining the licensing application and approval process

Seven participants identified permit acquisition constraints as an important barrier that influence the implementation of clean energy initiatives in this barrier category. They indicated that the process to acquire permits is onerous and need to be improved. The participants highlighted a strong need for authorities to review the entire licensing application and approval process and streamline it to ensure efficiency and integration among different licencing authorities. This approach is supported in section 2.13.3 by Moorthy *et al.* (2019:9), who is of the view that streamlining these policies and developing user-friendly procedures will increase the attractiveness of clean energy initiatives.

The actions proposed align with the interventions made by the SA government, summarised in section 2.13.3.2 of the literature review, to mitigate against the challenges of poor coordinator by various government institutions. Government plans to overcome this barrier by establishing a one-point entry for all energy project applications by streamlining the approval processes across various government institutions and entities (RSA2, 2022). This is believed to bridge the gap and

overcome the barriers and hopefully eliminate the frustrations experienced by the project implementation teams and applicants.

4.5.4 Awareness and information opportunities

4.5.4.1 Subsidize learning and skilling programmes

An example of how awareness and information opportunities can be achieved through the clean energy initiatives implementation drive is for the South African government to develop and subsidize learning and skilling programmes and make them available for companies that intend to adopt and implement clean energy technologies. This opportunity identified during the case study is believed to bridge the knowledge gap in the industry and increase the local technical knowledge and skills. It will also reduce the dependency on consultants and other technical expertise outsourced outside the organization.

4.5.4.2 Knowledge sharing and research and development

To address the lack of knowledge gap, as identified in section 4.2.4, the participants suggested that the consultants that are employed to commission these technologies should properly share the technical knowledge with the on-site teams and those involved in the projects as part of the project hand-over to the operations. Investment in research and development is key in addressing the awareness and information barriers in adopting clean energy at the mining industry (Moorthy *et al.*, 2019:18).

Moorthy *et al.* (2019) in section 2.11.4 of the literature review believe investing in R&D can break this barrier and enhance the attractiveness of renewable energy and increase their investment by organizations.

In Figure 4-4, six participants mentioned that involving communities in the clean energy projects can help to close the gap of some of these barriers while empowering them. Educating and empowering local people can also offer economic opportunities, for example, by developing manufacturing plants in the country can also create job opportunities.

4.5.5 Land opportunities

4.5.5.1 Building clean technologies on top of structures

Availability of land suitable for construction of clean energy technologies is a barrier identified by six participants. The main concerns raised were the lengthy timelines taken to acquire land, especially in cases where land is not owned by the organisation. To overcome this barrier, mining

operations that do not have sufficient land needed to develop clean energy technologies can consider alternative solutions, such as floating solar panels that can be built on top of dams. This option is being explored by Operation 3. These floating solar panels are expected to reduce energy and evaporation from their pollution control dams (AAP5, 2020:36). Participant 7 indicated that there is also no need to apply for new permits for this initiative, only amendment of existing permits will be required. It provides other environmental benefits, such as water saving, because of reduced evaporation expected from the dam. Another opportunity identified during the interviews, which was raised by Participant 1, is that manufacturers of clean energy technologies should consider advancing technologies by introducing compact units which require less land space. This creates economic opportunities for the markets and for R&D institutions to investigate, redesign and develop compact clean energy technologies.

4.5.5.2 Partnership with industries and government

An opportunity to overcome the land constraint barrier proposed by Participant 4 is the use of available land outside the boundaries of the operation where clean energy technologies can be developed by using the transmission lines from the national utility supplier to wheel electricity back to the mining operations. They also suggested that government can get involved by offering land where mining companies can build large scale clean energy technologies. The government can use this barrier as an opportunity to drive their strategies and plans related to sustainable energy management. They can further lease state-owned land that is suitable for construction of large-scale clean energy technology through a consortium formed with similar industries to develop clean energy initiatives such as renewable energy plants and wheel electricity to them. Mining companies can also collaborate with host communities and lease their land to build clean energy technologies. In this manner, the communities will also benefit from the electricity generated, which becomes a 'win-win' situation.

4.5.5.3 Community development

Concerns about theft of solar panels that are built or planned to be constructed outside the boundaries of the operations was raised as a barrier to implementing these initiatives. To address the theft issues, as identified in Figure 4-4, the participants suggested that the organisation adopt a proactive approach that will ensure the host communities are involved and included in the project processes through inclusive procurement. Although these initiatives may require technical knowledge and skills, the organisation can take the local communities along and empower them to participate in the non-technical aspects of the project. They can also provide programmes to upskill the local community who can conduct maintenance of their technologies, thus creating job opportunities and enhance the relationship between the two parties.

