Creating sustainable physical sciences learning environments through the teaching of renewable energy

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Declaration

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I , **Kgantse Nancy Ramongalo**, declare that the Master's Degree research dissertation or interrelated, publishable manuscripts/published articles, or coursework Master's Degree mini-dissertation that I herewith submit for the Master's Degree qualification **Master of Education with specialisation in Subject Education in Science and Technology** at the University of the Free State is my independent work, and that I have not previously submitted it for a qualification at another institution of higher education.

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Abstract

Teaching of the topic of clean and renewable energy in the subject of physical sciences in South Africa is inadequate – if it is taught at all. This inadequacy continues, despite the provisions of the Sustainable Development Goals on education and the potential benefits of clean energy to the social, economic and environmental aspects of life and living. The aim of this study was to justify the need to create sustainable physical sciences learning environments through the teaching of renewable energy. The study was guided by transformative paradigm principles, which emphasise cultural diversity and social justice, to address societal injustices and inequality. It highlights the need for these principles in communities that are struggling to access energy, despite solar energy (sunlight) availability year round. Three schools were involved in this study. The first was for learners on farms, the second was located in a predominantly Black community, and the third was well resourced, with a merged laboratory. Interviews were conducted with physical sciences teachers at these schools to observe their teaching and learning environments. The participants were qualified Grade 10, 11 and 12 physical sciences teachers with BSc chemistry, B.Tech engineering science, and Postgraduate Certificate in Education (PGCE) qualifications, respectively. All teachers had more than five years of teaching experience teaching physical sciences throughout the Further Education and Training phase. The data show that none of the participants incorporated renewable energy into their lessons, because there was no curriculum on the subject. Participants blamed the curriculum for their failure to teach and assess the topics of renewable energy. Other barriers to teaching renewable energy content included shortcomings in relation to resources and teacher knowledge. If renewable energy is not taught, it tends to contribute to deepening epistemological inequity, given the digital age that confronts learning. Teachers struggle to teach renewable energy ideas due to lack of pedagogical content. The study recommends incorporating renewable energy content in physical sciences to enhance the relevance and responsiveness of learners to social, economic, and environmental challenges.

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List of abbreviations

AC	Alternating current
CAPS	Curriculum and Assessment Policy Statement
DBE	Department of Basic Education
DC	Direct current
FET	Further Education and Training
POPIA	Protection of Personal Information Act
PV	Photovoltaic
SDG	Sustainable Development Goal

CHAPTER 1

ORIENTATION ON CREATING SUSTAINABLE PHYSICAL SCIENCES LEARNING ENVIRONMENTS THROUGH THE TEACHING OF RENEWABLE ENERGY

1.1 INTRODUCTION

This study investigated the creation of sustainable learning environments for the subject of physical sciences through the teaching of renewable energy content. This chapter orients the reader about the study. It starts by providing background information and the rationale for undertaking the study. This is followed by the problem statement that encompasses the research questions and research objectives consistent with the background. An overview of the literature highlights the theoretical framework, operational concepts and related literature. The overview on methodology follows, with subheadings such as research design, trustworthiness, data analysis and ethical issues, as well as the delimitations of the study. The chapter also gives highlights on how the data will be presented, analysed and interpreted. Finally, the chapter concludes with an overview on the findings, conclusions and recommendations.

1.2 BACKGROUND

The use of renewable energy dates back to ancient times (Penna, 2019; Smil, 2018). The earliest examples were waterwheels that imitate the principles of hydropower. The first hydroelectric project started in 1878 at the hands of the Victorian inventor William Armstrong, six years before the invention of the modern steam turbine (Penna, 2019; Smil, 2018). The electricity generated by this innovative endeavour, however, had much lower capacity than modern-day waterwheels/watermills and generated only enough energy to power one electric bulb (Penna, 2019; Smil, 2018).

The windmill is a similar invention to a waterwheel. The first electricity-generating windmill was invented by Charles Bush and this windmill produced approximately 12 kW of electricity (Höfer, 2009; Penna, 2019). By about CE 635, the use of windmills had spread throughout much of the

Middle East and Central Asia. Windmills were the most popular renewable energy source in the world in 1590, until solar energy gained traction over 100 years later (Höfer, 2009; Penna, 2019). Although the first solar collector was made in 1767, the French physicist Alexandre-Edmond had discovered in 1839 that light striking metal electrodes in an electrolyte solution produces electric currents (Penna, 2019; Smil, 2018).

French financier Augustin Mouchot created the first solar energy system in 1860, based on his belief that the coal supply on earth would eventually run out. This creation motivated Alexandre-Edmond to make further advancements to his invention, and establishing North America's first hydroelectric power station in 1882 (Höfer, 2009; Penna, 2019; Smil, 2018). The first light-to-electricity solar cells and commercial solar water heaters were created in the late 1800s (Penna, 2019; Smil, 2018). In 1954, the International Solar Energy Society was founded and, during that period, solar energy research expanded (Strum, 1985).

From then on, the efficiency of solar cells increased and, by the early 1960s, solar thermal energy was Israel's main source of hot water (Scavo, 2015). Tensions in the Middle East in the 1970s gave rise to an energy crisis and an increase in oil prices hastened the advancement of solar energy developments (Scavo, 2015). During the 1990s, government measures, such as tax cuts and technological breakthroughs in energy generation contributed to the growth of the solar energy industry (Knuth, 2018). Construction of large-scale solar power plants started, and the amount of distributed solar electricity produced increased in Asian, European and African countries alike (Knuth, 2018).

In 2009, the South African government introduced the feed-in tariff as a policy to stimulate the renewable energy sector, which is administered by the National Energy Regulator of South Africa (NERSA; Odeku et al., 2010). The goal of the programme was to provide incentives to businesses and individual investors who supported the government's drive to increase the production of renewable energy (Jain & Jain, 2017; Odeku et al., 2010). By reducing the financial risk and guaranteeing a ready market, this incentive was made achievable. The renewable energy produced by certified companies is purchased by the national electrical utility companies at predetermined pricing and integrated into the national grid (Akom et al., 2021; Odeku et al., 2010). Exemptions from payment of corporate tax was another driving force behind the promotion of renewable energy in South Africa (Jain & Jain, 2017).

Today, renewable energy has now also become a source of energy for electric automobiles. Electric vehicle owners are now able to charge their vehicles using rooftop solar systems and solar-powered public stations (Erickson & Ma, 2021). The year 2022 saw a record 26% growth in solar photovoltaic (PV) output, to around 1 300 terawatt hours of power produced (Habiyaremye et al., 2022).

According to South Africa's Department of Economic Development, 400 000 jobs could be produced by the sector by 2030 (Habiyaremye et al., 2022; Henneman et al., 2016). Even before that, by 2025, South Africa envisages to have cut its emissions of greenhouse gases by 42% (Henneman et al., 2016). This expectation echoes the need for teaching and learning about renewable energy, as it may be difficult to implement the creation of green jobs without the availability of skilled workers, just as it may be difficult to achieve 42% reduction in emissions without educated renewable energy awareness. The creation of sustainable physical sciences learning environments through teaching about renewable energy offer long-term viability of the learning about and application of renewable energy, and could enable learners to sustain themselves, their communities and their environments (Ben-Eliyahu, 2021; Cortese, 1999; Department of Education, 2003; DBE, 2011; Stats SA, 2019; Ochonogor & Mohapi, 2020; Tlali, 2017).

Sustainable physical sciences learning environments are inclusive and instil social responsibility, in accordance with the goals of the Curriculum and Assessment Policy Statement (CAPS) for physical sciences (DBE, 2011). The South African basic education curriculum advocates for providing learning that equips "all learners with knowledge, skills and values necessary for meaningful participation in society" (DBE, 2011, p. 8). Accordingly, inclusivity and social responsibility are in line with the concept of sustainability, and with the United Nations Sustainable Development Goals (SDGs; Cortese, 1999; Sachs, 2012; Stats SA, 2019). Renewable energy could assist in achieving SDGs in practical and tangible ways (Cock, 2019; McCauley et al., 2018; Smith, 2019).

South Africa's current electricity supply system is unsustainable, partly due to the depletion of coal reserves (Strambo et al., 2019), the constantly increasing cost of electricity and the carbon footprint burning coal leaves behind, and the compromised health of citizens, especially those who live in areas where coal is mined (Van der Nest, 2015). Sustainable energy alternatives, such as wind, water and solar energy, are the most common renewable energy options. They do not deplete, they emit no harmful gases into the atmosphere, and they are more affordable for citizens in the long term, especially when individuals have the basic knowledge and skills to do the basic maintenance of their energy systems themselves (Physicsworld, 2019; Smith, 2019; Ruiz-Mallén & Heras, 2020). Having knowledge and skills in relation to renewable energy helps citizens to choose the best renewable energy option(s) for their households. Most African countries, including South Africa, generally receive sun exposure throughout the year, so it is practical and attainable to strive to use solar energy as the main power supply throughout Africa (Physicsworld, 2019).

Learners need electricity to learn, due to the demands of the Fourth Industrial Revolution (Xu et al., 2018). Learners' need for reliable electricity was aggravated by the impositions of online learning caused by the COVID-19 pandemic (Ally & Wark, 2019; Tria, 2020). Most South African learners have no source of electricity other than coal-generated electricity (Calitz & Wright, 2021). In the event of load shedding, citizens, including learners, do not know how to harness energy from the sun, wind, water or organic material.

The historic, massive provision of coal-generated electricity to households by the public utility cannot provide electricity to all South African citizens, especially not those living in underprivileged and poor communities (Calitz & Wright, 2021). This state of affairs, which is still being experienced in the 21st century, was, needless to say, sponsored by socio-economic and environmental factors and decision-making (Ceglia et al., 2022; Sheehy-Skeffington, 2020).

Currently, the only occasion when physical science teachers can incorporate a form of the topic of renewable energy in their lessons is through the topic of photoelectric effect, in Grade 12 (DBE, 2011). Through the practical application of the photoelectric effect, learners can observe light shining on metal and the metal ejecting electrons as a result (DBE, 2011). By explaining this process, a link to solar energy principles can be constructed. This shows that solar energy is barely introduced to learners. South African learners should be able to harness the abundant solar energy to fulfil some of their daily energy needs. This situation regarding the curriculum aroused my interest, and led to questions about the extent to which renewable energy content, with its benefits related to sustainability, is taught in physical sciences.

1.3 PROBLEM STATEMENT

Attempts to create sustainable learning environments are informed by the need to equip learners with the requisite competences for meaningful societal participation (DBE, 2011). Meaningful societal participation, in this case, involves inclusive and collaborative modes of teaching and learning that are consistent with the learners' diverse backgrounds and learning needs. Accordingly, the learners' learning needs, which represent their otherwise subjugated voices, must be prioritised. Hence, knowledge of the multiple means to generate electricity, in particular, renewable energy, become relevant for the creation of sustainable learning environments. The inclusion of renewable energy in the curriculum would also afford opportunities for equipping learners with functional and empowering knowledge, skills and values.

Sustainable physical sciences learning environments are learning spaces that offer and afford opportunities to i) gain scientific knowledge about concepts, theories and laws that enable the harnessing of solar, water and wind energy; ii) acquire values that encourage protecting the environment and using resources sustainably; and iii) develop learners' skills to collaboratively identify and use the materials needed to assemble renewable-energy-related components for their immediate energy needs, while being cognisant of the need to balance the social, economic and environmental impacts.

The use and application of energy for the sustenance of the social, economic and the environmental aspects of life and living is pervasive (Liko, 2019). In education, the manifestations of sustainable energy generation and use reside in the provision and support of teaching and learning media, resources and processes through which knowledge, values and skills are transmitted and exchanged (Hays & Reinders, 2020; Hoque et al., 2022). In recent years, our over-reliance and over-utilisation of coal-generated energy has proven to be unsustainable (Kopein et al., 2018; Saculsan & Mori, 2020).

Unsustainability is confirmed by reported and much publicised depletion of coal, the availability of mostly poor-quality coal, the expense of energy production equipment, and limited human resources capital that possess the requisite skills (Espinoza et al., 2015; Hower et al., 2022; Strambo et al., 2019; Yi et al., 2023). Consequently, in addition to other effects, undersupply of energy hampers progress with teaching and learning. Accordingly, attempts are under way, albeit delayed, to move to mixed-grid and off-grid solutions for acquiring electricity (Akom et al., 2021). This calls for investigation of teaching and learning about renewable energy at basic education level.

Teaching and learning about renewable energy in the subject of physical sciences is limited, because it does not progress across the grades as much as current and static electricity does (DBE, 2011). This shortcoming is in place despite the educational and socio-economic needs imposed on humanity by the "new normal" of load shedding in South Africa (Van der Nest, 2015; Du Venage, 2020) and by the COVID-19 pandemic (Chihib et al., 2021).

1.3.1 Research questions

Based on the background presented in Section 1.3, I ask the following question: How can teachers create sustainable physical sciences learning environments through teaching about renewable energy? This question is supported by the following sub-questions:

- To what extent is renewable energy included in the curriculum?
- To what extent do physical sciences teachers incorporate renewable energy in their physical sciences lessons about energy?
- What challenges are experienced when teaching renewable energy?
- How can teachers teach about renewable energy to facilitate the creation of sustainable physical sciences learning environments?

1.3.2 Research aims and objectives

With the above questions in mind, the study aimed to justify the need to create sustainable physical sciences learning environments through teaching about renewable energy. To achieve this aim, the following objectives were pursued.

- To justify the incorporation of renewable energy in creating sustainable physical sciences learning environments;
- To draw lessons from teachers' experiences, if any, of teaching about renewable energy, with the purpose of establishing mechanisms to circumvent the challenges already

experienced or likely to be experienced (when teaching the topic of renewable energy); and

- To reflect on the usefulness of teaching about renewable energy, with the view to creating sustainable physical sciences learning environments.

1.4 OVERVIEW OF LITERATURE

The 2030 SDGs are the blueprint for achieving a sustainable future globally (Stats SA, 2019; United Nations General Assembly, 2015). The SDGs have three indispensable pillars, namely, social, economic and environmental development, that take into account various national realities, capacities and levels of development, while respecting national policies and priorities (Sachs, 2012; Stats SA, 2019); the pillars are consistent with the principles of inclusivity (Smith, 2019). Education is critical for the achievement of SDGs with their seven outcome targets and three means of implementation (Cebrián et al., 2020; Smith, 2019.).

Relevant to this study are the outcome targets, or signposts, that still require contextualisation, reflection and integration with national policy development efforts. Signposts (unquantified) that are pertinent to this study are ensuring (i) relevant skills for the world of work; (ii) relevant learning for citizenship in a global world; and (iii) safe and inclusive learning environments (United Nations General Assembly, 2015). The critical principle undergirding the implementation of SDG 4, on education, is its alignment with national education sector development efforts (Stats SA, 2019). To this end, this study sought to add a voice to the alignment of SDG 4 and national policy efforts, by exploring the integration of renewable energy (SDG 7) in science education lessons (United Nations General Assembly, 2015).

SDG 7 is about "ensuring access to affordable, reliable, sustainable and modern energy for all" (United Nations General Assembly, 2015, p. 21). In line with this goal are the targets to "substantially increase the share of renewable energy in the global energy mix and enhance international cooperation to facilitate access to … renewable energy" (United Nations General Assembly, 2015, p. 21). Additionally, researchers claim that the availability of an efficient, consistent and affordable energy supply will have a considerable effect on all three the pillars of the SDGs, because an energy supply is critical for the functioning and development of human societies (Cock, 2019; McCauley et al., 2018).

The issue motivating this study is the extent to which renewable energy as a topic is prevalent in science learning, to the extent that science education graduates are prepared well in advance for envisioned future work environments (Smith, 2019; Stats SA, 2019). The timely and appropriate preparation of science education learners is critical and urgent, considering the general aims of the South African curriculum, Grades R–12, in particular, as stated in the CAPS, for the purpose of "equipping learners ,… with the knowledge, skills and values necessary for self-fulfilment, and meaningful participation in society as citizens of a free country" and "facilitating the transition of learners from education institutions to the workplace" (DBE, 2011, pp. 4-5). Consequently, the undergirding CAPS principles of credibility, quality and efficiency become instructive.

Some countries have progressively integrated knowledge of renewable energy in their basic education syllabi, to teach students about its importance from an early age (Cebrián et al., 2020; Smith, 2019). China, Japan, Australia and Russia have included the topic of renewable energy as a significant part of their curricula and general school cultures. For example, China has undertaken a green electricity programme that provides renewable energy to many of its schools. Solar panels on school grounds provide a powerful message to pupils about the significance of transitioning to sustainable energy (World Bank, 2012).

Hong Kong schools have implemented a solar education programme that gives primary and secondary school pupils hands-on experience, provides them with information technology skills, and presents them with problem-based learning opportunities to create solutions (Close, 2003). The initiative aims to increase the learners' and, ultimately, the population's knowledge and understanding of the contribution of renewable energy technologies to everyday life, and to broaden the expertise of local construction experts in remote electrical tilt installations (Close, 2003). Japanese learners, in turn, are given the opportunity to gain functional skills that enable them to work with renewable energy from a young age through learning how solar energy systems work, and constructing models of these systems in classrooms under the topic of power, energy and the energy network (Solar Energy International, 2021).

In Australia, the Victorian Solar Energy Council instituted a renewable energy education initiative in schools that uses the constructivist approach, and primary and secondary school teaching packages were created for this reason (Kandpal & Broman, 2015; Solar Energy International, 2021). In 1987, the kits contained batteries, direct current (DC) to alternating current (AC) inverter, DC fuse box, small solar panels, charger and a guide on how to build the system. The kits were made available to elementary schools in Victoria at no cost, and in-service training courses for teachers who would be using them were established (Charters, 1990; Kandpal & Broman, 2015). The materials in the packages contain games and activities for experimental work, as well as instructions for building simple experimental apparatus for use in the classroom and outdoors.

Similarly, the Moscow Institute of New Technologies in Education launched a course for secondary and educational solar laboratories (Koltun & Gukhman, 1993; Kandpal & Broman, 2015). It was becoming increasingly clear that school learners needed to gain an understanding and experience of the complexities of engineering energy system designs and be able to follow a design project from conception to completion, including testing and performance evaluation (Kandpal & Broman, 2015).

In order to achieve this goal, from 1990, secondary school learners in Victoria have been challenged to design, build and compete in a Model 11 solar car for a competition, using readily available, low-cost components. Learners have to rely on the knowledge they gained under the topic of solar energy and do further research in order to produce the solar car (Wellington, 1996; Kandpal & Broman, 2015). The low-cost components that were used (and which can be bought at electronics shops in first, second and most third-world countries) include single solar panel connector kits, solar power inverters, DC fuse boxes, chargers, small polycrystalline solar panels and recycled materials (Wellington, 1996, Kandpal & Broman, 2015; IRENA 2015; Physicsworld, 2019; Solar Energy International, 2021).

Interest in exploiting renewable energy sources through appropriate technology could be instilled at the school level by demonstrating the direct connection of renewable energy use to humans and their environment (IRENA 2015; Physicsworld, 2019: Smith, 2019; Solar Energy International, 2021). To this end, simple laboratory-scale demonstration models might be employed. This technique aids in dispelling questions regarding the origins and implications of difficulties that mankind faces, such as climate change caused by the greenhouse effect and load shedding caused by a strained power supply (Solar Energy International, 2021; Tria, 2020).

African countries are lagging behind in implementing measures to incorporate renewable energy at basic education level (IRENA, 2015). African governments – those of Egypt, Ethiopia, Kenya, Morocco and South Africa – have launched projects to generate electricity from renewable sources, such as wind, solar, biomass and hydropower, at levels from postgraduate to commercial, but not to a considerable extent at school level (IRENA, 2015; Kimuli et al., 2017). This shortcoming places functional knowledge of renewable energy out of reach for many Africans, as few reach postgraduate levels of study.

South Africa and Chile have each invested 1.4% of their gross domestic products in renewable energy, which is the highest investment proportion in the world (O'Meara, 2020). An investment of this magnitude requires citizens who are significantly aware of renewable energy, who have the skills to participate effectively in renewable energy and who will, at least, have the basic knowledge needed to play their part in maintaining the efforts made by the state, otherwise, this impressive investment will be difficult to sustain (Cebrián et al., 2020; Smith, 2019; Solar Energy International, 2021).

Teachers in African countries, including South Africa, still refer mostly to coal-generated electricity when learners are taught energy and power supply principles (DBE, 2011). Learners (and South Africans in general), especially those from disadvantaged backgrounds, continue to be disadvantaged by the difficulty of accessing energy (electricity), and these struggles have been aggravated by the COVID-19 pandemic (Chihib et al., 2021). This energy is also required for study purposes, after online study was imposed by the demands of the Fourth Industrial Revolution (Ally & Wark, 2019; Chihib et al., 2021). These are trying times, because people are not taught well enough about how to use the abundant energy from the sun in their everyday lives.

1.4.1 Theoretical framework

The theoretical framework used by this study is based on the constructivist theory. Constructivism is defined as a learning method that argues that people actively create or build their own knowledge, and that reality is shaped by people's experiences (Huitt, 2003). In developing constructivist concepts, according to Arends (1998), the constructivist approach states that learners construct meaning through experience, and that meaning is impacted by the interaction of past knowledge and new experiences.