4.5.6 Existing and planned clean energy initiatives by other mining companies

During the interviews, the participants were asked to provide clean energy initiatives that are adopted or planned by other mining companies and confirm their applicability to the case study organisation. Only two out of 15 participants were aware of existing and planned clean energy initiatives by other mining companies or industries that the case study organisation has not yet explored. Most participants are of the view that the case study organisation is leading the way in the country in terms of clean energy implementation and instead other mining companies are learning from the initiatives that the organisation has in place. The case study organisation has explored technologies that are available on the market, however Participant 3 mentioned that molten salt energy storage is a technology that is yet to be explored by the case study organisation. Meanwhile, Participant 5 highlighted that CSP technology that uses mirrors or lenses to generate electricity is another initiative implemented in the Northern Cape that the case study organisation is yet to explore. These participants believe this technology is applicable to the mining industry and can be explored by some case study operations.

4.6 Actions taken by the case study operations to address clean energy initiative implementation barriers

It is clear from section 4.4 that the case study operations encountered several barriers that influenced the implementation of clean energy initiatives. To ensure success and promote implementation of clean energy initiatives, it is crucial to identify actions to overcome these barriers. Section 4.6.1 to 4.6.5 will cover the actions taken by the case study operations to bridge the gaps caused by the barriers.

4.6.1 Addressing technical barriers

4.6.1.1 Hybrid of energy technologies

From the case study, a lack of technical expertise and intermittency of renewable resources were the most important technical barriers identified. During the semi structured interviews with participants 1, 4, 6, 8 and 11, concerns of inconsistent supply of energy caused by renewable technologies and the importance of having sufficient energy storage systems to use as backup when installing renewable technologies, such as solar were raised. To overcome this barrier, the case study organisation is looking to adopt a mixture of energy technologies, including different types of storage systems that will ensure the operations achieve a base load capacity and provide a stable supply. For example, Operation 1 adopted a hybrid of solar, utility supply and batteries to ensure consistent energy supply to their effluent treatment plant and training centre. Battery storage units can be used as back-up when energy supply to the operation is interrupted. When

integrated with renewable energy technologies, battery storage units are known to enhance the reliability of energy supply in the mining operations and can be used as a substitute to fossil fuel. The actions identified to address this barrier were identified in 2.11.1 of the literature review in which Yagoot *et al.* (2016:478-479) and Moorthy *et al.* (2019:7) believe it can be mitigated by installing large storage batteries or similar devices to improve the energy and compensate for the lost energy time.

Operation 2 developed a haul truck that uses a hybrid fuel cell and battery system, which replaces the trucks that are powered by diesel. The operation is in the process of testing this new technology and plans to expand the scope in future by replacing its entire fleet once fully tested. This may be extended to other case study operations when the trial is successful. This new hydrogen technology, which is replacing the use of diesel, is said to be efficient by generating more power compared to its predecessor (AAP2, 2021:63). In addition, as indicated in section 4.3, the case study organisation, through its partnership with EDF, plans to develop a network of on and off-site solar and wind farms to supply renewable electricity to SA operations in the next 10 years, which will also include the much-needed energy storage devices.

4.6.1.2 Training and skills development

Lack of technical expertise is the highest technical barrier identified in the case study. The case study reveals that clean energy technologies, such as renewables, are relatively new and require technical expertise. The case study brought attention to a significant gap concerning the skills development of the workforce engaged in the implementation and maintenance of these technologies.

Operation 8 that developed a clean energy power plant with a capacity of 5MW to generate electricity from waste heat recovered from the Converter Plant, encountered the same barrier during project implementation. To address this barrier, Participant 13 indicated that their operation developed plant operations manuals using guidance from the OEM, which they further used to develop procedures. Sen and Ganguly (2017:1175) as indicated in section 2.10.1 of the literature review, reported that this gap can be closed by training the workforce involved in the implementation of these initiatives and in addition, ensuring that necessary resources such as spare parts and other components needed are easily accessible. In line with the approach adopted by Sen and Ganguly, they also provided training to the artisans relating to the technical aspects of the technology (Sen & Ganguly, 2017:1175). Using the procedures, they further developed the planned tasks observations (PTO), which the supervisors use on a regular basis to establish the competency of the artisans. Through this approach, the process followed by Operation 8 can be regarded as sustainable because of the foundation laid for new employees in

terms of training and implementation. Similarly, to overcome this barrier, four artisans from Operation 2 were trained and certified to operate and maintain the solar systems. Although they outsourced the skills from outside for maintenance, they made sure the artisans were taken along in terms of skills development. Also, there's an opportunity to add the solar tech module in the training modules offered to electricians to prepare them for the large scale 100MW plant that is planned in the case operation.

Operation 8 experienced the barrier of accessibility of spares and equipment in SA during project implementation. To close this gap, the operation approached the local market to help them supply the required spares and equipment that align with their specifications. Minor modifications were then made to the plant to ensure that the spares and equipment that were available in the local markets, were suitable. This was a great contribution to the local market, which also enhanced the economy of the host town. In line with observations from the literature review in section 2.1.10, Sen and Ganguly (2017:1175) also acknowledge the importance of having quick access to spare parts and other components.

4.6.2 Addressing economic and financial barriers

4.6.2.1 Risk ranking during project evaluation

To address the barrier of fossil fuel abundance, accessibility and affordability, two participants indicated that the case study organisation changed the approach in terms of the evaluation process for clean energy projects. To elevate the importance of ESG, they reported that a risk-based approach, which uses a risk ranking method, has been recently adopted to consider all the ESG components. Previously, a risk ranking process that was used to evaluate projects did not take into consideration some of the ESG components. This new approach ensures that projects are evaluated in a manner that clean energy and stay in business projects compete.

4.7.2.2 Partnership with IPP

An economic and financial opportunity realised at Operation 2 is their collaboration with a leading independent power producer and EDF to build the 100MW solar PV plant. This consortium has brought upon economic benefits in that the community is a beneficiary from the dividends of the project without having to invest financially in the project for the duration of its life (AAP7, 2021:62). Likewise, the implemented and planned initiatives such as solar technology, provides a major opportunity to decrease the operational expenditure of the business.

4.6.2.2 High efficiency inverters and rooftop solar panels

Battery storage systems were identified as one of the expensive components among renewable energy system, in the case study. To off-set the high cost of these storage systems and address the financial constraints barrier, Participant 4 indicated that they adopted a different model for their projects in which batteries are not required. Because purchasing storage batteries would be expensive especially for large scale solar plants, they opted to install high efficiency inverters and rooftop solar panels, which will run in parallel, to power the operations and infrastructure without using batteries. This includes disconnecting the grid supply when the sun is available and switching back on when solar energy is unavailable. This model is applied by Operations 6 and 7 who are planning to develop a 1MWp carport Solar PV plant, that will be mounted on top of parking structures connected to high efficiency inverters, to generate clean energy (AAP2, 2021:62).

4.6.3 Addressing institutional barriers

4.6.3.1 Relaxed licensing requirements

One important theme identified during document analysis and interviews is the developments underway in South Africa regarding the energy regulations that are being reviewed to allow industries to generate their own energy for private use. Five participants mentioned that the South African government recently relaxed the licensing requirements by entirely removing the licensing threshold for embedded generation, allowing the private sector to generate their own electricity. The changes in the energy regulations, which were announced by the South African President, were welcomed by the participants, who mentioned that this will create opportunities for operations to develop large-scale solar projects because of reduced red tape. Furthermore, the government also plans to relax the licensing requirements for solar project installations in areas where environmental sensitivity is classified low and medium (RSA2, 2022). These developments, which are welcomed by the case study organisation, will unlock opportunities for large scale solar projects in the case study organisation and the industry at large (AAP5, 2020:43). The case study organisation is already making use of this opportunity through the 100MW Solar PV plant that will be developed in Operation 2. The operation wanted to develop beyond 100MW but could not increase the capacity because of the regulatory red tapes.

4.6.3.2 Energy reduction targets and incentives and public funding

To address the barrier of inefficient government policies and regulations, the business unfortunately does not have control over these inefficiencies, however, they have measures in place to control and reduce the energy intensity. Examples of measures introduced include energy reduction targets, energy efficiency initiatives and others mentioned in section 2.12. Some

of the opportunities identified in section 2.13.3 of the literature review related to inefficient government policies, is that, enabling activities, incentives and funding by government can play a role in the successful adoption and implementation of these initiatives (Winkler *et al.*, 2005:27).