Constructivism is a model of learning that emphasises the importance of the learner's social mind in the learning process. According to Smith (2017), the term constructivism was coined by Jean Piaget in the 1960s and is based on the idea that people acquire knowledge by combining their thoughts and experiences, including social interaction. This approach overlaps with social constructivism, which suggests that language and culture serve as the frameworks through which people perceive, communicate and comprehend reality. Constructivism is characterised by diversity and a variety of views, by rejecting objectivism and by asserting that learning occurs best when the learner gains information through active participation and experimentation.

This philosophy aligns with the theory of active learning, which demands that learners actively participate in research activities, projects, and assignments outside the traditional classroom setting.

1.4.2 Operational concepts

This section provides an overview of operational concepts involved in the creation of sustainable physical sciences learning environments and the topic of renewable energy.

1.4.2.1 Sustainable physical sciences learning environments

Sustainable learning is an education strategy that promotes dynamic learning, by focusing on environmental and the socio-economic impacts of knowledge and skills. It encourages functional adaptation and provides the learners with tools to succeed and flourish while being socially and environmentally responsible. Sustainable learning environments require durable materials and practices that do not inflict ecological harm.

Physical sciences learning environments are a combination of community involvement and environmentally conscious instruction. Physical sciences learners can learn in various settings, including at outside-of-school sites, using nature as a teaching tool, and using visual and audio technology teaching and learning tools. The quality and characteristics of a physical sciences learning environment are affected by factors such as the physical sciences CAPS document, year plans, lesson plans and management structures.

Physical sciences learning investigates physical and chemical phenomena through scientific inquiry and application of models, theories and laws. It is organised according to six main knowledge areas, that is, matter and materials, chemical systems, chemical change, mechanics, waves, sound, lights, electricity and magnetism, nuclear physics, photoelectric effect, and electronics. Physical sciences learning has the potential to empower learners to be more self-reliant and to empower communities through teaching and learning for socio-economic development and environmental management for sustainability.

1.4.2.2 Renewable energy

Renewable energy is generated from naturally replenished and non-depleting sources such as the sun and wind, which can be used for power generation, heating and cooling buildings and water, and transport. Non-renewable energy, on the other hand, comes from finite resources that may deplete over time, such as fossil fuels. Examples of renewable energy sources include biomass, geothermal resources, sunlight, water, and wind.

Geothermal energy is heat energy that is created and stored within the earth, and governed by the temperature of matter. It is inexpensive and ecologically friendly, but it is only found near tectonic plates. Biogas energy is a gas combination composed largely of methane and carbon dioxide, which is created by the decomposition of organic materials in the absence of oxygen. It can be used to generate power in a combined heat power gas engine or replace compressed natural gas in cars.

Hydropower tidal energy is a frequently used renewable energy source that accounts for about 3% of total global energy generated (Ang et al., 2022). The average capital cost of a hydropower plant is high because of the high cost of dam construction. Tidal energy uses the natural phenomenon of the movement of ocean water under the influence of the gravitational force known as tides, and can be harnessed twice a day as a long-term resource.

Wind energy is among the cleanest sources of renewable energy, and many industrialised countries have implemented various energy strategies involving wind to suit their demands. Wind energy can be generated in hilly regions where there is enough wind by using a turbine. South Africa has considerable wind potential, particularly around the Western and Eastern Cape coasts, and wind can contribute to achieving the sustainable energy objective as a secondary energy source.

Solar energy is one of the most widely used renewable energy sources on the planet. Africa receives more hours of strong sunlight per year than any other continent. The solar equipment industry in South Africa is expanding, with a yearly capacity for PV panel assembly of around 5 MW (Ebhota & Tabakov, 2021).

1.4.3 Related literature

The literature was studied to determine why and how sustainable physical sciences learning environments may be created through teaching about renewable energy. It considers bridging physical sciences education with sustainable development, by focusing on physical sciences curriculum, teacher knowledge, teaching and learning resources, research sources and credible reports.

1.4.3.1 Justification

Education plays a crucial role in understanding renewable energy, providing information, instilling values and raising public and community awareness. The 2030 SDGs aim to achieve a sustainable future globally, with three pillars: social, economic, and environmental development. Education is critical to achieving these goals, through seven outcome targets and three means of implementation. This study aims to align SDG 4 with national policy efforts by exploring the integration of renewable energy (SDG 7) in science education classes. SDG 7 aims to increase the share of renewable energy in the global energy mix and enhance international cooperation to facilitate access to renewable energy. The extent to which renewable energy is prevalent in science learning is essential for preparing graduates for future work environments. The integration of SDGs 4 and 7 with national education sector development initiatives is a crucial premise in support of its implementation.

The CAPS aims to equip learners with the knowledge, skills, and values necessary for self-fulfilment and meaningful participation in society (DBE, 2011). It emphasises the importance of inclusiveness, the accommodation of diverse cultures and advocating for equity and equality (DBE, 2011). The curriculum encourages the incorporation of indigenous knowledge systems and sustainability in contexts marred by inequality (DBE, 2011). However, there is limited physical sciences curriculum content, concepts, and skills evidence to support the balance between human and non-human entities. An emphasis on caring for and conserving non-human entities deserves equal status in teaching and learning environments for sustainability. Indigenous communities worldwide have prioritised community-based management of safe drinking water and sanitation, which involves group decision-making, shared accountability and sustainable behaviours. When communities participate in the sustenance of their environment, they are empowered to participate in improving and maintaining the quality of life in their neighbourhoods and finding ways to improve sustainable practices already known to them.

1.4.3.2 Mechanisms to circumvent challenges

Renewable energy education and training are crucial for combating climate change and promoting sustainable development. Places such as Hong Kong and Japan have integrated renewable energy knowledge into their basic education syllabi to teach students about its importance from an early age. However, there is a lack of official basic education plans to explicitly improve the extent to which renewable energy is covered in the curriculum.

The generation of renewable energy is expanding in the Middle East and North Africa, but it still falls short of meeting electricity demands and resource potential. South Africa has launched projects to generate electricity from renewable sources, but not to a great extent at the school level. This shortcoming places functional knowledge of renewable energy out of reach of physical sciences learners. Teaching learners about renewable energy in physical sciences has the potential to increase learners' opportunities to learn about energy, so that they can link it with authentic situations and promote systems-thinking approaches and integrated problem-solving prowess. This approach can transform the physical sciences learning environment into a sustainable learning environment that encapsulates principles and competences of education needed for sustainable development.

The teaching of learners about renewable energy in physical sciences can address social injustice, by curbing harmful gas emissions, alleviating health hazards and educating people about the importance of keeping the environment clean to ensure healthy living. However, the foundation for professional competence and decision-making in teaching renewable energy content is the availability of sufficient teacher knowledge. Raising awareness among teachers and providing teacher training in workshops and short courses can help close knowledge gaps and enable physical sciences teachers to use teaching and learning resources correctly and effectively.

1.4.3.3 Usefulness of renewable energy

The physical sciences CAPS document outlines the teaching and learning of physical sciences content, including clean energy, which can help raise awareness and knowledge about renewable energy and contribute to the achievement of SDG 7. This is particularly important in developing countries such as South Africa, where skills and infrastructure are lacking. The curriculum is essential for addressing the need for affordable, reliable, sustainable and modern energy. Good teacher knowledge about clean energy can improve time management, organisation, planning, creativity, motivation and engagement in clean energy content. Teaching and learning resources can support and enrich lessons, engage learners and foster active learning. These resources help teachers deliver effective teaching in diverse learning environments, by adding value to the teaching and learning experience.

1.5 OVERVIEW OF METHODOLOGY

This section overviews the methodology used in this study. It starts by discussing rhetoric, followed by the relationship between the researcher and participants, the research site, research design, the processes and procedures used and, lastly, the tools, techniques and methods used by the study.

1.5.1 Rhetoric

The rhetoric that was used during communication with participants considered their diverse cultures and the power differentials relating to their teaching and learning backgrounds. The participants were from different schools: a remote farming school with limited resources, a disadvantaged school with no lab and limited equipment, and a relatively affluent fee-paying school with a well-furnished classroom and well-resourced laboratory. These backgrounds communicated different messages, which required the phrasing of questions and follow-up questions in the context of the environments to be carefully considered.

1.5.2 Relationship between researcher and participants

The relationship the researcher has with participants requires attentive observation and interpretation of participants' experiences, with the aim of creating sustainable physical sciences learning environments. This study aimed to understand these experiences by listening to participants' statements about renewable energy teaching. The ethics of data collection and presentation were considered, by following guidelines presented in Section 3.2.3.

1.5.3 Research site

The research site included a selection of three schools where the participants taught. Interviews were conducted at three schools which had different levels of affluence, and the teaching and learning environments at the three schools were observed. Three physical sciences teachers were selected to participate in the study, based on criteria such as years of experience teaching physical sciences, exposure to workshops on physical sciences teaching, and availability and willingness to participate voluntarily.

The study established possible mechanisms to circumvent challenges faced when teaching about renewable energy, and the responses of experienced teachers to questions helped the researcher to reflect on the usefulness of teaching about renewable energy with the aim of creating sustainable physical sciences learning environments. The teachers assisted in checking the progression of renewable energy in teaching and learning across the whole Further Education and Training (FET) phase.

1.5.4 Research design

This qualitative research study used a case study design to examine the impact of renewable energy on sustainable physical sciences learning environments in South Africa. The study focused on the teaching of the topic of renewable energy in schools, to obtain a deeper understanding of the factors that influence instruction. The study used an instrumental case study design, as it was crucial for understanding the integration of renewable energy in education and the implementation of renewable energy in South Africa.

The study aimed to understand the reasons behind the guiding beliefs of physical sciences teachers regarding sustainable learning environments and renewable energy content. Contact with the participants was established, and a meeting was set up with the individual participant to discuss the study and establish a mutual understanding of the ethics and Protection of Personal Information Act (POPIA). The study emphasises the importance of truthfulness, anonymity, safekeeping of data, and the right to review, verify, and confirm the transcribed data and findings.

1.5.5 Processes and procedures

The processes and procedures the researcher followed included applying for title registration and ethics approval from the university, including permission to conduct research with the Free State Department of Basic Education and three participating schools. Each applicant was identified and compliant with the POPIA and ethics policy requirements. Face-to-face meetings were held to discuss the study, establish mutual understanding of ethics, and explain to participants that data would be used for research purposes only. Participants could withdraw at any time, maintain anonymity, and review data and findings.

1.5.6 Tools, techniques and methods

The study used various tools, techniques and methods to collect data on renewable energy teaching in a sustainable physical sciences learning environment, among which document analysis and interviews. The CAPS and related documents, textbooks, assessments and FET phase physical sciences examination papers were analysed to determine the explicitness of content, concepts, skills and values on renewable energy. Interviews and classroom observations of laboratories and equipment that could be potentially used to teach about renewable energy, were conducted with teachers to obtain insights on factors that affect the teaching of the topic of renewable energy. The free attitude interview technique was used to gather insights on renewable energy teaching. Participants were asked secondary research questions, and, depending on their responses, clarifying questions. This method led to interesting conversations and discussions, leading to the introduction of follow-up questions and confirmatory statements.

1.5.7 Trustworthiness

Trustworthiness in qualitative research is measured by conformability, credibility, transferability and dependability. Conformability ensures that the study is adaptable to other settings, which increases its dependability. Transferability ensures that the findings are applicable to various contexts, while credibility is established through member checks and triangulation in the South African context.

1.5.8 Data analysis

The data were analysed though documentary content analyses, interview transcriptions, thematic analysis and observations of the physical sciences learning environment at each school. The data gathered from the physical sciences CAPS document, textbooks and assessments, were tabulated with the main knowledge areas as the main headings, and patterns were identified. Data gathered through interviews were transcribed and sorted into themes. The observations confirmed or refuted the teaching situation regarding renewable energy. The data generated through the use of document analysis, interviews and observations were corroborated to enhance trustworthiness (Stahl & King, 2020).

1.5.9 Ethical concerns

The study involved obtaining ethical clearance from the University of the Free State ethics committee and negotiating consent from schools and prospective participants. The study adhered to research standards of the University of the Free State, Free State Department of Education and POPIA. Participants were independent volunteers, and were not paid or coerced to participate. Their independence was safeguarded by asking open-ended questions of which the answers were transcribed verbatim. Participants understood the researcher's role and were made aware of it in the study.

1.5.10 Limitations and delimitations of the study

This study may have not provided sufficient information on teaching the topic of renewable energy to science teachers because of the limited scope, time and participants of the study. Additionally, the study may have been biased because of the limited information and resources available for renewable energy teaching. The responses may have been influenced by participants' experiences and perceptions of teaching about renewable energy. The study focused on renewable energy in the FET phase, and excluded other science subjects such as life sciences, geography and technical sciences. The researcher's notions of renewable energy and sustainable development may have influenced the study scope.

1.6 OVERVIEW OF PRESENTATION, ANALYSIS AND INTERPRETATION OF DATA

This overview of the presentation, analysis and interpretation of data provides a summary of the need to ensure sustainable physical sciences learning environments, the challenges faced by teachers and the usefulness of renewable energy, and concludes by discussing the challenges faced in implementing renewable energy in physical sciences learning environments.

1.6.1 Justifying the incorporation of the topic of renewable energy in the teaching of physical sciences

The CAPS document aims to make learners aware of science principles through critical problem-solving. The explicit provision of the topic of renewable energy in the CAPS could enable teachers to learn, research, plan and teach about it, thereby motivating teaching and learning related to socio-scientific issues. Doing so could encourage learners to think critically and analyse their social, economic and environmental situations and identify solutions for air pollution, environmental degradation and load shedding. The explicit inclusion of renewable energy in textbooks could offer detailed information about policy framework content, concepts and skills, thereby exposing the authentic reality to teachers and learners. The textbooks could provide basic information on renewable energy sources, energy harnessing and connectivity. Assessments would be crucial for measuring individual learners' knowledge and skills on renewable energy. Assessments may help teachers make reliable decisions about a learner's development in relation to renewable-energy-related matters. The photoelectric effect, work function, cut-off frequency and photoelectric equation can be used to relate matter and energy through renewable energy. Including the topic of renewable energy in the curriculum could allow learners the opportunity to suggest ways in which renewable energy can offer a possible solution to achieve sustainability and clean energy in the South African context.

1.6.2 Teachers' experiences of teaching about renewable energy

The teachers' (participants') experiences of teaching the topic of renewable energy were focused on challenges and pedagogical content knowledge. Data were presented according to the themes in the CAPS, textbooks, assessments and teaching affordances, thereby highlighting the importance of education on renewable energy. The CAPS document only mentions the photoelectric effect as a form of renewable energy, which does not include the harnessing of solar energy. It is crucial that teachers possess content knowledge on renewable energy. They must be creative in identifying opportunities for incorporating renewable energy content, concepts and skills using appropriate resources, assessments and activities. The decision to obtain information about learner performance through assessments for learning rests on teachers' teaching affordances in relation to renewable energy.

In this study, the data indicate that the three teachers did not incorporate the topic of renewable energy in their teaching of physical sciences, because renewable energy was not explicitly included in the curriculum. The researcher observed this absence and referred to the authority bestowed by the curriculum for teaching. Other reasons for failing to teach the topic of renewable energy included lacking equipment, the teacher lacking skills, a lack of course material on renewable energy and the fact that training/workshops and research were not available on renewable energy. The teachers suggested that the physical sciences curriculum and teaching tools should continually evolve to meet the needs of learners and the country as a whole. Teachers believed that teaching learners about renewable energy is practical in South African schools, especially because of the large amount of sunlight experienced in South Africa, which would enable feasible application of solar energy.

1.6.3 Reflections on the usefulness of teaching about renewable energy

The usefulness of teaching can be measured by how much of the acquired knowledge can be applied to help the learner and society. Incorporating renewable energy into the physical sciences curriculum can help bridge the gap between knowledge on renewable energy and the implementation of SDG 7. The physical sciences curriculum informs the structure and content of physical sciences as a subject, and it directs the teaching and learning process.

Participants argued that the physical sciences curriculum should include the topic of renewable energy, because it is relevant at the moment, as the world has started talking about sustainability and clean energy. South Africa's commitment to sustainability and clean energy, on the one hand, and its experience of load shedding, on the other, confirms the need for a sustainable physical sciences curriculum that ensures the teaching of the topic of renewable energy.

The usefulness of the teaching affordance of renewable energy is that it will create the necessary bridge between knowledge of renewable energy and the implementation of SDG 7. It may promote both on- and off-grid solutions, including content, concepts, and skills of cross-border grid connections, on-grid renewable energy solutions and decentralised options. Teachers can use simulations, computers and teacher training to teach learners about renewable energy in schools.

All three participants expressed that the teaching affordance of renewable energy will require teaching material or equipment, teacher training, and explicit inclusion of renewable energy in the curriculum. These requirements correlate with challenges foresaw by the participants. Participant 2, for instance, argued that a renewable energy teaching affordance would lead to renewable energy implementation, which strongly correlates with the reports in literature discussed in Chapter 2.

1.7 OVERVIEW OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

This overview summarises the findings, conclusions and recommendations as they relate to the purpose of the study.

1.7.1 Purpose of the study

The study aimed to create sustainable physical sciences learning environments by incorporating the topic of renewable energy in the curriculum. It aimed to justify the need for this inclusion, draw lessons from teachers' experiences, and reflect on the usefulness of its explicit inclusion. A quality physical sciences education would instil knowledge and skills related to energy generation, concepts, theories, laws, and assembling artefacts. Teaching about renewable energy would promote equitable access to clean energy and balance economic, social, and environmental aspects. It would require an active sense of responsibility and an holistic approach to resource conservation.

1.7.2 Presenting and discussing the findings, conclusions and recommendations

The study focused on the need to incorporate knowledge of renewable energy into physical sciences teaching, on teachers' experiences of teaching renewable energy content and on the usefulness of teaching the topic of renewable energy. The lack of a curriculum on renewable energy is a significant issue, as the topic is not explicitly included in the curriculum. Teachers are deprived of the opportunity to teach learners about renewable energy, leading to a lack of functional awareness of SDG 7 in learners. This results in little effort by the state to mitigate the impacts of previous and contemporary social injustice practices. For example, if a family/person living in a rural area does have access to the electricity provided by the public utility, and does not know their renewable energy options and the basic maintenance thereof, that family/person remains at a disadvantage.

The usefulness of explicitly teaching about renewable energy cannot be denied, as fossil-fuel-generated electricity is expensive and presents a social burden for those who cannot afford it or access it. South Africa has the highest gross domestic product investment in solar energy in the world, and there is a need for knowledge and skills to be available to maintain equipment and mitigate risks involved in using renewable energy. Teaching the basic skills from school level will provide the basic 'know-how' and equip citizens with awareness of sustainability, thereby enabling the physical sciences learning environment to be sustainable in the South African context.

1.8 LAYOUT OF CHAPTERS

The arrangement of chapters of this thesis is as follows:

Chapter 1: Orientation

Chapter 2: Literature review in respect of creating sustainable physical sciences learning environments through teaching about renewable energy.

Chapter 3: Research design and methodology used for investigating the creation of sustainable physical sciences learning environments through teaching about renewable energy.

Chapter 4: Presentation, analysis and interpretation of data relating to creating sustainable physical sciences learning environments through teaching about renewable energy.

Chapter 5: Findings, recommendations and conclusion regarding the creation of sustainable physical sciences learning environments through teaching about renewable energy.

CHAPTER 2
REVIEW OF THE LITERATURE

2.1 INTRODUCTION

South Africa has pledged its commitment to the 2030 SDGs, which aim to achieve a sustainable future, globally, through three pillars: social, economic and environmental development. Education is crucial for achieving these goals, and the SDGs have seven outcome targets and three means of implementation. This study focused on the signposts of relevant skills for work, relevant learning for citizenship, and safe and inclusive physical sciences learning environments. The implementation of SDG 4, on education, is crucial for alignment with national education sector development efforts. The integration of renewable energy (SDG 7) in physical sciences learning environments may to contribute to this alignment.

SDG 7 aims to provide affordable, reliable, sustainable, and modern energy for all, with targets to increase the share of the global energy mix of renewable energy, and enhance international cooperation. According to Smith (2019) and Stats SA (2019), the issue is the low prevalence of renewable energy in science learning, which is supposed to ensure that graduates are well prepared for future work environments. Consequently, this study aimed to explore how knowledge of renewable energy can be used to create sustainable physical sciences learning environments.

This chapter reviews the literature on renewable energy in teaching, with the purpose of creating sustainable physical sciences learning environments. The chapter commences by discussing the background to the problem, which is followed by definitions and discussions of key concepts, then the theoretical framework applied to this study, and literature that relates to the study objectives.

2.2 APPROPRIATENESS OF CONSTRUCTIVISM FOR THIS STUDY

Constructivism is essentially a model of how learning occurs. Jean Piaget coined the term constructivism in the 1960s, and he was known to be a cognitive constructivist (Smith, 2017). According to Piaget, people acquire knowledge by combining their thoughts and experiences and interpreting the cognitive connections between their thoughts and experiences, including social interaction (Mengi-Dinçer et. al, 2021; Smith, 2017).