4.6.4 Addressing awareness and information barriers

4.6.4.1 Knowledge sharing

Inadequate research and development were identified as an important barrier in this barrier category. To address the lack of knowledge gap, which came out as a common theme, Operation 8, that developed a clean energy power plant to generate electricity from waste heat recovered from the convertor plant, experienced this barrier. This gap was addressed by involving the OEM, who shared the knowledge with the operation by developing manuals and procedures as well as training the artisans to allow them to maintain the technology.

Participant 2, who did not identify this as a barrier, mentioned that the clean energy initiatives, that the case study organisation has implemented, offers a learning opportunity for other mining companies and industries which have not yet implemented these initiatives. This was seen through a collaboration between some of the case study operations and the neighbouring mining companies regarding clean energy initiatives. It was reported that several engagements with several mining companies especially, neighbouring companies, were held to discuss opportunities and share learnings. The views expressed by Participant 2 find resonance in section 2.10.4, as noted by Igogo *et al.* (2021:10), who believe that mining companies can draw valuable insights from sectors that have effectively embraced clean energy technologies and methods through R&D.

4.6.4.2 Research and development

To address inadequate R&D, Operation 1 project team conducted their own research on the clean energy initiatives. This enabled them to prepare a good business case, which they presented to the leadership of the operation with the aim of gaining their support on the planned initiatives. Their presentation, among others, covered the environmental and financial benefits of the proposed project. Participant 15 indicated that through this approach, they successfully gained the support from the operational management. Participant 15 narrated his experience as follows: "*That's why we are also having support in terms of, you know implementation of the upcoming solar project. So, it's something that we've seen to have actually huge impact financially and operationally*".

4.6.5 Addressing land constraints barriers

4.6.5.1 Community engagement

Finding suitable land to construct clean energy technologies in the land surrounding the mining operations is a barrier identified by six participants. Conflicting land uses and land invasions by local communities is a common trend identified by the participants in this barrier category, which attributed to delays and disruptions in implementing clean energy initiatives in a few case study operations. To mitigate against these barriers, Operation 1 adopted a proactive approach to bridge the gap caused by land use constraints by outsourcing a social specialist who engaged with the local communities prior to project implementation. This offered the two parties' opportunities to address any concerns, find common ground and prevent potential delays and disruptions prior to entering the project implementation state.

4.6.5.2 Construction of clean technologies on top of structures

Operations that raised concerns about theft of renewable technology equipment believe this can be addressed by identifying alternatives to construction on land. For example, technologies such as solar panels can be built on top of existing structures within the operations. Operation 3 plans to install solar panels on top of evaporation dams, meanwhile, feasibility studies at Operations 6 and 7 are underway for a project where solar panels will be mounted on parking structures.

The actions identified in the case study to address the land constraints barrier align with those identified by Aman *et al.* (2015:1200) in section 2.11.5 of the literature review, in which the author reported that technologies such as solar can be mounted on structures such as rooftops. In Singapore where similar challenges were experienced, solar panels were successfully installed on top of the Keppel Bay Tower (Li *et al.*, 2022:1274). Another means of breaking this barrier identified by Igogo *et al.* (2021:11) as mentioned in section 2.10.5, is the collaboration that mining companies can establish with neighbouring industries and communities to employ a shared multi-technology microgrid systems to supply their energy needs. This approach can benefit the involved parties and enhance the relationship between the affected operations and communities.

4.7 Chapter summary

The research findings clearly demonstrate that technical factors are one of the biggest barriers to implementing clean energy initiatives. The most important technical factors identified were related to a lack of technical expertise required to operate and maintain clean energy initiatives, and the intermittency of renewable resources which cause inconsistent supply to the operations. Because of the high start-up capital costs associated with clean energy initiatives, and the inability of fossil

fuel energy to provide a positive business case due to fossil fuel abundance, accessibility and affordability, these barriers were identified as important economic and financial barriers. Lastly, the permit acquisition constraints regarding development of clean energy technology were deemed to be onerous and lengthy, and as a result viewed as important institutional barriers. This contributed to delays and disruptions in implementation of clean energy initiatives.

An important opportunity identified in the case study is the need to train and provide technical skills to the employees that are involved in the day-to-day implementation, operation, and maintenance of the clean energy initiatives. Improved technical skills will result in increased work efficiency and a reduced financial burden caused by outsourcing these services from external service providers. A common opportunity identified to overcome the intermittency of renewable resources is the employment of a mixture of technologies to safeguard against energy supply interruptions to the operations. Lastly, streamlining the policies and regulations related to clean energy is an important institutional opportunity proposed to address the permit acquisition constraints that was highlighted as a barrier in the case study.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter links the research outcome and the research question raised in section 1.4. It also covers a discussion on how the findings from the case study link to the existing literature and its contribution to existing knowledge. The chapter concludes with recommendations for future research.

The research successfully answered the research question: “*What barriers and opportunities may influence the implementation of clean energy initiatives in platinum mining*”. It achieved the research objectives by:

- Identifying and describing existing or proposed clean energy initiatives in the platinum mining case study;
- Identifying and characterising the barriers for implementing clean energy initiatives in platinum mining; and
- Identifying and evaluating potential opportunities for implementing clean energy initiatives in platinum mining and actions that have already been implemented in this regard.

The outcome of the research adds value to expanding the existing knowledge on barriers and opportunities to implementing clean energy initiatives in the mining industry. This case study also adds value by highlighting the barriers influencing the implementation of clean energy initiatives and the potential and implemented approaches to addressing these barriers. The research also identified opportunities for similar research by other mining organizations with similar operations.

5.2 Existing and proposed clean energy initiatives

To answer the first research objective, Table 4-2 describes the existing and proposed clean energy initiatives identified in the case study. While the case study organization is in the process of investigating other alternative energy sources to introduce in their energy mix to replace diesel and grid supplied electricity, the case study operations identified solar PV as the most suitable clean energy technology that offers the greatest impact (AAP5, 2020:43). This was mainly attributed to the availability of the natural sun energy resources required to generate energy in areas where most operations are located. Other types of clean energy such as wind, hydropower and others were also considered in the case study operations, however, the geographical limitations and climatic conditions were limiting factors to implementing these initiatives.

This result aligns with a study by Levesque (2015:32), who demonstrated that solar is one of the most preferred energy sources in copper heap leaching processes and other minerals industry. Strazzabosco *et al.* (2022:138), who investigated the extent to which renewable energy sources were adopted by Australian mining houses, also discovered that solar PV as the highest adopted renewable technology to power mining operations, because of its flexibility, scalability, and cost competitiveness.

5.3 Barriers and opportunities to the implementation of clean energy initiatives

To answer the second and third research objectives, the research revealed that technical factors are one of the important barriers influencing the implementation of clean energy initiatives. The most important technical barrier identified by the case study operations is a lack of technical expertise required to implement and maintain clean energy technologies. This result is similar to the findings by Sen and Ganguly (2017:1175), who discovered that lack of skilled expertise to operate and maintain renewable energy technologies is a major barrier in developing countries. In a similar study, Igogo *et al.* (2021:10), who explored challenges, opportunities, and enabling approaches to integrate renewable energy technologies into global mining operations (inclusive of exploration, extraction, beneficiation, processing, and refining activities), suggested that training and development programs be established in higher institutions to bridge this knowledge gap. It was therefore clear from this research that most of the participants believe that improving the skillset of the workforce through training and development programmes will add value in addressing this barrier.

Another key technical barrier identified is the intermittency of renewable resources, which results in inconsistent supply of energy to the operations. To overcome this barrier, the case study operations suggested that a hybrid of technologies be adopted to ensure uninterrupted supply to the operations and to meet their energy demands. This opportunity is supported by the research of Strazzabosco *et al.* (2022:142), who believe this approach can increase the reliability of energy supply in the Australian mining operations.

High start-up capital cost required to implement clean energy initiatives, and the inability of fossil fuel energy to provide a positive business case because of fossil fuel abundance, accessibility and affordability, were the most important economic and financial barriers observed in the case study. The case study suggests that high start-up capital barrier can be overcome through public funding and by providing incentives to industries that implement clean energy initiatives. Furthermore, the research results indicate that training and developing employees, responsible for implementing clean energy initiatives will also increase work efficiency and reduce the financial burden caused by outsourcing resources and services from external service providers. Lastly, in

line with the findings by von Hatzfeldt (2013:206), the author is of the view, that mining and other energy intensive industries in Chile, can collaborate to establish a fund that can be used to develop innovative technological projects and address other challenges. Through these collaborations, the surrounding communities can also benefit from the of surplus electricity generated and benefit through employment during project implementation.