This understanding, in essence, overlaps with social constructivism as described by Vygotsky (1978). According to Vygotsky's constructivism learning theory, language and culture serve as the frameworks via which people perceive, communicate and comprehend reality (Vygotsky, 1978). Smith (2017) and Vygotsky (1978) both reach the understanding that the learner actively participates in and assumes the role of the information constructor; this approach to learning was called a "most promising model" of learning by Yager (1991, p. 53), who speculated that constructivism may cause both the stimulation of new ideas and a gelling of existing ones, thereby alluding to a Kuhnian paradigm shift. The potential for active learning that is based on both cognitive and social constructivism is particularly fitting in a science learning environment (Aderman & Russell, 1990).

Constructivism is epitomised by diversity and the possibility of many views, rather than being a single or cohesive philosophy. It has several dimensions, including social dynamics, cognitive growth, and the significance of context (Alt, 2017; Mengi-Dinçer et. al, 2021). Constructivism is a philosophy that rejects objectivism and asserts the idea that a person may learn the truth about the natural world without needing varying degrees of true and accurate scientific approximations. The constructivist philosophy presents the notion that classroom instruction is not the only way for learning to occur, and that the learner's environment may serve as a learning space for the learner (Alt, 2017). For example, many scientific phenomena may be naturally observed outside traditional classrooms, and learners do their research for homework activities, projects and assignments outside the classroom setting (active learning). As a result, constructivism holds the view that learning occurs best when the learner gains information by doing and experiencing/experimenting in addition to hearing instruction and seeing content (Alt, 2017). This argument agrees with Piaget and Vygotsky's theory of active learning. The easiest way to understand the thinking behind this sort of philosophical approach is to consider the statement ascribed to the famous Chinese philosopher Confucius: "I hear and I forget, I see and I remember, I do and I understand" (Motoh, 2019, p. 287–300).

This means that a constructivist teacher should make sure their teaching is learner centred and that it enables the learner to co-create their own knowledge through active participation. In the same light, any constructivist qualitative researcher should strive for a researcher–participant relationship in which the participant is given the opportunity to communicate their views anonymously and without fear of being exposed. In this context, philosophy is given the critical responsibility of developing and disseminating the tools required for an axiological and ethical reconstruction, in order to protect participants and retain the integrity of the collected data (Alt, 2017; Huitt, 2003; Mengi-Dinçer et. al, 2021).

The researcher–participant relationship is a complicated one that encompasses methodological, ethical and epistemological concerns (Buchanan & Warwick, 2021). Considering their varying responsibilities, viewpoints and interests, the researcher and participant might be viewed as being in binary opposition of self and other (Buchanan & Warwick, 2021). Another way to look at this relationship is as a cooperative collaboration and co-creation of knowledge in which the participant and the researcher share ownership, authority and accountability (Huitt, 2003).

The relationship involves the interaction that exists between a psychological investigator and the individual(s) who supply the data; the investigator attempts to be an objective observer (as far as possible) who can see the other person's point of view and interpret their experiences. The investigator attempts this approach by paying close attention to participants' statements, as interviews are transcribed into data that is sorted, classified and highlighted.

Before starting any research activity, the researcher must carefully assess if the study might have the potential to hurt anyone involved. In the event that the researcher finds any potential negative impacts, they must look for the most effective way to reduce them (Buchanan & Warwick, 2021).

The researcher should ensure that reviewers, members of ethics boards and participants are adequately informed about the extent of the particular study endeavour (Head, 2020, pp. 72–83.). All participants should be thoroughly informed about the aim and methodology of the study (King, 2019). The project's lead researcher should provide contact information of the university through which the research is being conducted, the researcher and the assigned supervisor, to all participants, in case of complaints or ethical difficulties at any time during the study period, which may be addressed by the university through the ethics committee (Head, 2020).

Informed consent must always be obtained by the researcher from all parties participating in the research, before the study endeavour is carried out. Consent entails providing the participants with complete information about any potential dangers, the technique to be employed for data collection, and the way data will be handled (Head, 2020; King, 2019). The people in charge of each institution at which the research is conducted (such as the school's relevant head of department, head of school/principal, the relevant provincial Department of Education) must sign a compliance document between the participant(s) and the researcher (Head, 2020). When conducting research with children under 18, collaborating with schools requires signed parental authorisation. Parents must be informed about the research, including how their children will be involved in the research, how data will be collected and processed and what the acquired results will be used for. Consent requests should always offer an option to opt out of the research (Head, 2020).

The researcher must maintain the anonymity of all study participants, and the personal data collected from the participants must be utilised solely for the study and not for other purposes (Head, 2020; King, 2019). Personal data must be properly categorised and controlled to prevent unauthorised usage (Head, 2020).

Participants and participating schools should be able to request to view the data connected to the research before data management commences. If data are judged to be disagreeable by the participants or the participating school, the disagreeable data shall be destroyed upon presentation of a justified rationale for doing so (Head, 2020).

2.3 DEFINITIONS AND DISCUSSIONS OF OPERATIONAL CONCEPTS

This section identifies, defines and discusses critical concepts with the purpose of synthesising them into the coherent meaning that might be implied in this study. This section, therefore, eases and focuses the readership towards the aim of the study. To this end, the following concepts will be considered: sustainability, physical sciences, learning environments, sustainable physical sciences learning environments, renewable energy, teaching and learning. I will refer to policy documents (public mandates), research literature and other credible published books and reports.

The section commences by looking at sustainable physical sciences learning environments, teaching in this context and the role of renewable energy in achieving this learning environment.

2.3.1 Sustainable physical sciences learning environments

2.3.1.1 Sustainable learning

The term sustainable learning describes education strategies that support dynamic learning; information gained is foundational to sustainable development and is disseminated within a community (Ben-Eliyahu, 2021). Sustainable learning advocates for sustainable development by using techniques that are mindful of the environmental and socio-economic impact of learned knowledge and skills (Hoque et al., 2022). It encourages functional adaptation, and seeks to provide learners with the tools they need to succeed and flourish while being socially and environmentally responsible in the face of constantly shifting conditions and complex obstacles (Tlali, 2017).

For learners to learn this way, their imagination and creativity must be stimulated, so that they think beyond the classroom and also use any environment as a learning space. In order to stimulate learners' imaginations and creativity and to foster profound and transferable learning, sustainable learning places a strong emphasis on authenticity and meaningfulness (Ben-Eliyahu, 2021; Hoque et al., 2022). It is education that acknowledges the interdependence of biophysical and socio-economic issues and their interactions over time (Ben-Eliyahu, 2021) and seeks to maintain the social, economic and the environmental health of our surroundings. Sustainable learning must contain material that is durable and that promotes practices that will not inflict ecological harm. Consequently, this type of learning takes place in sustainable learning environments.

2.3.1.2 Sustainable learning environments

Sustainable learning environments promote an equitable and considerately inclusive approach for teaching and learning and the involvement and respectful and caring participation of communities in teaching and learning (Dube et al., 2023). Sustainable physical sciences learning environments are generally anchored on socio-scientific, issues-based approaches that advocate for a balance between the environmental, the social and economic aspects of life and living (Ben-Eliyahu, 2021; Tlali, 2017). Considering that the subject of physical sciences investigates physical and chemical phenomena that occur in nature (DBE, 2011), physical sciences learners can learn in a number of settings, including in outside-of-school sites and settings. The phrase physical sciences 'learning environments' is used as a preferred alternative to a physical sciences 'classroom', which connotes a room with rows of desks and a writing board, for example.

Sustainable learning environment refers to a school's culture, its prevailing ethos and characteristics, such as how learners interact with and treat one another and their environment, as well as the various ways in which physical sciences teachers can organise an educational setting to facilitate learning (Dube et al., 2023), for example, by presenting physical sciences lessons in a room or outside, using nature as a teaching tool or using visual and audio technological teaching and learning tools.

The physical sciences CAPS document, year plans and lesson plans and physical sciences management structures may also be regarded parts of the physical sciences learning environment, since the quality and characteristics of a physical sciences learning environment are affected by these elements and may support a dynamic, healthy learning ecosystem in which knowledge is developed jointly and shared within a community. Additionally, sustainable learning environments provide an atmosphere in which educators and education departments may develop a positive and forward-thinking science culture (Dube, 2023).

2.3.1.3 Physical sciences teaching and learning

"Physical Sciences investigate physical and chemical phenomena", which is learned "through scientific inquiry, application of scientific models, theories and laws in order to explain and predict events in the physical environment" (DBE, 2011, p. 8). Physical sciences learning is a means of gaining knowledge about the natural world, its processes, and how it came to be. It is a route to comprehension that entails observing, recording and sometimes testing the world around us.

Physical sciences is organised according to six main knowledge areas, namely, matter and materials, chemical systems, chemical change, mechanics, waves, sound and lights and electricity and magnetism (DBE, 2011, p. 8). A closer look at these knowledge areas and their topics or subtopics reveals that they all have one aspect in common, namely, energy. For example;

- **Energy and work** – Basic principles of energy and foundations for conservation and sustainability issues.
- **Thermodynamics –** Issues of heat, entropy, and energy use.

- **Electricity and magnetism –** Commercial power/energy and use.
- **Nuclear physics** – Commercial power/energy generation and waste.
- **Photoelectric effect** – Generation of solar energy from "the ejection of electrons from a metal plate when light falls on it".
- **Electronics –** Energy transport through different materials and electronic components (DBE, 2011).

Physical sciences learning has the power to concurrently change education and to empower learners to be more self-reliant, and also empower communities via teaching and learning to achieve socio-economic development and environmental management that is sustainable (Mengi-Dinçer et al., 2021; Spears et al., 2018).

2.3.2 Renewable energy

Renewable energy is energy that is generated from naturally replenished and non-depleting sources, such as the sun, wind, water and biomass (Cortese, 1999; Sachs, 2012). Non-renewable energy, in turn, is derived from finite resources (fossil fuels) that may be depleted over time, such as coal and oil. Biomass, geothermal resources, sunlight, water and wind are examples of renewable energy sources that can be turned into these sorts of clean, usable energy (Sachs, 2012).

2.3.2.1 Geothermal energy

Geothermal energy is heat energy that is created and stored within the earth. This is the energy that governs the temperature of matter (Ang et al., 2022). It is caused by the primordial creation of the earth, as well as radioactive disintegration of elements. Water from hot springs has been used since ancient times and today it is employed to generate energy. There are three forms of geothermal energy: liquid-dominated plant energy, geothermal energy and enhanced geothermal energy. Furthermore, because geothermal energy does not require any fuel, there is no fuel expense; however, capital costs are involved. Because the earth's heat content is substantially more than the heat collected, energy from geothermal sources is considered a renewable source, though extraction must be monitored to avoid local depletion. Examples of sources include hot springs, lava and geysers. Geothermal energy is inexpensive and ecologically friendly; however, it is only found near tectonic plates. Geothermal energy and biogas energy are the least used forms of energy globally.

2.3.2.2 Biogas energy

Biogas is a renewable energy source in the form of a gas combination composed largely of methane and carbon dioxide that is created by the decomposition of organic materials in the absence of oxygen (Ang et al., 2022). It may be made from raw materials such as farm waste, food waste, green waste, and so on. It can be created by anaerobic digestion using methanogen or by anaerobic organisms digesting materials in a closed environment. It is mostly composed of methane and carbon dioxide and is generated by microorganisms. Biogas is mostly composed of CH_4, CO_2, N_2, H_2, H_2S and O_2. The anaerobic reactor is also heavily influenced by the substrate composition. It may be utilised to generate power in a combined heat power gas engine and the waste heat used to heat the digester. It can be used to replace compressed natural gas in cars (Benbouaziz et al., 2021).

2.3.2.3 Hydropower

In the case of hydropower, electrical energy is created by harnessing the gravitational force of falling water energy through a turbine spinning (Ang et al., 2022). The energy production capability is determined by the available water supply. It is one of the most frequently used renewable energy source, accounting for 3% of total global energy (Ang et al., 2022). The average capital cost of a hydropower plant is high, because of the high cost of dam construction. Hydropower features pumped storage to save water for high-peak demand and its production may be regulated as needed.

Tidal energy works in a similar manner, except that it uses the natural phenomenon of movement of ocean water due to the gravitational force known as tides. Tidal energy can be harnessed twice a day as a long-term resource. It can be created by three techniques, namely, tidal barrages, tidal fences or tidal turbines. In all these cases, electrical energy is created by the mechanical energy of a turbine connected to generator. Because tides can be predicted, tidal energy is an easy energy source to work with, though it is costly, because it requires a large site to construct a dam, building the dam is expensive and a very high quality turbine design is required.

2.3.2.4 Wind energy

Wind energy is among the cleanest sources of renewable energy, and many industrialised countries have implemented various energy strategies to suit their demands by developing electrical power from wind energy (Ang et al., 2022; Brkic, 2020). The method of creating electric power using wind energy is quite simple; nevertheless, the wind energy conversion system is dependent on wind energy, which is unpredictable, making it difficult to achieve target output (Brkic, 2020). Wind energy may be generated in a hilly region where there is enough wind, and it can be generated using a turbine (Brkic, 2020). Wind spins a turbine's blades around a rotor and is routed via a gearbox to a generator, where voltage and current are generated. This voltage and current are then sent to a step-up transformer through a pair of rectifiers and inverters. Finally, it feeds to the grid through an inductor (Brkic, 2020; Franklin, 2018).

The wind energy causes the wind turbine to rotate; the mechanical energy of the wind turbine is transmitted to the generator via a gearbox. The gearbox assists in keeping the turbine and synchronous generator at the same speed. The generator output is AC, and is routed to a power electronics converter (Brkic, 2020; Franklin, 2018). The finished product can be transferred and delivered to home, industrial and commercial customers.

South Africa has considerable wind potential, notably around the Western and Eastern Cape coasts. Even though South Africa does not have constant high winds, wind can nonetheless contribute to the sustainable energy objective as a secondary energy source (Mukonza & Nhamo, 2018).

2.3.2.5 Solar energy

Solar energy is one of the most widely used renewable energy sources on the planet (Ang et al., 2022). According to the World Sunshine Map, Africa receives many more hours of strong sunlight per year than any other continent (Adebiyi et al., 2019). Consequently, solar energy is the most sustainable energy choice by far for African countries (Adebiyi et al., 2019; Khobai et al., 2020). In a single day, South Africa is subject to sun radiation levels ranging from 4.5 to 6.5 kWh/m^2. Annually, South Africa receives around 220 W/m^2 of global solar radiation, compared to approximately 100 W/m^2 for Europe and the United Kingdom and approximately 150 W/m^2 for the United States (Adebiyi et al., 2019; Khobai et al., 2020).

The solar equipment industry in South Africa is expanding and has the potential to thrive (Khobai et al., 2020). The yearly capacity for PV panel assembly is around 5 MW, and a number of South African firms manufacture solar panels, solar charged lighting and solar charged water heaters, resulting in job creation, economic growth and progress towards achieving SDG 2030 and Agenda 2063 (Adebiyi et al., 2019; Khobai et al., 2020).

2.3.2.6 Photovoltaic technology

A single PV device is a cell that provides about 1 or 2 watts of power. Each solar cell functions as a PN junction, and when photon particles collide with the surface of the solar panel, current flows as a result of the PV effect (Maddileti & Cherukuri, 2019). The semiconductor can be silicon or germanium (Maddileti & Cherukuri, 2019; Roos, 2009). 'Semi' means that these cells have a conductivity that is less than that of a metal, but more than that of an insulator (Khamisani, 2019). The amount and kind of light absorbed by a semiconductor is determined by its bandgap, which is the minimum amount of energy required to release electrons and allow the material to conduct electricity (Khamisani, 2019). Germanium or silicon will behave like an insulator in the absence of this energy.

Because silicone is the most dependable semiconductor, monocrystalline silicon and polycrystalline silicon semiconductors are used in nearly all solar panels on the market today (Franklin, 2018). When it is exposed to sunlight, the semiconductor absorbs the light and transfers the energy to negatively charged particles known as electrons (Maddileti & Cherukuri, 2019). Electrons pass through the semiconductor as electrical current. The current then passes through metal contacts, which are the grid-like lines on a solar cell, before reaching an inverter. The inverter transforms DC to AC, which then flows into the electric grid and connects to the circuit that makes up a home's electrical system (Maddileti & Cherukuri, 2019). Excess AC power can be sent back into the grid.

Solar irradiation strikes the solar panel, which charges a battery through a charge controller. The battery is then used to power any off-grid electrical devices (Khamisani, 2019). When operating on the grid, this energy is sent through an inverter to a step-up transformer. Following that, the stepped-up current is routed to the main grid (Khamisani, 2019). As indicated in Figure 2.1, when operating on the grid, this energy is sent through an inverter to a step-up transformer. Following that, the stepped-up current is routed to the main grid (Khamisani, 2019). The consumption meter measures how much power is being used and any excess power is fed back to the grid, which helps increase the capacity of the power authority (e.g., Eskom) to supply electricity to the rest of the country (Khamisani, 2019). This process makes solar energy a very good option for countries such as South Africa, which experience sun exposure year round (Khobai et al., 2020).

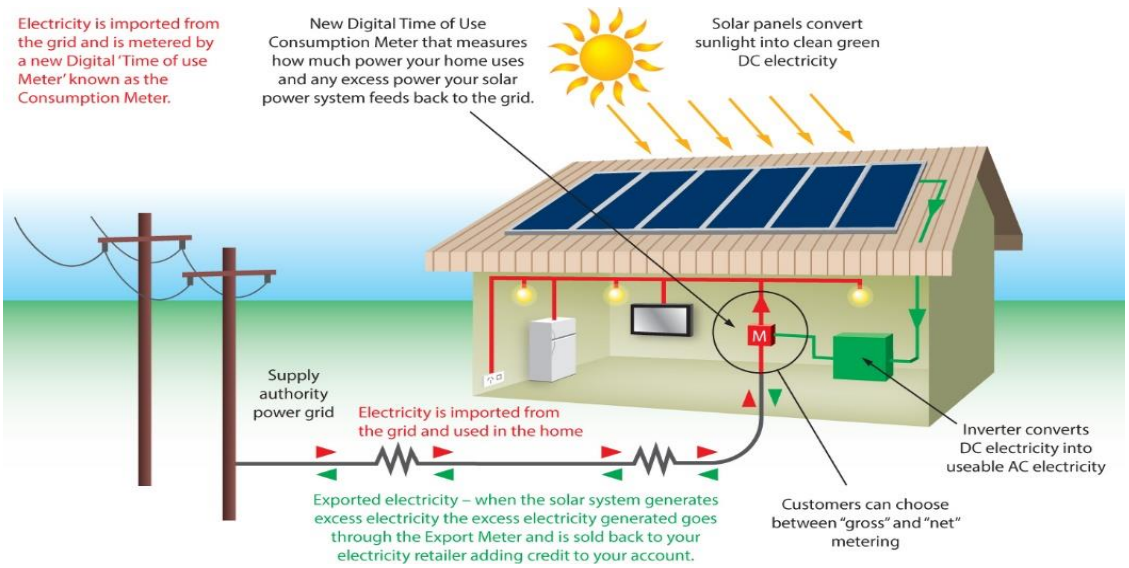

Figure 2.1: Grid-connected solar power

Source: https://www.skysolars.com/2_on-grid-solar-power-systems-2/ (retrieved 4 April 2023)

There is, of course, a cost connected with supplying residences in rural locations with electricity, which increases with distance from the grid (Akom et al., 2021). In such cases, where the expense of on-grid solar electrification is prohibitively expensive, an off-grid PV system can be used. The grid-tied system is most commonly encountered in urban and suburban areas that have already been electrified. The off-grid system is better suited to places where electrification has yet to be completed and/or the customer prefers not to feed back the energy generated at their end.

2.4 REVIEW OF RELATED LITERATURE

This section explores literature on the creation of sustainable physical sciences learning environments through the teaching of renewable energy. It commences by justifying the incorporation of renewable energy content into creating sustainable physical sciences learning environments, followed by mechanisms to circumvent challenges and, lastly, the usefulness of these learning environments. Concurrently, the physical sciences curriculum, teacher knowledge, and teaching and learning resources will be explored, as components that play an important role in renewable energy and the creation of sustainable physical sciences learning environments.

2.4.1 Justification for creating sustainable physical sciences learning environments through teaching about renewable energy

Scholars such as Celikler (2013), Kandpal and Broman (2014) and Guven and Sulun (2017) highlight the importance of education for gaining a better understanding of renewable energy, as well as in supplying and fostering information, instilling values and raising public and community awareness. For renewable energy generation efforts to progress at a faster pace, more detailed renewable energy principles and applications must be included in science subjects (Solar Energy International, 2021). The kind of sustainable learning environment that must be created will also be relevant for sustainable development and global citizenship (United Nations General Assembly, 2015).

The 2030 SDGs are the blueprint for achieving a sustainable future globally (Stats SA, 2019; United Nations General Assembly, 2015). The SDGs have three indispensable pillars, namely, social, economic and environmental development, that take into account various national realities, capacities and levels of development, while respecting national policies and priorities (Sachs, 2012; Stats SA, 2019). The pillars are consistent with the principles of inclusivity (Smith, 2019). Education is critical for the achievement of the SDGs, with their seven outcome targets and three means of implementation (Cebrián et al., 2020; Smith, 2019.).

Relevant to this study are the outcome targets, or signposts, that still require contextualisation, reflection and integration with national policy development efforts. Signposts (unquantified) that are pertinent to this study are ensuring (i) relevant skills for the world of work; (ii) relevant learning for citizenship in a global world; and (iii) safe and inclusive learning environments (United Nations General Assembly, 2015). The critical principle undergirding the implementation of SDG 4, on education, is its alignment with national education sector development efforts (Stats SA, 2019). To this end, this study seeks to add a voice to the alignment of SDG 4 and national policy efforts, by exploring the integration of renewable energy (SDG 7) in science education lessons.

SDG 7 relates to “ensuring access to affordable, reliable, sustainable and modern energy for all” (United Nations General Assembly, 2015, p. 21). In line with this goal are the targets to “substantially increase the share of renewable energy in the global energy mix and enhance international cooperation to facilitate access to … renewable energy” (United Nations General Assembly, 2015, p. 21). Additionally, researchers claim that the availability of an efficient, consistent and affordable energy supply would have a considerable effect on all three the pillars of the SDGs, because an energy supply is critical to the functioning and development of human societies (Cock, 2019; McCauley et al., 2018).

The issue is the extent to which renewable energy as a topic is prevalent in science learning and the extent to which science education graduates are prepared well in advance for envisioned future work environments (Smith, 2019; Stats SA, 2019). The timely and appropriate preparation of science education graduates is critical and urgent, considering the general aims of the South African curriculum, Grades R–12, in particular, as stated in the CAPS. The integration of SDG 4 with national education sector development initiatives is a crucial premise for supporting its implementation (Stats SA, 2019).

This section investigates how existing literature justifies the creation of sustainable physical sciences learning environments through the teaching of renewable energy. It commences with a focus on curriculum, followed by teacher knowledge and, lastly, teaching and learning resources as components that play an important role in renewable energy and the creation of sustainable physical sciences learning environments. Sources of information in this section include policy, previous research on the issue under consideration, other similar studies and credible reports.

2.4.1.1 Curriculum

The CAPS has the purpose of “equipping learners with the knowledge, skills and values necessary for self-fulfilment, and meaningful participation in society as citizens of a free country” and for “facilitating the transition of learners from education institutions to the workplace” (DBE, 2011, p. 4). The notions expressed in the CAPS regarding “equipping learners” suggest that learners should be armed, resourced and capacitated with competences that can enable them to engage with the complex realities of their physical environments, social and economic situations they are confronted with (Hays & Reinders, 2020). This notion is emphasised further by the goal of “facilitating the transition”, which suggests the relevance of competences in the learners’ current situations and contexts, and authentic future work-based demands (Hays & Reinders, 2020). Furthermore, the enabling competences suggested should inevitably be goal directed, with the goals being in the learners’ self-fulfilment and their ability to make meaningful contributions in their respective communities and societies. To this end, learners’ aspirations and social demands, which are interdependent with the economy (workplace) and entangled with the environment, are inescapably imperatives (Fredengren, 2021; Vannini & Vannini, 2019).

The entangling reality (Ceder, 2018; Vannini & Vannini, 2019) of the social, environmental and economic (ontological) aspects of life painted above resonate with the underpinnings of the transformative paradigm, in that it advocates for inclusivity, which suggests accommodation of diverse cultures to achieve social justice, which is associated with the redress of imbalances of the past and advocacy for equity and equality (DBE, 2011, p. 5). The role of teaching about renewable energy for sustainability in a context marred by inequality (social injustice) may not be overemphasised (Gebeyehu, 2018). The effect of this inequality can be traced to prevalence of households that still experience challenges relating to accessing energy (electricity), despite them being privileged by an abundance of natural solar energy, which they cannot access due to ‘ignorance’.

Renewable energy information can include how energy from the sun is trapped and stored and converted to other forms of energy (DiRuzza et al., 2017). This requires knowledge about photons, frequency and the relationship between matter and energy. Beyond this, information about actual materials (included in the curriculum) and their identification for use for generating renewable energy is needed. These implicit concepts are mentioned in the curriculum but are not packaged together under renewable energy.

Additionally, the curriculum encourages the incorporation of indigenous knowledge systems (DBE, 2011). However, despite the rich information on how energy was conserved and how a balance has been struck between the use of energy for human and non-human consumption, there is limited evidence that can confirm the indigenous knowledge in this regard. For instance, the general perception is that the human entities relate to ownership of the non-human components and entities of the environment (rationality sources). This places the human entity in a position of absolute power, to the extent that it can abuse and misuse non-human (Saculsan & Mori, 2020). In contrast, indigenous knowledge system settings observed and held in high regard maintain the balance between the human and non-human entities. To this end, Cortese (1999, p. 2) contends that “the environment is not a competing interest; it is the playing field on which interests intersect”. In the context of this study, the interests of the human and the non-human entities intersect. This idea suggests that due regard for the wellbeing and sustainability of non-human entities, such as the infrastructure and potential energy producing matter and material, are also of utmost importance (Lu et al., 2017).

Therefore, an emphasis on caring and conserving the non-human entities deserve equal status in the teaching and learning environments when it comes to sustainability (Gebeyehu, 2018; Hays & Reinders, 2020). This, furthermore, indicates the importance of a balance among the social, economic and environmental aspects of reality. It also suggests the importance of conservation of natural resources, such as water and electricity. Local municipalities struggle to provide water because they lack the electricity necessary for cleaning and pumping water to communities (Bazaanah & Mothapo, 2023). Over two billion people in rural Africa lack safe drinking water due to inadequate electricity supply (Okafor et al., 2024; Potgieter et al. 2019). Inadequate provision of safe drinking water makes it difficult to maintain public health, reduce waterborne illnesses, and improve overall quality of life (Bazaanah & Mothapo, 2023; Okafor et al., 2024).

Shortcomings regarding water supply in general hinders food production and cleaning of houses and facilities, compromises water sports and other day-to-day activities and hinders production of clothing, furniture and personal grooming items (Bazaanah & Mothapo, 2023; Okafor et al., 2024; Potgieter et al., 2019). In electricity-scarce areas, it may, therefore, be beneficial to find ways of supplying water through ways that do not require electricity.

For centuries, indigenous communities all over the world considered water as a shared resource and their traditional water conservation systems reflected this belief. They prioritised community-based management of safe drinking water and sanitation, which entailed group decision-making, shared accountability and sustainable behaviours (Mazzocchi, 2020). Community-based water management is a people-centred method of integrating culture with the protection of water to eradicate poverty, hunger, and illness and helps sustain energy (Mazzocchi, 2020). This water management system is the collective usage and management of water in rural and remote regions by a group of people who use communally owned infrastructure. Community-based water management focuses not only on responsible water management, but also on community empowerment and engagement. Because this method of water management is mostly natural, it does not harm the environment, does not require electricity for the pumping and distribution of water, and it does not require a great deal of money to implement, unlike most modern methods (Mazzocchi, 2020).

When communities take part in the sustenance of their environment, they are empowered to participate in improving and maintaining the quality of life in their neighbourhoods, and they have the opportunity to find ways to improve the sustainable practices already known to them. For example, in Himachal Pradesh, India, indigenous people created water conservation techniques using *Kuhls, Khads* and *Qanats* (Sharma et al., 2015; Singh et al., 2010). *Kuhl* irrigation systems consist of a complex network of canals and channels that crisscross the terrain. These canals use the principle of potential energy by using gravity (instead of an electric pump) for the flow of water from higher ground to lower ground, thereby allowing water to reach various agricultural areas in a regulated and orderly fashion without using electricity (Singh et al., 2010).

Khads are tiny check dams constructed across streams to replenish groundwater and prevent soil erosion and flooding by storing excess run-off after rainfall (Sahni, 2012; Singh et al., 2010). To build an architecturally strong *Khad*, the builder has to consider the physical science behind the stable construction of a dam (Hien & Van Chien, 2021; Sahni, 2012), including the type of material to be used and the centre of mass of the dam wall according to its height and width (Hien & Van Chien, 2021). If the centre of gravity is shifted to one side (because the wall was not built straight or was built on sloping terrain), the force of gravity acting downward causes a twisting effect known as a moment. If the moment is very small, the mortar between the bricks can withstand it and the wall will keep standing. However, if the moment is too great, the mortar will fracture, the bricks will fall, and the dam will collapse (Hien & Van Chien, 2021).

Qanats have been used for centuries to extract water. The techniques used vary, depending on the local context. Some are associated with surface water, while others include groundwater extraction and management (Nasiri & Mafakheri, 2015). This ancient water extraction and transportation technology is widely utilised in Morocco, Spain, Syria, Iran and Central and Eastern Asia, where it is known by different names, such as *Khettara* in Morocco, *Qanat* or *Kārīz (Kāhrez*) in Central and Eastern Asia, including China, and *galerias* in Spain (Canavas, 2014). This approach has been used for millennia to extend the life of deserts (Canavas, 2014).

These traditional water harvesting systems reflect a strong awareness of local ecosystems and sustainable water management that require little to no electricity, contrary to the water harvesting, cleaning and transporting techniques used in most parts of the world today (Chowdhury & Behera, 2020). These sustainable water management methods may be small scale compared to municipal systems, but they contribute to sustainability, in that they are safe for the environment, cheaper to maintain and eliminate the emission of harmful gases that are released when generating enough electricity for water management (Chowdhury & Behera, 2020).

Teaching young people about this indigenous knowledge gives them an opportunity to participate in sustainable practices and, possibly, even improving them to accommodate modern societies (Mazzocchi, 2020). The appropriate preparation of physical sciences learners in sustainable practices is critical for ensuring that physical sciences graduates are well prepared for SDG 7 work environments (Gebeyehu, 2018; Hays & Reinders, 2020).

2.4.1.2 Physical sciences teaching affordance

The physical sciences teaching affordance of renewable energy is essentially the ability and willingness of physical sciences teachers to grant physical sciences learners the opportunity to gain an understanding of renewable energy. Scholars, such as Celikler (2013), Kandpal and Broman (2014) and Guven and Sulun (2017) highlight the importance of education in gaining a better understanding of renewable energy, as well as in supplying and fostering information, instilling values, and raising public and community awareness (Celikler, 2013; Guven & Sulun, 2017; Kandpal & Broman, 2014). For renewable energy implementation efforts to progress at a better pace, more detailed renewable energy principles and applications must be included in physical sciences teaching (Solar Energy International, 2021). Doing so would ensure that citizens have the opportunity to gain applicable skills, not only for a sustainable workplace, but also to become members of a clean-energy society (Kimuli et al, 2017). This kind of sustainable learning environment is relevant for global citizenship (United Nations General Assembly, 2015). The integration of SDG 7 with national education sector development initiatives is a crucial premise for supporting the achievement of the sustainable development goals (Stats SA, 2019).

For physical sciences teachers to afford learners the opportunity to learn about renewable energy, they themselves must possess adequate knowledge. In Section 2.4.1.3, I discuss how teachers could be afforded the means to teach about renewable energy through acquiring teacher knowledge and teaching and learning resources.

2.4.1.3 Teachers' renewable energy content knowledge

Teachers' content knowledge of renewable energy refers to teacher cognitions of renewable energy, their consciousness of it and knowledge of its concepts, principles and scientific laws associated with renewable energy. The concepts, principles and scientific laws referred to here can be drawn from a solar cell and PV system components (Franklin, 2018; Roos, 2009). For instance, the concepts relating to the solar cell are sunlight, anti-reflection coating, front and back contacts, n-type and p-type semiconductors, transparent adhesive and cover glass. From PV system components, concepts such as charge controller, inverter and DC and AC loads, can be highlighted (Franklin, 2018). Furthermore, the concepts of biofuels can also be included in the content about renewable energy (Goossen et al., 2017).

As can be seen from this list of concepts related to renewable energy, many of them are part of the curriculum, except for charge controllers and n-type and p-type semiconductors, which are not emphasised, but may be mentioned in passing, depending on the teacher's interest and knowledge. Similarly, the principles and or scientific laws derived from these concepts are already part of the curriculum and may only need to be emphasised in relation to renewable energy for sustainable development.

For instance, the notions associated with sunlight include the principle that sunlight comprises or is pockets of energy, that is, photons travelling in a wave-like manner, the dual nature of light and possessing energy, $\boldsymbol{E = hf, h = 6.62 \times 10^{-34} J.s}$, where $\boldsymbol{E}$ is the energy of a photon, a particle of light, $\boldsymbol{h}$ is Plank's constant and $\boldsymbol{f}$ is the frequency of the photon wave (Andrews, 2023). Evidently, there is agreement between concepts of sunlight as energy and the construct or scientific law articulated in the mathematical expression stated above.

The principles that attempt to explain the behaviour of photons when they interact with matter could include, for instance, that a photon does not have mass and it becomes distinct once it come in contact with matter, hence, all of its energy is transferred to the material it comes into contact with (Andrews, 2023). Consequential to this principle emerges the desire to access the energy in the material obtained from the photons (Andrews, 2023). To this end, it becomes imperative to use material that would enhance optimum access to this energy, hence, components such as the n-type and p-type plates of semiconductors and the anti-reflection coating (Shah, 2022).

Essentially, solar cell and the PV system components can be described as equivalents of a cell and electric circuits as taught in physical sciences curriculum main knowledge area on electricity (DBE, 2011). Figure 2.2 depicts a solar cell with possible concepts, soliciting principles and associated scientific laws.

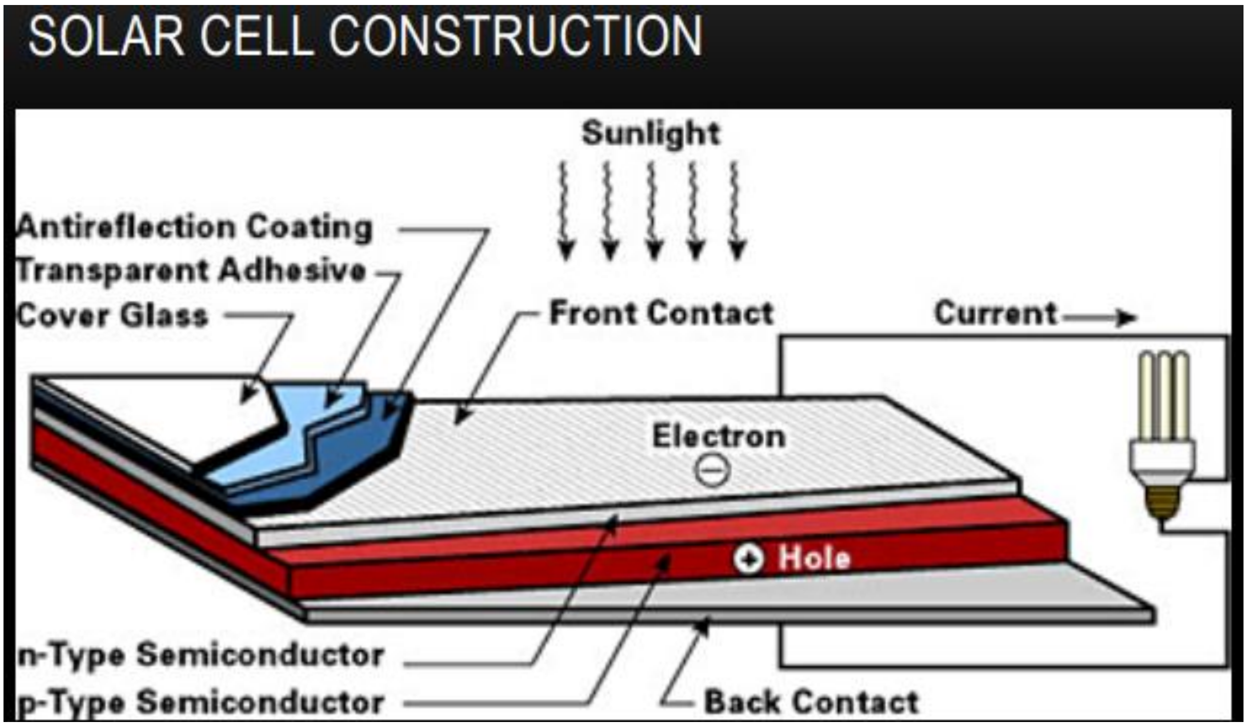

Figure 2.2: Solar cell construction

Source: https://studiousguy.com/solar-cell-working-principle/#google_vignette (retrieved 2 May 2023)

As indicated in Figure 2.2, concepts such as anti-reflection coating and n-type and p-type semiconductors may constitute some of the basic concepts that may be accounted for scientifically. Similarly, the sunlight shining on the front contact will elicit discussions on the principles of absorption, reflection and conversion of light photons when in contact with matter (Andrews, 2023). Subsequently, the scientific laws relating to the flow of charge (electric current) and its conversion into light in the connected bulb may follow (Andrews, 2023; Franklin, 2018). This is similar to the electric circuits present in conventional physical sciences teaching of electricity.

The principles of flow of charge (electrons) can, then, be explained in the same way as it is in the current setup. Similarly, the PV system components, which include battery, converter, charge controller, AC load and DC load, afford opportunities to teach and to acquire renewable energy content knowledge from concepts to principles and scientific laws (Andrews, 2023; Franklin, 2018). Evidently, the principles immediately above require insightful and critical reflection on the relational comprehension of the various non-human entities with respective human entities. This relational critical reflection focuses on the use and relative values of all the non-human components, with the human entities situated in the same environment for mutual economic and social benefits, in this case, energy for sustainability (Vannini & Vannini, 2019).

Furlong (2000) says that teacher knowledge is a relational and reflective practice. Reflective physical sciences teaching practice involves a physical sciences teacher evaluating and critiquing their practice in relation to the progress of the learners, the feedback of the learners, the classroom environment, and the effectiveness of the teacher’s teaching tools. This relational reflective practice is undertaken with an aim of improving teaching by noticing shortcomings and making the necessary adjustments to ensure current and future advancements (Brandenburg et al., 2017) A physical sciences teacher must be aware of shortcomings in their lesson, in order to critique their teaching of renewable energy in an effective manner (Sonia, 2017).

Possession of adequate and sound renewable energy content knowledge enables one to critically assess the correctness and quality of the information imparted to learners (Ben-Eliyahu, 2021; Mengi-Dinçer et al., 2021). Similarly, the choice of modes and mechanisms of imparting of such content knowledge are directly influenced by the quality and depth of the teacher’s renewable energy content knowledge (Popova et al., 2016; Spears et al., 2018).

The current and future demands of learning, teaching and applying the principles of renewable energy in authentic situations have become urgent (Gebeyehu, 2018; Hoque et al., 2022). These demands are exacerbated by the depletion of fossil fuels (Strambo et al., 2019; Yi et al., 2023) that result in limited energy supply, as evidenced by load shedding and negative effects on the economy, and worsened by the scarcity of water (Du Plessis, 2017; Van der Nest, 2015; Yi et al., 2023).

This situation prompts the need for massive, continuous development and production of physical sciences teachers who can teach about renewable energy competently (Spears et al., 2018). Teachers who are knowledgeable about renewable energy content have the potential to render relevant the teaching of physical sciences and, as such, contribute to equipping learners with skills, knowledge and values that are relevant for their self-fulfilment and meaningful participation in their communities (Spears et al., 2018). Teachers who enhance their knowledge and abilities are better equipped to make judgements about curriculum and teaching and have the potential to create a sustainable physical science learning environment (Antink-Meyer & Aldeman, 2021; Mokkapati & Mada, 2018; Tlali, 2017).

2.4.1.4 Teaching and learning resources for renewable energy

The term teaching resources refers to a broad category of items that educators utilise to impart knowledge (Merritt et al., 2019). Therefore, renewable energy teaching and learning resources are any teaching aids that encourage and assist the process of teaching and learning about renewable energy content, concepts and skills. Teaching resources affect the instructional components of lesson planning in the classroom (Merritt et al., 2019). These resources include renewable energy system components, such as charge controllers, batteries, inverters, DC load, AC load and PV panels (Boxwell, 2010). These components may be assembled or connected as an independent energy generating system, where the controller can be directly connected to an electrical appliance, or the battery can be disconnected after charging and used to replace a disposable battery in basic circuit (Boxwell, 2010; Cameron & Craig, 2020), as currently demonstrated in schools. Practical activities and project opportunities are given in the CAPS document, and these opportunities may be used to design and make models of the solar cell and the PV system.

The solar cell and the PV system models could be the initial project for Grade 10, given the ample opportunities that CAPS provides. In later grades, learners could be required to build he solar cell and the PV system using authentic material. These models, while having the purpose of assessing learners' competences, can also be utilised as teaching and learning aids. If a teaching and learning aid is found to be effective, it could be purchased from the learners who created them, mainly because learners would have spent money to purchase material and spent time building the models. In this way, the projects serve multiple purposes, inclusive of creating economic and social value, because the models can then be used to provide energy on a small scale, perhaps to charge a laptop/cell phone or to light a bulb.