The research found that the inability of some of the clean energy projects to provide a good business case because of the abundance, accessibility and affordability of fossil fuels, puts clean energy at a disadvantage compared to fossil fuels. The literature review identified a need to increase the attractiveness of clean energy technologies to overcome this gap by improving financial incentives and funding systems (Von Hatzfeldt, 2013:206; Gangazhe, 2016:34; Abdmouleh, 2015: 259-261). Another opportunity identified by the case study is the introduction of strict and punitive measures against excessive fossil fuel consumption through legislative instruments. By imposing punitive measures, subsidizing clean energy technologies, and increasing the affordability of clean energy, industries will be obliged and motivated to adopt and implement clean energy over conventional energy types.

An important observation that displays similarities in both the case study and the literature review findings was on the permit acquisition constraints experienced. The lengthy timelines and processes required to obtain necessary permits and approvals from various licensing authorities and government institutions is an important institutional barrier experienced by the case study organisations, which was reported to cause delays in project implementation. This observation is supported by Moorthy *et al.* (2019:7-8) who argues that bureaucratic complexities, such as poor planning and coordination delay project implementation. Therefore, streamlining the policies and regulations is an opportunity proposed by the research to bridge the gap of poor coordination.

An interesting observation from the evidence gathered from the case study that was not reflected in the barriers during the literature review, is concerns about theft of solar panels on land or areas outside the boundaries of the case study operations. Similar to this finding, Hilson (2002:65) provided arguments that land-use conflict between mining companies and their host communities is a contributing factor to the land constraint barrier. A common approach to address theft concerns and land constraints related barrier is construction of solar panels on top of existing structures such as rooftops, buildings, and others. This was identified by the case study and the literature review. An important opportunity identified in the case study to overcome theft, land use constraints and other social related issues, is the involvement of the host communities in the clean energy projects which may be through skills development, inclusive procurement, and others.

Unavailability of infrastructure to enable and support large-scale development and implementation of clean energy initiatives, is a barrier identified by the case study operations that was not identified during literature review. It was found that establishing gas and/or transmission lines near the operations will require major infrastructure upgrades, which would need high capital input. To overcome this barrier, the case study operations suggested the establishment of a consortium of mining companies, government institutions and other industries to develop such infrastructures. This suggestion also presents an opportunity for future research.

Awareness and information barriers were regarded as one of the least important barriers identified by the case study operations. However, inadequate research and development of clean energy technologies were seen as an important barrier identified in this barrier category. Both case study findings and the literature review results suggest that clean energy technologies have insufficient research and development, thereby creating a knowledge gap. Both the case study findings and Moorthy *et al.* (2019) suggest that this barrier can be overcome by investing in research and development regarding clean energy initiatives. Such an approach will expand the existing knowledge-base, while also increasing the attractiveness of clean energy initiatives for adoption by mining organizations.

During the literature review, limited studies related to the barriers and opportunities that influence the implementation of clean energy initiatives in the South African platinum mining context could be found. From the alignment observed during the literature review and the case study on the barriers and opportunities that influence the implementation of clean energy initiatives and actions taken to overcome the barriers, it can be argued that the case study's findings will be useful to the energy specialists and other mining companies. This includes industries with similar metallurgical processes and activities, including mining, concentrating, smelting, and refining activities. It can also play an important role in guiding and informing the policy makers responsible for developing and reviewing policies and strategies on sustainable energy and associated technologies (Luthra *et al.*, 2015:763).

When comparing the case study findings with research studies conducted in similar contexts, it can be concluded that key similarities exist in the barriers and opportunities and the actions taken to overcome the barriers that influence the implementation of clean energy initiatives.

5.4 Recommendations

The outcome of the research clearly highlights the importance of investing in training and development of the workforce responsible for implementation, operation, and maintenance of clean energy technologies to overcome the technical barrier related to a lack of technical

expertise. Establishing training and development programs in higher institutions and facilities by the public and private sector are an important opportunity identified by the case study and the literature review to bridge this knowledge gap. It will also contribute to an increase in skills and competencies required to implement clean energy initiatives. This is an opportunity for mining operations to provide the necessary skill for the staff involved in the operation of clean energy initiatives. The government can further support the implementation of clean energy initiatives by funding and subsidising the private institutions that intend to develop learning facilities.

Better qualified and skilled staff will be able to operate and maintain the clean energy facilities efficiently. Addressing this barrier will also add value to the operations by improving the reliability of the clean energy technologies through improved maintenance. This will subsequently reduce/limit the downtime periods when clean energy such as renewables is not available. In addition, the financial burden of having to outsource the services for maintenance and operation of clean energy technologies will also be reduced.

To increase the attractiveness of clean energy technologies, both the case study and the literature review findings highlighted that government can influence this through institutional and financial systems. The literature review by Von Hatzfeldt *et al.* (2013:206) points out that the public funding system in both private and public sectors need to be improved and can be extended to R&D in clean energy, pre-investment studies and project start-up. To expand the existing knowledge gap, government can provide support by developing and funding new and existing research institutions on clean energy technologies.

To address the barriers of high start-up capital cost and a lack of infrastructure (such as electricity transmission lines and gas pipelines) needed to support the implementation of clean energy technologies, the case study findings suggest that government play a role of coordinating and collaborating with mining companies, government, and other energy intensive industries to fund and develop innovative clean energy technology projects collectively. This association can also be used to share ideas, conduct research and address other challenges related to clean energy. In addition, the current energy policies and guidelines should be revised to improve financial incentives and public funding related to clean energy initiatives.

Lastly, the government should consider streamlining energy policies and regulations to bridge the gap of poor coordination among various government institutions and other permit acquisition constraints.

5.5 Areas of future research

It is acknowledged that the mining industry may not be homogenous, as assumed in this research. Hence there's an opportunity for further research to explore the degree of uniformity of the case study with other mining operations in other sectors. Such research will be able to determine if, and to what extent the results of this research can be applicable to various other mining operations and sectors.

Unavailability of infrastructure to support and enable dissemination of clean energy in the mining industry is a technical barrier identified by the case study which presents an opportunity for further research. In this regard, energy intensive industries can collaborate with the government to upgrade and develop infrastructure, such as electricity transmission lines and gas pipelines that will further support the development of large-scale clean energy projects for the mining organizations. Further research to investigate measures to overcome this barrier can be pursued by government and interested and affected industries.

A third potential area for research is investigating measures to address the social issues related to theft of solar panels, land-use conflicts between the mining organizations and host communities, and land invasions by communities in areas earmarked for development of large-scale clean energy projects. Although these social issues were not identified as the most important barriers in this research, they can potentially cause disruptions and delays in project implementation for the mining operations located in proximity of communities.

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ANNEXURE A

SEMI STRUCTURED INTERVIEW QUESTIONNAIRE

RESEARCH BACKGROUND

This research aims to explore the barriers and opportunities to the implementation of clean energy initiatives in the mining industry, using Southern African Anglo-American Platinum (AAP) operations as a case study.

The research aim will be addressed through the following objectives:

- Identifying and describing existing or proposed clean energy initiatives in the platinum mining case study (AAP).
- Identifying and characterizing the barriers for implementing clean energy initiatives in platinum mining.
- Identifying and evaluating opportunities for implementing clean energy initiatives in platinum mining.

Clean energy defined:

- *Clean energy refers to energy that comes from natural renewable sources or processes that are constantly replenished. Clean energy also refers to the use of technologies to improve energy efficiency, capture pollutants, recover and store energy.*

INTERVIEW QUESTIONS

Demographic data:

Participant name and surname:				
Name of operation:				
Province/country of operation:				
Designation:				
No of years in the role:				
No of years' experience in mining:				
Qualifications:				
Do you have experience in the clean energy field?	Yes	No	No of years	
What role do you play in relation to energy management?				

Opening questions:

1. Do you support the introduction of clean energy in the mining industry? And is it applicable? Please elaborate?

2. Do you think there is appetite for uptake of clean energy initiatives in the mining industry? Please elaborate/motivate why you say so?

3. In your view, what are the advantages/benefits of implementing clean energy initiatives in the mining industry?

4. In your view, what are the disadvantages/drawbacks of implementing clean energy initiatives in the mining industry?

5. Are there existing and/or planned clean energy initiatives in AAP/your operation that you are aware of? Please elaborate?

Technical Barriers

Technical barriers also refer to the technical performance and reliability of clean energy technologies. Technical barriers to implementing clean energy includes inadequate and intermittent renewable energy resources; inappropriate and inadequate technology design and operation; and lack of or inadequate expertise required to design, maintain, and operate clean energy technologies.

1. In your experience, which of the following technical barriers prevent or delay the implementation of clean energy technologies in AAP?