In this way, learners are already being prepared to enter the workplace (Ben-Eliyahu, 2021). This will be in line with the goals provided for in the CAPS document (DBE, 2011). The only difference between a basic disposable battery-powered circuit as demonstrated in physical sciences Grade 10, 11 or 12 (see Figure 2.3) and a solar cell circuit (see Figure 2.4) is that the latter is charged by the sun.

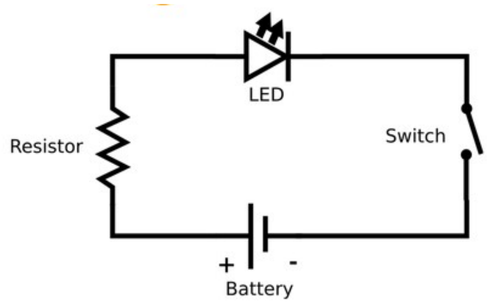

Figure 2.3: Traditional basic circuit diagram

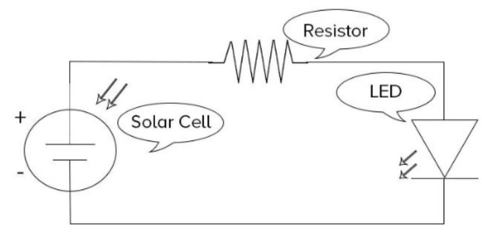

Figure 2.4: Basic solar circuit diagram

The solar cell is a connection of the solar panel, inverter and battery (Boxwell, 2010). When the battery is charged, it can be used on its own, without the panel (Boxwell, 2010; Cameron & Craig, 2020). This means the solar energy practical experiments are the easiest to do in a classroom setup, while wind and water energies could be done as projects or assignments (Cameron & Craig, 2020).

2.4.2 Mechanisms to circumvent challenges

This section focuses on mechanisms that can be applied to circumvent possible challenges to creating sustainable physical sciences learning environments through the teaching of renewable energy. It considers the components that play an important role in renewable energy teaching and the creation of sustainable physical sciences learning environments.

2.4.2.1 Curriculum affordance

Studies indicate that, in order to combat climate change and promote sustainable development, education and training related to renewable energy must be disseminated to future generations as soon as possible (Gebeyehu, 2018; Hoque et al., 2022). Knowledge of renewable energy is essential for future scientific literacy and resonates and fits in with teachers' competences for or in education for sustainable development (Antink-Meyer & Aldeman, 2021; Dignath, 2021; Kimuli et al., 2017).

Certain countries have progressively integrated knowledge of renewable energy in their basic education syllabi, to teach students about its importance from an early age (Cebrián et al., 2020; Smith, 2019). For a instance, Hong Kong has implemented a solar education programme that gives primary and secondary school pupils hands-on experience, provides them with information technology skills and presents them with problem-based learning opportunities to create solutions (Close, 2003). The initiative aims to increase the population's knowledge and understanding of the contribution of renewable energy technologies to everyday life, and to broaden the expertise of local construction experts in remote electrical tilt installations (Close, 2003). In turn, the integration of renewable energy into the Japanese curriculum affords learners the opportunity to gain functional skills that enable them to work with renewable energy from a young age.

Countries in the first and developing world have implemented similar programmes (Solar Energy International, 2021). Renewable energy is expanding in the Middle East and North Africa, thanks mostly to regulatory incentives that capitalise on the cost effectiveness of solar PV and onshore wind generation, though this expansion is not as notable at school level (Sayed et al., 2023). Despite increased renewable capacity growth in sub-Saharan Africa, the area still falls short of meeting its electricity demands and resource potential (Adebiyi et al., 2019).

South Africa, specifically, has launched projects to generate electricity from renewable sources such as wind, solar, biomass and hydropower at levels from postgraduate to commercial, though not to a considerable extent at school level (Akinbami et al., 2021; Kimuli et. al, 2017; Stats SA, 2019). This shortcoming places functional knowledge of renewable energy out of reach of physical sciences learners. At present, there appears to be no official basic education plans (or education policy) to explicitly improve on the extent to which renewable energy is covered in the basic education curriculum.

African countries, including South Africa, still refer mostly to coal-generated electricity when learners are taught about energy and power supply principles (DBE, 2011). This is odd, because South Africa has invested the highest portion of its gross domestic product in the world in renewable energy (O'Meara, 2020). An investment of this magnitude requires citizens who are aware of renewable energy, who have the skills to participate effectively in renewable energy developments and, who will, at least, have the basic knowledge needed to play their part in maintaining the efforts made by the state, otherwise, this impressive investment will be difficult to sustain (Cebrián et al., 2020; Smith, 2019; Solar Energy International, 2021).

2.4.2.2 Renewable energy teaching affordances

The teaching of renewable energy in physical sciences has the potential to present learners with opportunities to learn about energy, in a manner that links it and integrates it with expectations of authentic situations, not limited to prospective places of employment. To this end, teaching about renewable energy has the potential to promote teachers' systems thinking approaches and integrated problem-solving prowess (Rieckmann, 2022). These competences can be promoted by teaching in ways that link the energy generation by fossil fuels with that generated by solar, wind, hydro, and biomass.

When this is done, the physical sciences learning environment can be said to have been transformed into a sustainable learning environment, because it would be encapsulating the principles and competences of education for sustainable development (Dube et al., 2023). This view resonates with that expressed by Gebeyehu (2018) and entrenches the teaching of physical sciences for social benefits to address possible social injustice (MacKenzie, 2020; Saini, 2022).

Carbajo and Cabeza (2019), Mpedi (2022) Saini (2022) and Mengi-Dinçer et al. (2021) support and strengthen this notion by contending that renewable energy offers opportunities to curb the emission of harmful gases such as CO and CO_2 into the atmosphere and assists in working towards sustainable development. These notions extend the teaching of renewable energy to consider the possible environmental impact associated with the generation of energy, which is not limited to phenomena such as acid rain, land degradation, air, soil and water pollution and global warming due to the depletion of the ozone layer (Bales, 2017; Gebeyehu, 2018).

Additionally, teaching about renewable energy affords opportunities to educate people about the importance of keeping the environment clean for healthy living for both animals and humans alike (Mengi-Dinçer et al., 2021). Therefore, teaching about renewable energy in physical sciences lessons has the potential to facilitate the creation of creative ways, through projects and activities, to reconcile science with social and economic realities. For this reconciliation to be possible, the physical sciences teacher has to be knowledgeable about the required renewable energy content (Ally & Wark, 2019; Antink-Meyer & Aldeman, 2021; Mokkapati, 2018).

The foundation for professional competence and decision-making in the teaching of renewable energy content is the availability of sufficient teacher knowledge, as is the case with any subject matter (Antink-Meyer & Aldeman, 2021; Sonia, 2017). Learner achievement in learning about renewable energy may suffer from a physical sciences teacher's lack of knowledge, since oblivious teachers force their pupils to lag behind, which turns teaching into a semi-profession (Mokkapati, 2018; Rashtizadeh, 2020; Sonia, 2017). Raising awareness amongst teachers and providing teacher training in the form of workshops and short courses have shown to be the most effective ways to close gaps in knowledge (Dignath, 2021; Mokkapati, 2018; Popova et al., 2016). Doing so would also give physical sciences teachers the ability to use teaching and learning resources correctly and effectively (Dignath, 2021).

2.4.2.3 Teachers' content knowledge of renewable energy

Teachers' content knowledge of renewable energy refers to their awareness and understanding of its concepts, principles and scientific laws. Many of the scientific laws are already part of the curriculum and may only need to be highlighted in relation to renewable energy for sustainable development. For example, the concept of sunlight, as energy generated during the excitement of an electron from a lower energy level to a higher energy level, is an Aufbau principle that learners learn about in Grades 10 and 11, until its advancement in Grade 12 to the photoelectric effect (DBE, 2011). The interaction of photons with matter (under sound, light and waves) results in reflection and absorption, which are all principles used in solar ovens. Wind and water turbines/mills are based on principles of mechanics. A teacher's lack of awareness about relevant principles relating to renewable energy means they will fail to provide learners with the opportunity to learn about renewable energy, even if the teacher had an opportunity to teach them.

2.4.2.4 Teaching and learning resources for renewable energy

Renewable energy teaching and learning resources have the potential to extend the proximity of physical sciences learning environments to the learners' households and prospective workplaces, where energy is generated. They diversify access to the learning of socio-scientific issues, particularly those directly dependent on energy and energy supply, and not limited to water purification and water supply, food production and global warming (Gebeyehu, 2018). In the context of this study, the diversification of access to learning of socio-scientific issues heightens opportunities to expose learners to authentic situations early on in their prospective careers and impel the possibility of increased functional and meaningful learning. Consequently, learners' meaningful participation in the society and their self-fulfilment (DBE, 2011) are potentially eased.

The extension of proximity of physical sciences learning environments to sustainability and the role played by renewable energy in sustainability, could challenge the curriculum to expand on the teaching of semi-metals such as silicon and germanium. The content addressed in the textbooks in respect of the teaching and learning of renewable energy content may be extended and deepened in ways similar to those given under the main knowledge area of chemical systems, such as the chemical industry and mining industry (DBE, 2011). In physical sciences, the mining of coal receives more attention than renewable energy, even though greenhouse gas emissions from mining are an ongoing issue (Ali et al., 2019; Mohsin et al., 2021).

For example, the effect of pollution on maize output has been especially concerning in the coal-mining region of Mpumalanga (Laisani & Jegede, 2019). The concerns and incidents relating to the environmental and socio-economic impacts of coal mining in the Mpumalanga area are generally well reported (Kritzinger & Snyman, 2022; Shongwe, 2018). Conflict situations in the form of community activism and lawsuits have persisted as a result of the government and industry's inadequate reaction on the ongoing environmental degradation and detrimental health impacts on the community (Laisani & Jegede, 2019). Furthermore, it is believed that the government's lack of action was highly politicised and that unethical agreements between mining businesses and government officials or community leaders are mostly to blame (Laisani & Jegede, 2019). Many citizens in Emalahleni long for a cleaner environment for the sake of their crops, livestock and health, and demand that coal mining should be abandoned entirely, since its drawbacks outweigh its advantages (Laisani & Jegede, 2019).

The incomplete combustion of carbonaceous fuels, or black carbon, has an impact in coal-mining areas worldwide. Black carbon absorbs solar energy and warms the earth's atmosphere (greenhouse effect; Mohsin et al., 2021). Methane is created in abundant quantities throughout the coal-mining process, and leakage owing to faulty blocking measures, fissures, and vents in mines allows it to seep outside (Zhou et al., 2020). According to an environmental impact assessment, methane gas emissions from mining account for 1% of worldwide greenhouse gas emissions (Mohsin et al., 2021).

The inclusion of renewable energy components in the physical sciences curriculum may bring about much needed balance to the environmental, economic and the social aspects of energy generation. Metalloids are a necessary renewable energy component, but are not covered fully under the main knowledge area on matter and materials (DBE, 2011). Scepticism about the heavy emphasis on the chemical industry, as a result of the dominance of economic over environmental and social aspects, should not be overemphasised. This contention is adequately addressed by Ali et al. (2019) and Lu et al. (2017).

Contrary to the scepticism alluded to in the previous paragraph, teaching and learning resources related to renewable energy, in the form of projects, promise immense benefits that have the potential to deepen and extend physical sciences content knowledge. Projects, such as the shoe box solar oven and the cardboard-and-stick wind turbine (see Figures 2.5 and 2.6), may afford learners opportunities to contribute to environmental preservation through the development and application of a bricoleur mindset (De Bernardi & Pedrini, 2020). This mindset will instil in learners enquiring minds, which ask probing questions on alternative ways of using materials and matter that would otherwise be abandoned as waste (Cameron & Craig, 2020; De Bernardi & Pedrini, 2020). For instance, the shoe box in Figure 2.5 would have been thrown away as waste, instead, it has been used as a solar oven and, similarly, the cardboard and the stick have been constructed into a turbine (Cameron & Craig, 2020). The best projects may also be used by the teacher for demonstrations, which alleviates the costs of construction further. Figures 2.5 and 2.6

are examples of inexpensive projects that can be used to introduce the basic principles of renewable energy.

Figure 2.5: Shoe box solar oven

Figure 2.6: Wooden wind turbine

Figure 2.5 shows a solar oven made out of a shoe box, aluminium foil and transparent plastic. The shoebox solar oven captures sunlight and converts it to heat energy. Sunlight is reflected into the box by the aluminium foil and is absorbed by the black construction paper. The sun's rays are directed into the box, thereby producing a small, yet extremely hot region. The greenhouse effect causes the confined air within the box to heat up. By keeping heat from escaping, the clear plastic lid keeps the temperature high. Consequently, food placed in the shoebox solar oven cooks without the need for electricity, petrol, diesel, propane gas, or paraffin.

Figure 2.6 is a picture of a wind turbine made of wood. This model can be made more functional by connecting the wind turbine to a coil that can turn to generate electricity. The 'turbine' component of a wind turbine is the rotor blades at its front. Wind passes over the turbine blades, spinning them around. The wind loses some kinetic energy (energy of movement), while the turbine obtains the same amount. A turbine's energy output is proportional to the area swept out by its rotor blades and the speed of the wind; in other words, the longer the rotor blades and the faster the wind, the more energy a turbine produces. The generator generates electric current from the turning turbine, which goes through the cable that is connected to a light bulb in the cardboard house, and the light bulb lights up.

Another alternative and inexpensive tool for teaching learners about renewable energy is using videos or drawings (Merritt et al., 2019). Figure 2.7 is a schematic representation of any renewable energy system. The synthesis of biofuels can be demonstrated as in Figure 2.7.

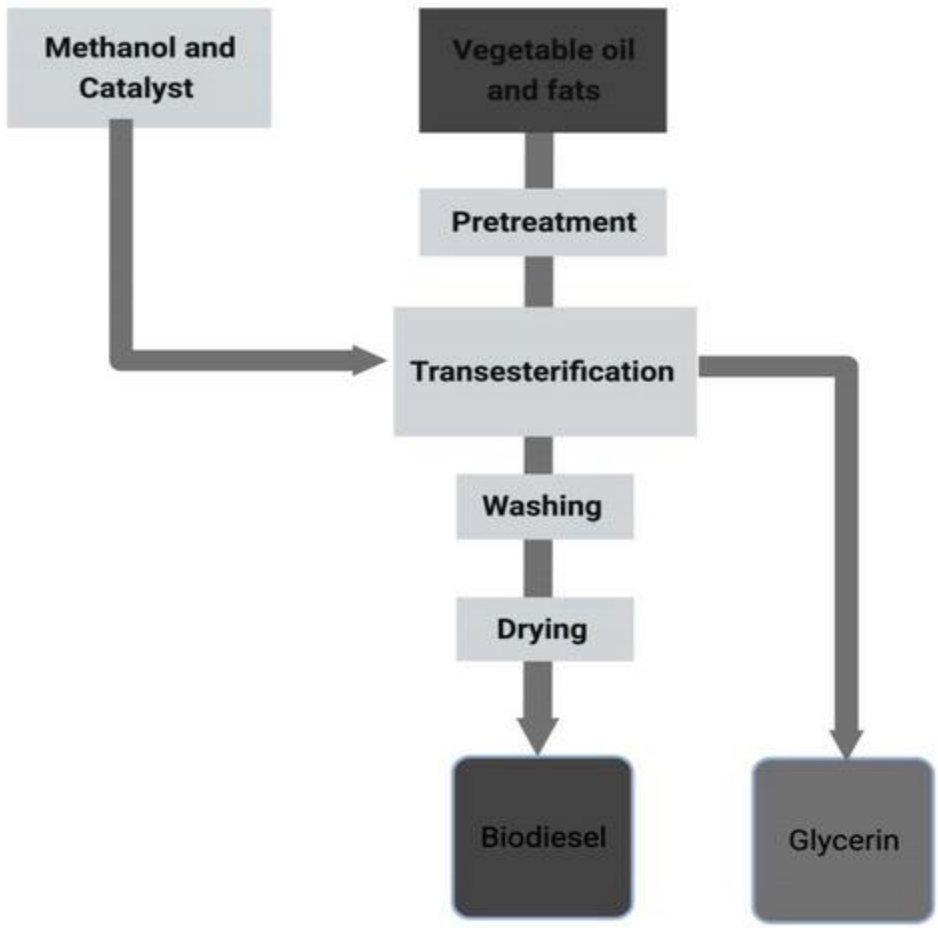

Figure 2.7: Biodiesel production process from crude vegetable oil and fats

Figure 2.7 is a mind map or schematic representation of how biodiesel is made by chemically reacting vegetable oil or animal fat with methanol (an alcohol). The reaction requires a catalyst, which is a strong base, such as sodium or potassium hydroxide, and through the process of transesterification, forms new chemical compounds known as methyl esters (biodiesel) and glycerine. The methyl esters are washed and dried to remove glycerol and the methanol to obtain a purer biodiesel product.

2.4.3 Reflecting on the usefulness of teaching about renewable energy for creating sustainable physical sciences learning environments

Sustainable physical sciences learning environments encourage learners to acquire competencies that are required for meaningful and practical application of science principles in learners' daily lives (Hays & Reinders, 2020; Tlali, 2017). Learners' science knowledge should enable them to sustain their livelihoods and contribute in their communities during phenomena such as the Fourth Industrial Revolution, climate change and the COVID-19 pandemic (Chihib et al., 2021; Gebeyehu, 2018), all three of which are closely related to sustainable energy.

The very existence of the Fourth Industrial Revolution necessitates sustainable energy (Ally & Wark, 2019), while working remotely with electrically powered computers for online learning and online meetings due to COVID-19 health protocols increased the demand for that sustainable energy. The climate change that humanity started noticing from the 1800s indicates that generating energy from fossil fuels is not sustainable (Gebeyehu, 2018). Climate change, which notably increases the frequency and intensity of extreme weather events, has hampered attempts to attain the SDGs (Gebeyehu, 2018; Tria, 2020).

Extreme weather and climate events have exposed millions of people to severe food insecurity and diminished water security, with the greatest consequences documented in numerous regions and/or populations in Asia, Central and South America, Africa, the Arctic and small islands. In some marine zones, ocean warming and acidity have harmed food output from shellfish aquaculture and fisheries (Baag & Mandal, 2022; Stewart-Sinclair et al., 2020). It would be beneficial for learners to be given the opportunity of learning principles of renewable energy and being able to apply what they have learned (Ally & Wark, 2019).

The next section reflects further on the usefulness of renewable energy for creating sustainable physical sciences learning environments through teaching about renewable energy. It goes on to look at curriculum, teacher knowledge and teaching and learning resources as components that play an important role in renewable energy and the creation of sustainable physical sciences learning environments.

2.4.3.1 Curriculum

The physical sciences CAPS document provides a structure for the teaching and learning of physical sciences content through teaching, learning and assessment guidelines. Including clean energy in the curriculum would be useful, as it would allow the formal, detailed and possibly effective teaching and learning of knowledge on renewable energy. Effective teaching and learning in relation to renewable energy can raise awareness and knowledge of clean energy, which, in turn, could help achieve SDG 7. While awareness campaigns can be successful, the curriculum can reach every Grade 10, 11 and 12 physical sciences learner, as they progress through the schooling system.

In this way, citizens would get to know enough about clean energy to actually help implement and maintain it. This is especially important in developing countries such as South Africa, where skills and infrastructure have not developed to meet clean energy goals. An important aspect of physical sciences is appreciating and comprehending its applications and societal value. The physical sciences curriculum is essential for addressing contextual difficulties, such affordable, reliable, sustainable, and modern energy for everyone. Its ability to address such a contextual issue would make the physical sciences learning environment sustainable.

This contextualisation is consistent with the views expressed by Cortese (1999) and Ochonogor and Mohapi (2020), who stress that sustainable learning environments are learning spaces in which knowledge is relevant and functional (Ben-Eliyahu, 2021; Cortese, 1999; DBE, 2011; Department of Education, 2003; Ochonogor & Mohapi, 2020; Stats SA, 2019). In this way, sustainable physical sciences learning environments will be inclusive and instil a sense of social responsibility, in accordance with the aims and objectives of the physical sciences CAPS (DBE, 2011). Inclusivity and social responsibility are also consistent with the notion of sustainability, as well as the SDGs (Cortese, 1999; Sachs, 2012; Stats SA, 2019) and Agenda 2063.

2.4.3.2 Physical sciences teaching affordance

Physical sciences teaching affordance is crucial for developing a better understanding of renewable energy, as well as for providing and fostering information, instilling values and raising public and community awareness (Guven & Sulun, 2017; Solar Energy International, 2021). Teaching about renewable energy may help teachers become more adept at integrated problem-solving and systems thinking while they do their renewable energy lesson planning and design-related projects and assignments (Rieckmann, 2022). Competencies of teachers and learners can, thus, be strengthened through teaching that connects the production of energy from fossil fuels with solar, wind, water and biomass.

As soon as this is has been achieved, the physical sciences learning environment will have evolved into a sustainable learning environment, since it will embody the values and skills of education for sustainable development (Ben-Eliyahu, 2021; Dube et al., 2023). In this learning environment, physical sciences teaching affords opportunities to learn about renewable energy for social advantages and mitigation against unsustainable electricity supply (Gebeyehu, 2018; MacKenzie, 2020; Saini, 2022). As an authoritative figure in the physical sciences classroom or laboratory, the teacher has the liberty to link existing principles in the curriculum with renewable energy and raise awareness among learners about the renewable energy that is all around them (Ben-Eliyahu, 2021).

2.4.3.3 Teachers' content knowledge on renewable energy

Adequate teacher knowledge on renewable energy could improve their time management, organisation, and planning. It could also strengthen relevant creativity for when challenges such as lack of resources arise. It would also motivate the teacher to motivate and engage learners in the clean energy content. Good understanding of pedagogical content aids in increasing student achievement and feedback quality. When teacher knowledge is relevant to a major challenge, such as sustainability and the usefulness of teaching renewable energy, it is simpler for the teacher to contribute to the success of educational innovations, and maintain a sustainable physical sciences learning environment.

2.4.3.4 Teaching and learning resources

Renewable energy teaching and learning resources can support and enrich lesson content, assist learners to learn new concepts, and provide practice opportunities for applying renewable energy principles. These resources can engage, impact motivation, and pique learners' interest in renewable energy. They can be used as tools to foster active learning, the development of various abilities, and the adoption of desirable values and attitudes towards clean energy. Physical sciences teachers require these tools and resources to deliver excellent teaching and learning in a physical sciences learning environment with learners of varying abilities and learning needs. Teaching and learning resources aid in the delivery of personalised learning and the reinforcement of effective teaching, thereby adding significant value to the teaching and learning experience.

2.5 CONCLUSION

This chapter reviewed the literature on renewable energy in teaching that has the purpose of creating sustainable physical sciences learning environments. The study commenced by discussing the background to the problem, which was followed by definitions and discussions of key concepts, then the theoretical framework, and related literature in accordance with the study objectives. The next chapter will discuss the methodology and design that was used to generate data in relation to the creation of sustainable physical sciences learning environments through the teaching of content related to renewable energy.

CHAPTER 3

METHODOLOGY AND STUDY DESIGN

3.1 INTRODUCTION

This chapter discusses the methodology and design used by this study to generate data on the creation of sustainable physical sciences learning environments through the teaching of content on renewable energy. It includes a discussion on the transformative paradigm that couches the study, the rhetorical relationship between researcher and participants, the research design, tools, techniques and methods for generating data, trustworthiness, data analysis, ethics considerations, limitations and delimitations of the study, and the research site.

3.2 METHODOLOGY

This section discusses the methodology. It commences by explaining the transformative paradigm and, within it, ontology and epistemology, and the appropriateness of the transformative paradigm, as subtopics.

3.2.1 The transformative paradigm

This study is underpinned by transformative paradigm principles, among which cultural diversity and social justice (Hays & Reinders, 2020). The transformational paradigm is founded on the idea that injustice and inequality are ubiquitous, and the conviction that research and analysis are critical instruments for alleviating these societal injustices and the marginalisation of citizens. We see the need for cultural diversity and social justice arise in cases where communities are struggling to access energy (electricity) in a country where solar energy is available year round (Prăvălie et al., 2019).

Few South Africans have access to a constant supply of energy to sustain their lives consistent with their diverse cultural backgrounds and socio-economic statuses. Renewable energy is a good alternative for citizens from diverse socio-economic and cultural backgrounds. However, there is not enough provision or education about renewable options (Hoque et al., 2022). In winter, learners in rural areas currently have to learn in cold, unconducive learning environments. Load shedding affects all South Africans, including businesses and common citizens, who are faced with the costly inconvenience of an inconsistent power supply. This study advocates for diversification of energy sources to enable access to energy by disadvantaged schools and communities, and to ease access to services that may require the use of energy. In this sense, the study purpose aligns with the need for transformation (Romm, 2015), from single to diversified mixed-grid and even off-grid options. Accordingly, this study purpose is consistent with cultural diversity as propounded by the transformative paradigm.

3.2.1.1 Ontology

The truth or reality about the creation of sustainable physical sciences learning environments through the teaching of renewable energy topics is complex. The origins of the complexity of this reality is multifold, in the sense that physical sciences learning environments aim at understanding complex natural phenomena, their origins and processes, with the purpose of learning how to bring about a useful balance to sustain the current and future wellbeing of human and non-human things. In this case, renewable energy, as a natural phenomenon to be understood, receives limited attention in physical sciences learning environments. As a result, the teaching of renewable energy content in physical sciences is confronted by limited pedagogical content knowledge, resources and learning activities.

In contrast, at national and global levels, provision of basic energy to communities is experiencing a movement towards mixed-grid and off-grid solutions (Akom et al., 2021). It is, accordingly, imperative that renewable energy aspects of the mixed grid and off grid is taught at schools. Renewable energy has the potential to respond to the much needed social justice and culturally diverse needs of the communities. It also has the potential of bringing about a balance between time and resource allocation for renewable energy in relation to energy based on fossil fuels. In the long run, this could contribute to the balance needed between the social, economic and the environmental needs of future generations. Arguably, physical sciences learning environments do not teach about renewable energy (exclusion), despite renewable energy currently offering an alternative to fossil-fuel-generated energy.

This situation has the potential effect of commodification and the economically unaffordable provision of energy, as indicated by the fact that fossil fuel energy is not accessible to everyone. Consequently, the creation of sustainable physical sciences learning environments is an attempt to challenge this situation and promote the explicit inclusion of and teaching about renewable energy for social justice.

For electricity to be socially just, it must first be accessible to all. This should be accomplished by accommodating diverse citizens, including those who live in remote/rural areas, townships and suburban areas. Diversity in energy generation and supply is necessary because, for far too long, vulnerable communities' concerns have been minimised in energy policy, energy innovation and energy supply, while fossil fuel interests have profited at the expense of others. Striving for a future in which communities in different regions can rely on their own regionally appropriate local mix of renewable energy sources is ideal, because renewable energy is abundant, perpetual and free. To appreciate this bricolage of energy, accounts of different persons in various settings and from various points of view were elicited.

3.2.1.2 Epistemology

The aim of knowing how renewable energy can be used to create sustainable physical sciences learning environments was pursued through the interactions between the researcher and participants. These interactions included one-on-one interviews with questions based on documentary analysis (see Section 3.6), to generate discussions and solicit deep engagements. Further interactions followed up on issues that needed clarity and confirmation, and were not limited to understanding how available resources were or could be used to teach about renewable energy. These follow-up interactions were useful, because they helped to unravel the complex cultural contexts that inform or may have historically informed the exclusion or inexplicit inclusion of teaching about renewable energy in physical sciences (Romm, 2015). The purpose of interacting and enquiring further about the "historical and contextual" base of knowing about renewable energy was, in this case, to understand renewable energy teaching actions that hold potential for "increased justice" for those deprived of access to energy (Romm, 2015).

Accordingly, the knowledge about renewable energy and the creation of sustainable learning environments relied upon the information, both historical and contextual, provided by the participants. We can say that knowledge, in this study, was not only subjective, but was also constructed on the information obtained from the social backgrounds of the participants and based on our interactions. It is, however, important to note that this knowledge was on scientific information relating to energy and the teaching of renewable energy.

3.2.1.3 Appropriateness of the transformative paradigm

The main research question and the aim of the study relate to complex phenomena and processes. For instance, notions of sustainability in sustainable learning environments presuppose the concurrence of economic, environmental and social aspects of energy. Similarly, the creation of such learning environments is equally complex, more so because they involve diverse perspectives and cultural and theoretical elements. It is these complexities that warrant transformation for social justice focusing on accessibility to energy as a basic service. Consistent with the above, the transformative paradigm advocates for social justice and equality. The resonance between the main research question and the paradigm facilitated a logical, systematic discussion of the study.

3.2.2 Rhetoric

Rhetoric is the art of effective speaking or writing (Zappen, 2019), which, in this case, was influenced by or considerate of participants' diverse cultures and the power differentials inherent in their teaching and learning backgrounds. I was, accordingly, considerate and sensitive to the issue of language (Mooney & Evans, 2018; Talbot, 2019), and I accommodated diverse perspectives, different circumstances and theoretical positions without losing sight of inclusivity and social justice. Participants of different backgrounds (see Section 3.3.3) communicated different messages that required well thought-out phrasing of questions and follow-up questions in the context of the environment.

3.2.3 Relationship between researcher and the participants

Once I had gained access to school and had identified participants, I expressed appreciation of the participants' time and expertise in relation to the energy-related topics in physical sciences. I humbly and respectfully shared my views about possible benefits the participants could expect from contributing to the study. Regarding teaching and learning-related benefits, the participants confirmed that they were excited about how the topic of renewable energy could be topical and useful to them. We subsequently discussed and agreed upon the way the study would be implemented in a way that did not distract from the usual teaching and learning programme at their respective schools.

Among the process and procedural issues we agreed upon, were i) the estimated time and duration of the interviews; ii) dates on which interviews would be conducted; iii) venues, modes and media for conducting interviews; iv) possible arrangements for additional, follow-up and confirmatory interviews; v) the techniques and approaches the interview would follow; and vi) checking the apparatus and resources to support the teaching of renewable energy content, where such were available.

The participants were interviewed individually. Before the start of the interview, attempts were made to kick-start the conversation casually by talking about general and interesting matters. For instance, we chatted about how well learners behaved and how they managed their workload, the discipline in the classroom and laboratory, and looking after apparatus and resources. These conversations served to ease tensions and provided a cushion for smooth and free-flowing views and ideas. It is interesting that approaching interviews this way seemed to strengthen my working relations with the participants, because it opened up time for engagement beyond just the agreed-upon arrangements for data gathering. Even after the data collection stage, I received calls from participants who asked me how the study was going, and requesting me to keep them abreast with the study developments.

3.3 RESEARCH SITE AND PARTICIPANTS

This section describes the site of research, the selection of participants and the participants' profiles, and how they contributed to achieving the objectives of the study.

3.3.1 Site

The research site refers to the location at which the interviews were conducted. Participant 1 taught at a school based on a smallholding, which was meant for learners who lived on farms in the vicinity. Participant 2 taught at a school in a predominantly Black community in a typical South

African context, which had experience historical inequalities. The third participant taught at a school that was well resourced, with the physical sciences classroom being merged with an equipped laboratory.

The interviews with physical sciences teachers were carried out at the three schools where the teachers taught (see Section 3.3.3). The schools were chosen as the research sites to enable observation of the physical sciences laboratories and equipment that is or could be used for the teaching of renewable energy at those schools, including anything that the teachers might want to show or demonstrate before, during or after the interviews. My presence on the school premises also gave me the opportunity to improve on the interview by asking about what I observed on the school premises or in the physical sciences learning environments when I was present.

3.3.2 Selection of participants

Three physical sciences teachers were selected to participate in the study, one from each school based on the criteria that i) the teacher had at least five years' experience of teaching physical sciences, with experience in natural sciences as an added advantage; ii) the teacher had been exposed to workshops on physical sciences teaching; and) that they were available and willing to participate in the study voluntarily.

I drew lessons from teachers' experiences of teaching about renewable energy, with the purpose of establishing mechanisms to circumvent the challenges already experienced or likely to be experienced when they taught the topic of renewable energy. The responses of experienced physical sciences teachers helped me to reflect on the usefulness of teaching about renewable energy with the aim of creating sustainable physical sciences learning environments.

3.3.3 Participants' profiles

Qualified Grade 10, 11 and 12 physical sciences teachers were selected as participants in this study. The background of Participant 1 represents that of a typical school situated in a remote farming area, where learners and teachers can only access the school after travelling long distances by bus or privately owned vehicles, cycling or walking from neighbouring farms and distant township residential areas. Participant 2 was from an equally disadvantaged school in terms of resources relevant for teaching science – the school had no laboratory or science kits. The third participant was from a relatively affluent fee-paying school with well-furnished and resourced physical sciences classrooms fitted with projectors, computers and other ICT gadgets such as a Physics Education Technology (PhET), and at the back of the classroom was a well-furnished and well-resourced laboratory.

Participant 1 had a BSc chemistry degree and a PGCE qualification specialising in teaching physical sciences, natural sciences and life sciences. Participant 2 had a B.Tech degree in engineering science and a PGCE qualification, specialising in physical sciences, natural sciences and mathematics. The third participant had a four-year degree in education, specialising in physical sciences, natural sciences and geography. All three teachers had experience of teaching across the whole FET phase.

These teachers were specifically chosen to enable and assist in the checking of progression of teaching and learning on renewable energy topics across the whole FET phase. The physical sciences teachers had to have a minimum of five years' physical sciences teaching experience. This was to ensure that participants responded by referring to their pedagogical knowledge and their experience in practice; they had also had enough time to try different teaching approaches and techniques for teaching about energy. The physical sciences teachers had to be from three schools of different affluence levels. Affluence levels of schools were determined by checking how well resourced a school was, and what the school fees were at each specific school. Most importantly, participants had to be available and willing to participate in the process of collecting good quality data.

3.4 RESEARCH DESIGN

The research design guided the research process by outlining procedures and strategies for data collection and analysis. The section commences by discussing the research approach, followed by the actual design and, lastly, the processes and procedures that were followed.

3.4.1 Qualitative approach

This research followed a qualitative approach. A qualitative research approach allowed me to observe physical sciences laboratories and equipment in the presence of participants at the schools where they teach. Observations of these laboratories and equipment in the presence of the physical sciences teachers allowed me to ask questions about the extent to which they teach renewable energy. This enabled me to discover genuine factors, trends in thoughts, opinions and beliefs about energy and teaching about renewable energy specifically. The participants were comfortable about showing me factors that positively and negatively affected and influenced their instruction and, as a result, I was able to ask clarity-seeking questions if and when answers were vague or not clear enough, ask further questions based on my observations of their body language (if they seemed hesitant or as if they had had a thought that they did not express) and ask about what I observed in the physical sciences classrooms. This qualitative approach enabled me to dive deeper into the possibility of renewable energy creating sustainable physical sciences learning environments.

3.4.2 Case study design

A case study research design was chosen for this study because of the small size of the study. The type of case study design chosen is an instrumental one. An instrumental case study research design was chosen because the case under examination, that is, sustainable physical sciences learning environments through the teaching of renewable energy topics, was seen as crucial to understanding not only renewable energy in the subject of physical sciences, but also physical sciences education and the implementation of renewable energy in South Africa working in sync to contribute significantly towards attaining the 2030 SDGs. These notions are consistent with Baxter's (2008) description of instrumental case study designs. Education about renewable energy that is envisioned for integration in the national grid should be synchronised with implementation. This alignment between energy implementation and education often requires learning before implementing, in order to avoid a lack of the knowledge and skills to implement, loss of time and money because of having to import the knowledge and skills and unsustainable implementation practices because of a lack of nationwide awareness and a scarcity of skilled workers. Consequently, the instrumental case study design enabled me to learn the reasons behind the guiding beliefs that physical sciences teachers held about sustainable physical sciences learning environments and renewable energy content.

3.5 PROCESSES AND PROCEDURES

The processes and procedures followed in this study were the following, First, I applied for title registration through the university's usual processes and then applied for ethics approval to allow me to collect data. In this process, I included requests for permission to conduct research from the Free State DBE and the three schools of the teachers who participated in the study. Each applicant was recruited or identified according to criteria (see Section 3.3) and compliant with the prescriptions of the of POPIA and ethics policy requirements, which were disclosed to and discussed with the participants (South Africa, 2013). I attach copies of title registration and ethics approval letters as Annexures E and F respectively.

After establishing contact with the schools and participants, I made arrangements to meet them in person to discuss the study and to establish mutual understanding of the ethics and POPIA in respect of the use of data for research purposes only, participation on voluntary basis, the right to withdraw at any time, the possible risks of time spent participating in the study, the obligation to provide information as truthfully and honest as possible, the anonymity of the participants' information and details, safekeeping of the data, and the right to review, verify and confirm or refute the transcribed data and findings (Ciuk & Latusek, 2018).

3.5.1 Tools (voice recording, interview questions)

Physical sciences CAPS, the physical sciences textbooks currently in use, assessments of learning and end-of-year examination papers were analysed to determine the extent to which content, concepts, skills and values on renewable energy and its teaching were explicit. Subsequently, to confirm or refute the analysis, interviews and laboratories and equipment observations were conducted with teachers to obtain further insights on renewable energy. The curriculum analysis encompassed all main knowledge areas, namely, mechanics, waves, sound and light, electricity and magnetism, chemical change, chemical systems and matter and materials.

Interviews and observations enabled me to seek clarity on factors affecting the teaching of renewable energy in physical sciences and to dig deeper to understand underlying issues surrounding the teaching of renewable energy for sustainable physical sciences learning environment. The interviews were recorded and transcribed verbatim.

3.5.2 Free attitude interview technique

Research techniques denote the broad strategies or frameworks that directed this study. The techniques are the ways in which data were collected for the purpose of determining how to create sustainable physical sciences learning environments. In order to dig deep for insightful information about renewable energy and its teaching, the principles of free attitude interviews were used as technique (Holloway & Jefferson, 2008).

First, the participants were asked ice-breaking questions in the form of secondary research questions, for instance, “please share with me your knowledge about renewable energy, what it is, and where under the curriculum it is taught”. The participant was then given the freedom to express their views without interruption; I noted points I needed to seek clarity on. Subsequently, upon completion of their response, I followed up with clarity-seeking questions based on the responses or aspect thereof.

Clarity-seeking questions and corresponding responses usually resulted in new information that had not been part of the initial response. This led to interesting conversations and further questions and responses, to the point that no new information could be brought out. Beyond that point, follow-up questions that introduced the subsequent secondary research questions ensued. The newly introduced secondary question followed a similar pattern of asking clarity-seeking questions and corresponding responses and discussions to the point of saturation (Abdul Majid et al., 2018). Confirmatory statements that sought to *summarise* the discussion at any point of the process for each question were considered for data included for the purposes of this study.

3.5.3 Trustworthiness

Trustworthiness refers to the adequacy of qualitative research instruments and outputs, measured by conformability, credibility, transferability and dependability (Stahl & King, 2020). Conformability here refers to the degree to which the research findings in this study can adapt and be applied to physical sciences settings in other schools for the creation of sustainable physical sciences learning environments. This helps to make the study transferable (Stahl & King, 2020). To achieve this, data were generated from different schools with different socio-economic backgrounds, with the participants having diverse experiences and training in the teaching of physical sciences. The transferability of this study means that the research results will be applicable to other physical sciences learning environments with varying circumstances and contexts, which would increase its dependability (Stahl & King, 2020). To this end, participants' diverse school backgrounds and experiences suggest that the finding of this study could be applicable to schools in quintiles 1, 2 and 5. Regarding credibility, the relevance of teaching about renewable energy at a time when schools experienced the reality of load-shedding and as a result of which learning was affected adversely, attest to the credibility of the findings.

3.6 DATA ANALYSIS

The data were analysed by finding patterns, insights and significance relating to sustainable physical sciences learning environments through the teaching of renewable energy (Sinkovics, 2018). The first data set was from documentary content analysis of the physical sciences CAPS document, FET phase physical sciences end-of-year exam papers and FET phase physical sciences textbooks. The second data set was gathered from interviews, which were instrumental in corroborating the observations from the documentary analysis and providing further inference. The transcripts of the interviews were checked for explicit inclusion of concepts, content and skills related to renewable energy.

The information from the transcribed interviews was sorted into themes and subthemes according to common or similar messages, meanings and ideas. All this was done after or concurrent with organising the data according to identified principal topics or ideas that had come to light throughout data processing, and in line with the objectives of the study (see Chapter 1).

The third data set was observation of physical sciences laboratories and equipment to check the resources that might be used for teaching about renewable energy, with a focus on the generation of electricity. Resources such as electroscopes, zinc plates and sources of ultraviolet rays for photoelectric effects, wind and water-based turbine models for generating electricity, as well as solar cell models and harts were examined. The observed situation regarding resources was used to confirm, refute and make sense of the actual situation regarding the teaching of renewable energy.

3.7 ETHICS CONSIDERATIONS

I applied and obtained ethical clearance from the University of the Free State ethics committee. I subsequently contacted the schools and prospective participants to negotiate for their permission and consent, respectively, to participate in the study. Matters I discussed with the participants before commencement of data collection once they had given their consent to participate in the study included the following: confidentiality and anonymity of personal information, autonomy and voluntary participation in the study, limiting risks that may arise from the study and alignment of the study and their interests, as well as openness and transparency regarding data checking for confirmation or refutation (South Africa, 2013).

I considered these ethical issues at every stage of the study process by adhering to the research standards of the University of the Free State, Free State Department of Basic Education and the POPIA. The participants were independent volunteers in the study, as they were not paid or coerced to participate. Their independence was safeguarded further by asking open-ended questions, as far as possible, to ensure that their replies were their own expressions. These responses were transcribed verbatim to protect the independence of their expressions. I also asked for clarity when their responses seemed unclear, to avoid making assumptions.

There was minimal chance of injury to the participants, because the interviews were conducted at their schools, which were familiar environments, and they did not have to drive elsewhere, which eliminated any chances of a vehicle accident and expenses. The participants understood the researcher's role, because it was communicated with the schools where participants taught before interviews were conducted. The participants were also made aware that they could ask clarity-seeking questions about the research, its purpose and the role of the researcher in the study.