Technical barrier	Tick if applicable	Any examples/motivation?
Inappropriate technology		
Intermittent nature of renewable energy		
Lack of technical expertise		
Poor reliability		
Accessibility of spares & equipment in SA		
Inadequate systems e.g., technical standards, guidelines procedures etc.		
Other		

2. In your opinion, which are the top two technical barriers and why?

3. How do these technical barriers affect the level of uptake of clean energy initiatives?

4. What actions were taken to address the technical barriers identified?

5. In your opinion, what opportunities can be taken to address the technical barriers identified?

Economic and Financial Barriers

These barriers refer to economic and financial factors that influence the adoption of clean energy initiatives. These include subsidy unavailability, high start-up capital, unavailability of funding from investors and institutions, and others.

1. In your experience, which of the following economic and financial barriers prevent or delay the implementation of clean energy technologies in AAP?

Economic and financial barrier	Tick if applicable	Any examples/motivation?
Access to funding		
High start-up capital costs		
High technology importation costs		
Fossil fuel abundance, accessibility & affordability		
High land acquisition costs		
Other		

2. In your opinion, which are the top two economic and financial barriers and why?

3. How do these economic and financial barriers affect the level of uptake of clean energy initiatives?

4. What actions were taken to address the economic and financial barriers identified?

5. In your opinion, what opportunities can be taken to address the economic and financial barriers identified?

Institutional Barriers

Institutional barriers refer to the government regulations and policies that stimulate the adoption of clean energy technologies by businesses and industries. Institutional barriers can be in the form of administration, incentives, and infrastructure requirements.

1. In your experience, which of the following institutional barriers prevent or delay the implementation of clean energy technologies in AAP?

Institutional barrier	Tick if applicable	Any examples/motivation?
Lack of/inefficient government policies		
Lack of/inadequate incentives		
Unrealistic targets (e.g., renewable electricity generation)		
Bureaucratic complexities (e.g. poor planning & coordination)		
Permit acquisition		
Other		

2. In your opinion, which are the top two institutional barriers and why?

3. How do these institutional barriers affect the level of uptake of clean energy initiatives?

4. Do you think the South African legal and policy framework supports mining companies to adopt clean energy initiatives? Please elaborate?

5. What actions were taken to address the institutional barriers identified?

6. In your opinion, what opportunities can be taken to address the institutional barriers identified?

Awareness and Information barrier

This refers to lack of knowledge and information by the public/organisation regarding clean energy. Uncertainties and resistance by the public/organisation can act as barrier to deploying clean energy technologies.

1. In your experience, which of the following awareness and information barriers prevent or delay the implementation of clean energy technologies in AAP?

Awareness and information barrier	Tick if applicable	Any examples/motivation?
Lack of information & knowledge		
Lack of consumer awareness		
Inadequate research & development		
Other		

2. In your opinion, which are the top two awareness and information barriers and why?

3. How do these awareness and information barriers affect the level of uptake of clean energy initiatives?

4. What actions were taken to address the awareness and information barriers identified?

5. In your opinion, what opportunities can be taken to address the awareness and information barriers identified?

Land constraints barrier

Land constraints barriers refers to availability of land that is of less mineral value and suitable in terms of land grade and cover for construction of renewable technology such as PV solar and wind turbines.

1. In your experience, which of the following land constraints barriers prevent or delay the implementation of clean energy technologies in AAP?

Land constraints barrier	Tick where applicable	Any examples/motivation?
Land use constraints		
Land availability		
Other		

2. In your opinion, which are the top two land constraints barriers and why?

3. How do these land constraints barriers affect the level of uptake of clean energy initiatives?

4. What actions were taken to address the land constraints barriers identified?

5. In your opinion, what opportunities can be taken to address the land constraint barriers identified?

Closing questions

1. In addition to the barriers identified above, are there other barriers that you are aware of that prevent or delay the implementation of clean energy technologies in AAP?

2. To ensure greater adoption of clean energy in the mining sector, what could be done to create an enabling environment, apart from the actions already mentioned to address the various barriers?

3. Are there existing and proposed/planned clean energy initiatives adopted by other mining companies or industries that you are aware of that have not been explored yet in AAP?

4. Do you think these initiatives can be applied to the platinum mining industry? Elaborate on what can work and what will not work?

5. Do you have any closing comments or questions regarding the implementation of clean energy initiatives in the mining sector?