3.8 LIMITATIONS AND DELIMITATIONS OF THE STUDY

Because of its limited scope, time and number of participants, this study may have not pooled adequate lessons that could inform science teachers on how to teach about renewable energy using available limited resources. Another limitation was the possibility of bias, which could be traced to limited information and resources available for teaching renewable energy and, as such, prompting exploration based on the researcher's expectations. Responses had a degree of bias, because the responses of the participants were influenced by their own experiences of teaching physical sciences and their knowledge of, preferences for and perceptions of renewable energy.

The scope of the study was sustainable physical sciences learning environments and energy, in particular renewable energy in the FET phase, and not in the senior, intermediate or foundation phases. The study also excluded other science subjects in this phase, namely, life sciences, geography and technical sciences, which may have the potential to teach about energy and, hence, opportunities for learning about renewable energy. Beliefs about renewable energy and sustainable development may have, furthermore, affected or influenced the scope of the study.

3.9 CONCLUSION

This chapter discussed the methodology and design used for generating data on the creation of sustainable physical sciences learning environments through the teaching of renewable energy content. I discussed the transformative paradigm that couches the study, the rhetorical relationship between the researcher and participants, the research design, tools, techniques and methods that were applied for generating data, trustworthiness, data analysis, ethics considerations, limitations and delimitations of the study, and the research site. The next chapter presents, analyses and interprets the data.

CHAPTER 4
PRESENTATION, ANALYS AND INTERPRETATION OF DATA

4.1 INTRODUCTION

This chapter presents, analyses and interprets the data generated by the study. The analysis was be done with the intent of scrutinising, interpreting and understanding the data and extracting valuable information that could provide insight into the topic and support knowledge of renewable energy and its possible impact on the creation of sustainable physical sciences learning environments. The chapter commences with a discussion of the need to create sustainable physical sciences learning environments through the teaching of renewable energy content, which is followed by mechanisms to circumvent the challenges experienced, and then the usefulness of renewable energy for creating sustainable physical sciences learning environments. The chapter ends with a conclusion.

4.2 JUSTIFYING THE INCORPORATION OF RENEWABLE ENERGY CONTENT IN THE TEACING OF PHYSICAL SCIENCES

This section focuses on the justification for creating sustainable physical sciences learning environments through the teaching of renewable energy content. It discusses curriculum, teacher knowledge and teaching and learning resources as components that play an important role in renewable energy and the creation of sustainable physical sciences learning environments.

After this discussion, I will provide information based on empirical data that were judged on whether it agreed with, confirmed or refuted the literature (see Chapter 2) that represented policy, previous research on the issue under consideration, other, similar studies and credible reports.

Table 4.1 depicts analysis of the CAPS document for Grades 10–12.

Table 4.1: Summary of codes and themes

Questions	N	Codes	Themes	Subthemes
To what extent do physical sciences teachers **incorporate** renewable energy in their physical sciences lessons about energy?	3	CAPS affordances for renewable energy	Renewable energy teaching opportunities	Electricity
				Waves, sound and light
			Integrative approach	
What challenges are experienced when teaching renewable energy?	3	Renewable energy relevant resources	Teachers' content knowledge on renewable energy	Renewable energy content coverage (Depth and complexity vs basic)
			Renewable energy equipment	
		Explicit renewable-energy-related policy imperative	Curriculum on renewable energy	
How can teachers teach renewable energy to facilitate the creation of sustainable physical sciences learning environments?	5	Teacher training in renewable energy	Teacher training. Renewable energy inclusion in physical sciences curriculum	

The main knowledge areas reviewed in the CAPS for Grades 10–12 are matter and material, chemical systems, chemical change, mechanics, work, sound and light and electricity and magnetism. The aim of the CAPS document is to make learners aware of the natural sciences through the application of critical problem-solving. Renewable energy presents a solution for the problems we experience today, such as those related to sustainability and clean energy.

In this particular instance, I wanted to determine whether information about renewable energy is explicit in the CAPS. Where it was not found to be explicit, it is indicted by "No" and where it was found to be explicit, it is indicated by "Yes" (see Table 4.2).

4.2.1 CAPS affordances

Explicit provision of content about renewable energy in the curriculum document, CAPS, essentially affords teachers the opportunities to learn, research, plan and teach (i.e. facilitate learning) about renewable energy. Providing this content, in turn, motivates teaching and learning that relates and has the potential to respond to socio-scientific issues that are directly and indirectly influenced by and influence the use of renewable energy. In the same way, learners will, accordingly, be challenged to think critically and analyse their social, economic and environmental situations and contexts with a view to applying knowledge on renewable energy in authentic settings. In this way, the learning environment becomes the starting point where authentic energy-related problems are identified and traced with a view to suggesting scientifically sound solutions to contemporary problems.

Furthermore, an implicit inclusion or reference to renewable energy in the CAPS, as a topic, would be extended to concepts, content and skills, activities and guidelines for teachers, as is the case with the other topics in the CAPS document. Consequently, the CAPS for physical sciences, that is, physics and chemistry for Grades 10–12, was analysed for possibly explicit inclusion of renewable energy from main knowledge areas, topics, concepts, content and skills. Consequently, Table 4.2 depicts the analysis of the CAPS conducted in this study.

Table 4.2: Raw data excerpts of the physical sciences CAPS document

Criteria		Main knowledge area in physical sciences CAPS																	
		Matter and material			Chemical systems			Chemical change			Mechanics			Sound, light and waves			Electricity and magnetism		
		Topic	Concepts & Content	Skills	Topic	Concepts & Content	Skills	Topic	Concepts & Content	Skills	Topic	Concepts & Content	Skills	Topic	Concepts & Content	Skills	Topic	Concepts & Content	Skills
Physical sciences CAPS	Grade 10	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Grade 11	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Grade 12	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No

Table 4.2 provides information according to the main knowledge areas, namely, matter and materials, chemical systems, chemical change, mechanics, sound, light and waves and electricity and magnetism. Whether the CAPS was explicit on these topics was checked further by referring to topics for each knowledge area, as well as content, concepts and skills columns. The “No” in Table 4.2 above denotes instances where the curriculum statement for physical sciences is not explicit about renewable energy.

4.2.1.1 Opportunities to teach renewable energy content

As Table 4.2 shows, the CAPS for physical sciences is not explicit on renewable energy under topic, concepts, content and skills, except for Grade 12, under the topic of the photoelectric effect, as extended by the additional information under the content, concepts and skills column, not limited to the following:

> Give the significance of the photoelectric effect: it establishes the quantum theory and it illustrates the particle nature of light”; and the definition of concepts, “cut-off frequency, f_o”, and “work function”, as well as “photoelectric equation: $E = W_o + KE_{max}$, where $E = hf$ and $W_o = hf_o$” (DBE, 2011:132).

This explicit content appears to be limited to theory and excludes practical information that would be required to connect meaningfully with harnessing solar energy as contemplated under the column on teachers’ guidelines. It does, however, give hope for the introduction of teaching of solar-based renewable energy content. The practical activities column, in the same way, refers only to a practical demonstration of the photoelectric effect, which is limited and open to teachers’ discretion. Additionally, the material provided under resources for this demonstration, namely, “Mercury discharged lamp, photo sensitive vacuum tube, set of light filters, circuit to produce retarding voltage across photo tube, oscilloscope and ammeter” are good examples of tools for harnessing solar energy and measuring the current harnessed. However, except for the ammeter, the other apparatus are meant for their use only, namely, demonstration. The idea that “work function is material specific” suggests the need to establish work function values and their corresponding materials. This need, however, does not seem to find space for expression anywhere else in the physical sciences CAPS, which tends to limit the extent to which this knowledge can be applied meaningfully.

The guiding statement under the column on teachers' guidelines for Grade 11 chemical systems, lithosphere, reads,

> The focus here should be on the *earth and its resources*, the *sustainable energy, our responsibility towards future generations* and not chemistry or chemical reactions. The skills that should be addressed here are analysis, synthesis, giving own opinions, summarising, conducting and others" (my emphasis) (DBE, 2011, p. 95).

Similarly, under the teachers' guidelines column for Grade 12, sound, light and waves main knowledge area, on the topic photoelectric effect, the CAPS provides that, *"Link to the harnessing of solar energy"* (my emphasis) (DBE, 2011, p. 132).

The guidelines in the two statements above seem to guide teachers to the topic of energy, in particular, renewable energy. Solar energy is perennial, which connects it to notions of sustainable energy. Additionally, teachers seem to be guided towards teaching for "responsibility towards future generations". The instruction to "link to the harnessing of solar energy", as given in the second statement, suggests that the harnessing of solar energy (Sivaram, 2018) is either a topic or content that has been taught before, possibly in the preceding grades or lessons. It also suggests that teachers possess adequate content knowledge and skills on the harnessing of solar energy. Furthermore, the concept of harnessing suggests purposeful "collection", "storage", and "use" of, in this case, solar energy. This suggests an equivalent to generation of energy, such as in the cells and batteries used to produce electricity through fossil fuel. However, the physical sciences CAPS document does not refer to the generation of electricity through solar cells or other forms of renewable energy sources. The introduction of and teaching about other forms of electricity generation, such as with solar cells, could enable the replacement of cells and batteries based on fossil fuels, under the main knowledge area of electricity. To this end, harnessing solar energy would equate to sustainable energy; it has the potential facilitate responsibility towards future generations, as suggested in the CAPS. The silence and/or implicitness of the physical sciences CAPS about harnessing of solar energy, which would be an equivalent of teaching about renewable energy, could contribute to depriving learners of much needed knowledge about energy that could be utilised to augment the limited energy obtained through electricity generated with fossil fuels.

The fact that many learners who are affected by load shedding are originally from already impoverished households that cannot afford alternative sources of energy to, for instance, charge their cell phones and computers to access study material, continues to perpetuate social injustice (Bales, 2017; Carbajo & Cabeza, 2019; MacKenzie, 2020; see Chapter 2). The reason for this consideration is historical and the impact of load shedding exacerbates their already negatively affected situation, socially, economically and environmentally (Erero, 2023).

Similarly, energy provision has certain cultural connections. Before energy was generated by fossil fuels, cultures relied on other ways of generating energy for domestic and other purposes. By not being explicit about the teaching of renewable energy content, the CAPS denies learners, furthermore, the opportunity to use critical thought through the application of renewable energy principles together with knowledge from their diverse cultural backgrounds (Noyoo, 2007).. This could enable the construction of new knowledge that could benefit the application of renewable energy principles (McCauley et al., 2018; Smith, 2017). In this way, learners' critical analysis, problem-solving and creativity could be derailed. To circumvent the continuation of social injustice and disrespect for cultural diversity, it maybe imperative for the teaching of renewable energy content to be explicitly stated, to give it deserving and substantive authority.

In light of this analysis of the CAPS document, it became imperative to consider the main knowledge areas that have the potential to explicitly include renewable energy in the preferred physical sciences textbooks (see Chapter 3).

4.2.2 Textbooks affordances

Textbooks have the potential to provide richer and relatively detailed information about the content, concepts and skills drawn from the policy framework. They extend and bring closer the authentic reality to the target audience, in this case, teachers and learners. Thus, textbooks can provide basic information that is necessary for learners to construct new knowledge through learning about, experimenting on and applying the skills learned. The basic information in this regard will relate to connectivity, how energy can be harnessed from to source to where it is required just as with fossil electricity. Similarly for renewable energy: Textbooks would expose teachers and learners to knowledge of clean energy sources, in addition to the traditional cell or battery we are accustomed to, and could perhaps introduce learners to photo cells. All this can be tested in the laboratory to determine what materials are in a battery. A similar activity is beneficial for renewable energy.

Three preferred textbooks used at the three schools were analysed for their possible explicit provision for teaching of renewable energy content. Three main knowledge areas, namely, chemical systems, waves, sound and light and electricity and magnetism, were probed for insight about explicit renewable energy content under their respective topics, content, concepts and skills. Table 4.3 sets out the data obtained from the analysis of these textbooks.

Table 4.3: Raw data excerpts of physical sciences FET phase textbooks

Document	N(3)		Chemical systems (Module 8) Topics	Chemical systems (Module 8) Content, Concepts & Skills	Waves, sound and light (Module 2) Topics	Waves, sound and light (Module 2) Content, Concepts & Skills	Electricity and magnetism (Module 5) Topics	Electricity and magnetism (Module 5) Content, Concepts & Skills
Textbooks	1	Grade 10	UNIT 3: Water quality and purification	"Global systems are inter-related. Any change that occurs in one system affects other systems"	UNIT 9: The nature of Electromagnetic radiation UNIT 10: Electromagnetic spectrum UNIT 11: Photons	Characteristics & uses of EM Energy of a photon	UNIT 1: Magnetism & magnetic fields UNIT 2: Electrostatics UNIT 5: EMF & potential difference UNIT 6: Current	Phenomena associated with the earth's magnetic field Polarisation EMF, terminal potential difference across a battery Why a battery goes flat
	1	Grade 11	UNIT 7: Mining and the environment	Fossil fuels – Alternative energy sources (descriptions and environmental impact)	UNIT 1: Reflection	Reflection of light, Geometrical optics, Laws of reflection	UINIT 5: Magnetic field of an electric current UNIT 7: Induction UNIT 8: Faraday's law of induction	Demonstration 1: Observe the magnetic field around a current-carrying wire Electromagnetic induction Direction of induced magnetic field
	1	Grade 12			Reflection Photoelectric effect	Laws of reflection Geometrical optics Generation of solar energy from "the ejection of electrons from a metal plate when light falls on it"	Electric circuits Electromagnetism Electrodynamics	

The textbooks refer to the CAPS main knowledge areas as modules, for instance, chemical systems in Module 8, waves, sound and light in Module 2, and electricity and magnetism in Module 5. The CAPS divides each module into units or topics. My analysis focused on the content, concepts and skills set out in textbooks, with the expectation of finding explicit information that relates to renewable energy. For example, Unit 3: Water quality and purification, states that world systems (environmental, economic and social systems) are inter-related, and any change that occurs in one system affects other systems (Oxford Successful, 2007a). The global systems referred to in this statement include solar systems (which is about energy) and the water cycle. This statement has the potential to connect renewable energy to water quality and purification, hence, its selection as data, even though it is not explicit (see Chapter 2).

The information given in Table 4.3 suggests that, for Grade 10, there are opportunities to include renewable energy in all three main knowledge areas. Although the information appears to be limited to issues pertaining to content, concepts and skills on renewable energy, the following seems to afford opportunities for renewable energy: "phenomena associated with the earth's magnetic field" given under Grade 10 electricity and magnetism, which refers to auroras and magnetic storms – the processes during which matter is ionised by energy from the sun, from which the earth is protected by a magnetic field. The concepts of ionisation of matter opens up for deeper engagement on energy and its interaction with matter, such that the matter emits energy in the form of moving charge. A discussion about conditions under which such emissions occur would be helpful, in that it could challenge learners on whether energy from the sun can emit charge from ordinary materials, such as metals.

A critical question that could arise is whether matter is energy or energy is matter, given $E = mc^2$, where E is energy and is equal to the product of mass and speed of light squared (Oxford Successful, 2007a; 2007b; 2007c). Knowing that mass is the amount of matter in a body, does this mean that energy 'E' is equivalent to the amount of matter 'm' in a body? Learners' discussions of such questions, based on scientific principles such as $E = mc^2$, has the potential to stimulate learners' critical thinking. Additionally, E is set to be energy of light, which is equivalent to the energy of a photon, yet a photon does not have mass, hence $E = hf$. Does this equation mean that energy of a photon is equivalent to its frequency? What does this mean in concrete terms? In this sense, learners' analytical thinking skills are invoked in relation to what the relationship between matter and energy really is.

Similarly, the content on polarisation, under electricity and magnetism (electrostatics), gives hope for teaching about the possibility of matter and materials being polarised and charged. This can be extended to the loss or transference of charge from a metal or accumulation of charge on one end of an object, by energy from the sun. The unique characteristics of these materials and matter, as well as the different energy bands, strengths (frequencies), tend to connect this topic to the notions of EMF, terminal potential difference across a battery. A critical thinking question can be raised about the polarity in electrostatics in relation to that in a battery or cell (terminals). In the same vein, how can the charge induced in electrostatics be channelled as a charge is channelled from a cell? An attempt to respond to these questions could trigger critical thinking about renewable energy.

Evidently, the critical questions asked and discussed above tend to provide aspects of the curriculum through the textbook opportunity for extending content, concepts and skills on electricity and magnetism waves, sound and light, to renewable energy. Additionally, a critical thinking approach to teaching and learning about these aspects in relation to renewable energy affords learners opportunities to think deeply about how energy relates to matter and how such energy may be understood and utilised meaningfully. However, the textbooks, like the physical sciences CAPS, do not provide anticipated, thought-provoking questions relating to energy and matter and, thus, fall short of heightening learners' creative, critical and problem-solving skills associated with renewable energy. To this end, the preferred textbooks, while compliant with the physical sciences CAPS, does not necessarily contribute to making science learning environments sustainable through teaching and learning renewable energy content.

Sustainable physical sciences learning environments promote meaningful and functional learning in which learners can use the knowledge they have gained on renewable energy to respond to their immediate energy-related challenges, and heighten advocacy against unsustainable practices that have the potential to compromise future generations, for instance, the much reported depletion of fossil energy resources (Strambo et al., 2019; Yi et al., 2023; see Chapter 2).

Accordingly, I conclude that the textbooks do not provide adequate information to enrich and extend learning through the inclusion of principles relating to renewable energy. Consequently, an inference that can be drawn in this regard is that the textbooks may inadvertently fail to contribute to the inclusion of renewable energy content. Thus, notions of social injustice and cultural diversity, as expressed for physical sciences CAPS affordances, also apply to the textbooks, because textbooks do not provide explicit content, concepts, and skills to connect and extend the curriculum knowledge through to renewable energy content. Textbooks can be seen more as commodities for economic purposes, as they have a very limited focus on social and environmental needs, which can be unlocked best by providing content, concepts and skills for enrichment on renewable energy topics.

4.2.3 Assessment affordances

Given the aforementioned analysis of the physical sciences CAPS document and textbooks, corroboration of the interpreted data was attempted by analysing assessments for explicit inclusion of renewable energy content.

Assessment is a process that "measures individual learners' attainment of knowledge (content, concepts and skills)" in renewable energy (DBE, 2011, p. 143). In essence, assessment is a beneficial teaching tool that enables teachers to make reliable decisions regarding a learner's development (DBE, 2011), in this case, on matter and materials relating to renewable energy content; therefore, extension of concepts, content and skills based on the photoelectric effect – not limited to work function, cut-off frequency and the photoelectric equation – may be useful to the teaching and learning of renewable energy and its assessment. The concept of work function and cut-off frequency provides opportunities to relate to matter and energy through renewable energy, especially considering the practical activity aspects, when integrated with theory. In this way, the assessments for learning provide learners with information regarding their strengths, shortcomings and development. Assessments also help educators, parents, and other stakeholders make decisions regarding learners' progress on renewable-energy-related content (DBE, 2011). For instance, for Grade 10, the policy provides 40 out of 150 marks (27%) for waves, sound and light, and 30 out of 150 (20%) for electricity and magnetism, and 20 out of 150 (13%) for chemical systems. These marks help to determine the contribution of renewable-energy-related content, concepts and skills to Grades 10, 11 and 12 controlled summative assessments.

In an attempt to establish the extent to which renewable energy is accounted for in these assessments, Table 4.4 depicts information, content, concepts, skills and scientific principles pertaining explicitly to renewable energy content in the three main knowledge areas.

Table 4.4: Information, content, concepts, skills and scientific principles pertaining explicitly to renewable energy from the three main knowledge areas

Assessments	N(3)	Chemical systems			Waves, sound and light			Electricity and magnetism			Total weightings
		Alternative energy sources (descriptions and environ-mental impact)	Synthesis of biofuels (trans-esterification of fats)	Weightings total	Light	Photoelectric effect	Weightings total	Electro-magnetism (wind energy)	Electrostatics	Weightings total	
QP 2022	1 Grade10	None	None	0 instead of 20	None	None	0 instead of 40	None	None	0 Instead of 35	0/95
QP 2022	1 Grade 11	None	None	0 instead of 20	None	None	0 instead of 32	Q6 (6) Q7 (17)	Q1.7, 1.8, 1.9, 1.10 (8)	31 instead of 50	31/102
QP 2022	1 Grade 12	None	None	0 instead of 18	Q1.10 (2) Q1.6 (2)	Q10 (14)	18 instead of 17	Q9 (11) Q1.2(2)	Q7 (17) Q1.7(2)	32 instead of 20	50/55

The top left side of Table 4.4 shows N(3), which is the number of physical sciences textbooks considered for analysis, and the top horizontal part of the table lists main knowledge areas that have the potential to accommodate renewable energy. These main knowledge areas are chemical systems, waves, sound and energy and electromagnetism. The row below the main knowledge areas depicts the topics, content, concepts or skills assessed by the selected summative assessments. The third column under each main knowledge area gives weighting as a percentage of the total marks allocated the topic per the total of the examination paper. For example, the expected total mark for Grade 12 electricity and magnetism is 20 marks, 17 marks for work, sound and energy, and 18 for chemical systems. This, essentially, means that a total of 55 marks should be allocated for knowledge areas that have the potential to teach renewable energy content in Grade 12.

As can be seen from Table 4.4, the total marks allocated for these knowledge areas in the 2022 summative assessments for Grade 12, is 50: 0 for chemical systems, 18 instead of 17 for waves, sound and light, and 32 instead of 20 for electricity and magnetism. The total mark gives a deficit of 5 marks, which is 55 expected marks minus the 50 marks allocated. An observation that be made from this include that i) mark allocation was not done according to policy on any of the occasions. For the 0 mark, 18 was expected, 18 allocated where 17 was expected and, finally, 32 marks allocated where 20 marks was expected, gives an assessment of 12 marks on this knowledge area, from which renewable energy is excluded; and ii) the assessments ignore the textbook's reference to a table of alternative energy resources.

Although the assessment includes 14 marks on photoelectric effect, to assess leaners' comprehension of the principles of work function and cut-off frequency, the assessment does not go beyond the release of electrons to refer to the harnessing of solar energy in the discharged electrons with a view to coming closer to the notions of renewable energy. A question on these notions could have been included under this question, considering the 5 marks deficit and the overassessment – 32 marks instead of 20 marks. The rest of the topics, concepts, content and skills examined in the summative assessment were also analysed to determine if they included references to renewable energy, but they did not. The whole examination paper lacked any mention of renewable energy.

Similarly, the Grade 11 summative assessment, as depicted in Table 4.4, displays similar shortcomings and continues to exclude questions on renewable energy topics, even where there are opportunities for inclusion. As tabulated above, the total marks allocated for the main knowledge areas in the 2022 summative assessments for Grade 11 is 31 marks, comprising 0 instead of 20 for chemical systems, 0 instead of 32 for waves, sound and light, and 31 instead of 50 for electricity and magnetism. The total mark gives a deficit of 71 marks, that is, 102 expected minus the 31 marks allocated. The observation that can be made from this is that mark allocation was not, on any of the occasions, according to policy. The 0 assessments under chemical systems and work, sound and energy could have been used to accommodate renewable energy principles and their application. The 29 mark deficit (50 – 31) under electricity and magnetism could have been made up by including renewable energy. These deficits account for 71 marks that could have had the potential to assess learners on renewable energy. Furthermore, the assessments overlook the CAPS document "teacher" guidelines, which, under the topic of the lithosphere, advises teachers to focus on sustainability.

The rest of the question paper was studied to determine if it included explicit mention of renewable energy, but it did not. Renewable energy was not included anywhere in the 2022 Grade 11 end-of-year examination. Equally, the Grade 10 end-of-year examination was assessed to determine if renewable energy was accommodated there. None of the topics under the three main knowledge areas explicitly included renewable energy. Just as for Grades 11 and 12, the rest of the topics in the assessment were analysed for the explicit inclusion of renewable energy, but they did not mention it.

The inference that can be made from this analysis is that sustainable energy, harnessing of solar energy and responsibility towards future generations in the context given in CAPS (Table 4.1), may not receive adequate attention, because they are neither topics, concepts, contents nor skills under the requisite main knowledge areas. For instance, upon analysis of the preferred textbook, alternative energy sources (Oxford Successful, 2007a) is discussed in a limited fashion and the textbook lacks in-depth content, concepts and skills on renewable energy, especially considering the extent to which content on current electricity and mining is covered.

It can, thus, be concluded that renewable energy is not explicitly taught at Grades 10 and 11 levels under any of the main knowledge areas, unless content, concepts and skills are provided in the curriculum. In Grade 12 it is taught under the photoelectric effect and is covered in the CAPS document, the prescribed physical sciences textbooks and assessments. It would be in the best interests of the country's commitment to SDGs if renewable energy is incorporated progressively in physical sciences throughout the FET phase. Failure to do so may result in young people lacking knowledge on what their electricity options are, causing them to choose according to their circumstances and desires. They may not know how to participate in achieving the SDGs through their electricity usage. It is recommended that renewable energy is afforded adequate content, concepts and skills for its teaching in the curriculum under main knowledge areas that afford opportunities to incorporate it, namely, chemical systems, waves, sound and light and electricity and magnetism, from Grade 10 onwards.

4.2.4 Teaching affordance

Teaching renewable energy affordances, in this context, hinge on teachers' competences regarding pedagogical content knowledge on renewable energy. Their creativity in identifying opportunities for incorporating renewable energy content, concepts and skills using appropriate resources, assessments and activities is imperative. This creativity would enable teachers to explore the inclusion of renewable energy under identified main knowledge areas, namely, chemical systems, waves, sound and light and electricity and magnetism. The teacher's decision-making power, as the authority figure in the learning environment or classroom, affords the teacher the possibility of teaching about renewable energy if the teacher wills. The decision to obtain information about learner performance through assessments for learning rests on teachers' teaching affordances for renewable energy. The skills and values relating to the teaching of renewable energy are commanded through teachers' renewable energy teaching affordances. The skills relate to knowledge on the operation of equipment and responsible ways of using such equipment to create sustainable learning environments that support the generation of renewable energy.

To establish the extent to which teachers incorporate renewable energy in their teaching of physical sciences with the aim of creating sustainable physical sciences learning environments, three teachers from three different schools, who had credible knowledge of physical sciences teaching, were interviewed individually. Their responses to questions on the extent to which they incorporated renewable energy in their teaching, if they did, were as follows:

> **Participant 1**: There are ways of generating electricity in a sense, but it [electricity chapter] doesn't dwell much on renewable energy. It includes only the sur-gates, it does not go further than that. And we have not maybe gone as far as, Eskom nuclear terms, windmills, hydro-electricity in deeper details, we just mention them, or they tell us to talk about them in mention but it does not say that we must teach about it.
>
> **Participant 2**: in Grade 10 … there is no part of renewable energy there, so it's not part of our curriculum. But a little bit of energy is there … there's just a little bit of information just, what are the renewable resources and non-renewable resources. But there's no topic about renewable energy. So I don't really teach it.
>
> **Participant 3**: Uhm… [like someone thinking deeply about something or trying to recollect some idea or information on something] It does not include it as a focus. It mostly focuses on fossil fuel produced electricity. We use the provided electricity for practicals and a standard battery for circuits. In Grade 12 we have the photoelectric effect, which is based on solar energy, I suppose then we can say it is there, it is included.

The data above indicates that neither of the three teachers at the three schools incorporated renewable energy in their teaching of physical sciences. The reason they cite is mainly that renewable energy is not in the curriculum. As can be seen from Participant 2's assertion that "I don't really teach it" and Participant 3's deeply thought about response, they do not teach renewable energy. Participant 1 added that the curriculum "does not say they [teachers] must teach about it [renewable energy]". These confirmations not only corroborate the observations made about the absence of renewable energy in the physical sciences curriculum, but also the authority bestowed by the curriculum for teaching.

It can be concluded that the assessments do not explicitly include renewable energy as a topic, mainly because renewable energy is not explicitly taught. This was confirmed by Participant 3, who in response to the question on whether renewable energy can be taught under current conditions said, "there is no use teaching them [learners] things that will not help them when they write exams". Furthermore, the participants identified other reasons why renewable energy cannot be taught, such as the absence of equipment, skills, management, renewable energy course material, training/workshops, and research on renewable energy.

Consequently, and based on the transformative prowess of teaching renewable energy, the teaching of physical sciences in these participants' schools barely contributes (if at all) to the creation of sustainable physical sciences learning environments through the teaching of renewable energy content. That being the case, it makes minimal contribution, or no contribution at all, to curbing the effects of past and current social injustice practices; instead, these practices are subtly perpetuated.

4.3 TEACHERS' EXPERIENCES OF TEACHING RENEWABLE ENERGY CONTENT

This section considers the participants' experiences in relation to teaching renewable energy content and reports on the participants' responses to the question, How can you and or do you teach or incorporate the teaching of renewable energy? Based on the participants' responses, the data relate to the challenges they experienced or are likely to experience should they be compelled to teach renewable energy content. Additionally, information relating to renewable energy pedagogical content knowledge was paramount; this is presented according to the themes in the CAPS and textbooks, assessment and teaching affordances.

4.3.1 Curriculum affordance

The physical sciences curriculum includes the CAPS document, physical sciences textbooks and physical sciences assessments. Curriculum affordance refers to the ability of these documents to provide opportunities to gain physical sciences knowledge according to the national aims and objectives of physical sciences: which are to promote "knowledge and skills in scientific inquiry and problem-solving; the construction and application of scientific and technological knowledge; an understanding of the nature of science and its relationships to technology, society and the environment" (DBE, 2011, p. 8). Fossil-fuel-based energy is the one of the biggest environment polluters in the world. The teaching and learning of renewable energy content can potentially enable this "construction and application of scientific and technological knowledge" (DBE, 2011, p. 8) of clean alternative sources of energy. This will create an opportunity to strengthen society's inventive skills for attaining SDG 7 and conserving the environment.

According to the document analysis and interpretation, the physical sciences CAPS document, physical sciences textbooks and physical sciences assessments do not explicitly mention renewable energy. To determine whether the curriculum could possibly explicitly include renewable energy, teachers were asked if they thought it would be feasible for learners in South African schools to start learning about renewable energy generation, and their responses were as follows:

> **Participant 1:** Solar energy, yes I think it is feasible. I think so because most of our provinces have hot temperatures such as Northern Cape, North West, Limpopo a lot, and KZN [KwaZulu-Natal], those provinces are very hot even in winter. If those solar panels would be used for those provinces it would work.
>
> **Interviewer:** How feasible is it to teach it from high school?
>
> **Participant 1:** I think it is feasible, because where I teach it's a technical school, already they do electrical technology and electronics, so there's equipment they use for studying. I think some other schools, outside or in their premises may have a small plant focusing on that, where they may have solar panels displayed. Showing how it works and should be handled. It would be better if it was in the curriculum and if learners would be given a chance to see it [renewable energy] work practically, as they learn better that way especially in science because high school is not practical based. Some students learn better by seeing to better link it with the scientific terms and theory for understanding.
>
> **Participant 2:** Yes, it's feasible from school already, because most of the learners they know about the solar panels, they know about those wind turbines. There is no topic that deals with renewable energy or maybe renewables resources, nothing. It's just that part, a little bit in Grade 8 and 9 actually, it's just a small part. So I think it will be feasible in the FET phase, it's going to fit perfectly there.
>
> **Participant 3:** Yes, It would. It would be good to have options, so that the best option can be chosen. Renewable energy could be very helpful. A lot of people have installed solar panels that are enough to power their houses fully, but they can't afford paying for the maintenance. For people who can't afford to pay for regular maintenance it would be good if they knew how to maintain the basic things themselves... It would be feasible if was in the syllabus [curriculum], because it would be part of the structure of the subject.

Participant 1 said that solar energy is feasible because most of South Africa's provinces experience hot temperatures. He went on to express that, to teach solar energy, it would be better if the topic was included in the curriculum and if learners were given a chance to see renewable energy work practically, as learners learn better by hearing and seeing, in contrast to hearing alone. He said that some learners (kinaesthetic learners) learn and understand better by seeing, to better link the information with the scientific terms and theory. Participant 2 said that he believes it will be feasible in the FET phase, where it will fit perfectly (because it had been introduced in the senior phase). Participant 3 said that, for people who cannot afford to pay for regular maintenance of the renewable energy sources in their homes, it would be good if they knew how to maintain the basic elements themselves. She went on to say that it would be feasible to teach learners about renewable energy if it was in the syllabus, because it would be part of the structure of the subject. All three participants confirmed that teaching renewable energy content would be feasible and they went on to express how helpful it would be for renewable energy to be included in the curriculum.

At this point, in the whole CAPS document, the only time a form of renewable energy was mentioned, was under teacher guidelines under the topic of the photoelectric effect. The way it is mentioned involves giving a *suggestion* for teachers, to let learners know that the photoelectric effect results in solar energy. In the same breath, the physical sciences curriculum states the *significance* of the photoelectric effect as establishing the quantum theory and it illustrates the particle nature of light and defines concepts. This presented significance does not highlight "solar energy", in fact, it takes the focus away from the harnessing of solar energy. The physical sciences CAPS document, the CAPS-aligned textbooks and assessments serve as a compass for giving a consistent, organised course for teaching and learning. The physical sciences curriculum intends to impart functional knowledge and inspire responsible citizenship in learners. This requires the curriculum to continually evolve and be updated to meet the current needs of the learners and the country as a whole. Failure to evolve defeats the intention of the physical sciences curriculum.

4.3.2 Teaching affordance

Teaching affordance may be described as engaging with learners to help them grasp and apply knowledge, concepts and skills. The goal of renewable energy teaching affordance is not only to impart information about clean energy, but also to change learners from passive consumers of abstract knowledge of its concepts, to active creators of their own and abstract and concrete knowledge relating to the harnessing of renewable energy. This teaching affordance should establish the pedagogical, social and ethical circumstances that allow learners to practically apply learned content, concepts and skills in their own lives and assist others with this knowledge. It is important to mitigate against hindrances in order to achieve the above ideals.

Given that all three participants agreed that teaching renewable energy is feasible, to establish what hinders physical sciences teaching affordance of renewable energy, teachers were asked what challenges they experienced or could potentially experience when teaching about renewable energy, and their responses were as follows:

> **Participant 1**: I think maybe because some of the electrical things [equipment] are dangerous, if for example the nuclear energy could get out of hand. But solar panels and other renewable ways would be doable. The other challenges would be equipment, we would not be able to teach other topics such as wind turbines in certain provinces for students to see how it generates electricity.
>
> **Participant 2**: Fitting it into our teaching plans when they are not in the CAPS and textbooks. We do not have a guiding structure. Equipment that can be used in the classroom for demonstration and practicals would also be a challenge. Also, we would have to learn it ourselves first, before we can teach it.
>
> **Participant 3**: Depending on how deep you want to go with teaching it, if teachers will be teaching the very basics, I'm sure the challenges would not be much. The school will just have buy the equipment for practicals. But if the physics of it is more complicated, teachers will need to do a lot more research on the principles and how they work and the department will have to design courses and workshops for teachers to learn about it.

Analysis of the above data indicates that teachers foresee possible hindrances to teaching about renewable energy to be dangerous electrical equipment, lack of equipment, lack of inclusion of renewable energy in the curriculum and lack of adequate teacher knowledge. This means that, according to the participants, should these above mentioned possible challenges be mitigated, the explicit teaching of renewable energy in physical sciences learning environments can be afforded.

4.4 REFLECTION ON THE USEFULNESS OF TEACHING RENEWABLE ENERGY TOPICS

The usefulness of teaching can be measured by how much the acquired knowledge can be applied to help oneself and or society. This section reflects on the usefulness of incorporating renewable energy content by analysing the way the physical sciences CAPS document, textbooks, assessments and teaching can afford explicit incorporation of renewable energy.

4.4.1 Curriculum affordances

The physical sciences curriculum informs the assembly and content of physical sciences as a subject and, to a large extent, it directs the physical sciences teaching and the learning process. To determine if it would be useful for the curriculum to afford the explicit inclusion of renewable energy, the participants were asked to justify whether there is a need to include renewable energy content in physical sciences, and their responses were as follows:

> **Participant 1:** I'd say it should be incorporated, I live in Qwaqwa and there's no electricity there for some time. It's time South Africa looks and searches for alternative new kinds of energies they can use. I think it's important, and maybe in the next five years we should have another alternative for electricity. As I see it the teaching of it [renewable energy] should be incorporated because it would be very helpful, to start with the students from natural science to plant seeds of multiple scientists as we are at lack on that in South Africa.
>
> **Participant 2:** In the future we are going to use green energy, which is a clean energy. So by now we should obviously move towards that even in curriculum. The department can just start in the lower grades. But I think in five years it will not just be a topic in Grade 8 or 9 then it ends there, it should be a continuous topic, or maybe have a module, because our current situation now as a country, we don't know anything about renewable energy, nothing. That's why we don't … most of our university students they are not innovative about that, that's why we don't even have much solution if there's load shedding now. We don't even have the students who can think because they do not have knowledge about it. Our learners and our people they need to know about renewable energy because we are just using the things [renewable sources] that are there and will forever be there. Some of the, in rural areas they don't have electricity, but there are rivers flowing there, but they don't have electricity and those wind turbines they can be installed there on the rural areas to produce electricity. So we can use renewable resources, I don't think we should be having load shedding, we are having load shedding because we are using non-renewable resources, let us move to renewable energy, which is a clean energy. So our country will be, so I think the department needs to sit down together with whoever is responsible for physical science because it fits nicely there. Just to introduce it in Grade 8 and 9, or maybe construct a module or a subject about renewable energy, then they take out creative arts so that every learner in Grade 8 and 9 knows about that energy. That one [renewable energy], we can even do the practicals, it's very easy it's not something that is hard. If we have enough information it can be shared amongst everyone in the country, you'll see every household will be having a solar panel.

> **Participant 3:** There is a need to incorporate renewable energy in the curriculum. It's justifiable because it is relevant at the moment. The world has started talking about sustainability and clean energy. Uhm, it would be good for the department [of education] to integrate it in into the curriculum so that we don't fall behind with the way we do things. I think it's difficult for third-world countries to leave what they know, to do what is better. We want to hold on to things even when they are not working. Teaching fossil-fuel-based electricity alone is not enough anymore, we should consider integrating clean energy into the curriculum.

The first participant originated from Qwaqwa and expressed that Qwaqwa residents experience power outages for extended periods of time (extended load shedding). According to the participant, "it's time South Africa looks and searches for alternative new kinds of energies they can use". The participant also expressed that "the teaching of renewable energy should be incorporated because it would be very helpful".

The second participant said that "In the future we are going to use green energy" so "we should obviously move towards that even in curriculum". According to this participant, our current situation as a country is that learners are unable to think in terms of renewable energy, because they do not have knowledge about it. The participant pointed out that, in rural areas, there is a lack of electricity, but there are flowing rivers that can generate hydro-electricity. He said that wind turbines can also be erected in rural areas to produce electricity. This participant raised an interesting suggestion and said renewable energy should be added as an independent subject, instead of only being a topic, concept, content or skill under another subject. He said that, if we have enough information, every household could have enough awareness and knowledge to implement solar energy in their own homes.

Participant 3 said that "there is a need to incorporate renewable energy in the curriculum", and he justified this view on the basis of South Africa's commitment to sustainability and clean energy. The participant expressed that "it would be good for the department [of education] to consider integrating it in the curriculum", so that South Africa does not fall behind. He added that "teaching fossil-fuel-based electricity alone is not enough anymore", and that "we should consider integrating clean energy into the curriculum".

All three participants believed that the physical sciences curriculum should incorporate the teaching of renewable energy content. The participants justified this stance by giving reasons such as the unsustainable power supply in some parts of the country, such as rural areas and Qwaqwa. The country's commitment to sustainability and clean energy, together with load shedding, encourage the need for a sustainable physical sciences curriculum that also teaches renewable energy content.

4.4.2 Teaching affordances

The usefulness of the teaching affordance of renewable energy is that it could create a necessary bridge between knowledge of renewable energy and the implementation of SDG 7. Teaching affordance of renewable energy may promote both on- and off-grid solutions. Content, concepts and skills of cross-border grid connections, on-grid renewable energy solutions and decentralised options will have to be taught if we are to accommodate the South African context or the different needs of different regions (rural areas, townships, farms and cities) in South Africa.

To gain information on how this bridge could be created, and how teaching renewable energy could be afforded, teachers were asked how renewable energy could be taught and they gave the following responses:

> **Participant 1**: I'd add to say if the education sector funds resources for the teaching and facilitation of solar energy in schools, then they may consider using simulations. They may provide computers where these would take place, in fact we need more technology in our schools because with computers we can do anything. Even if they won't go to the sites at least they would experience it being assisted by someone from the relevant sector to guide us and the students. If someone from the relevant sector would come it would give us an in-depth-knowledge for us as teachers because solar panels are now being mostly used. At least having them there to tell us if the simulation is correct as they deal with it the most would be great. Simulation workshop for teachers would be a great start because some of the questions students ask are out of our knowledge, then you would need an expert in that. This is an interesting topic, I'm enjoying it.
>
> **Interviewer**: How can teachers teach it?
>
> **Participant 2**: Now it's very easy because these learners already they have seen some of the homes they have solar panels. So, they have seen them so it will be easy for you to demonstrate them. And some of them when they move around, they have seen the wind turbine because even if we use wind we can produce the electricity. But mostly they are used at the farms because there's no electricity there but they can use those wind turbines to produce electricity,

> but it would be easier for learners to understand because there are something that they have seen but they don’t know that we can also use the wind to produce electricity. And you can even give them practicals to do those turbines just like windmill, they can even do a practical for a windmill so that, windmill takes water from the underground right? They can even experimentally do it, so it can be easily done. I don’t think it will be something that will be difficult.
>
> **Participant 3:** The curriculum will have to accommodate renewable energy in detail, and for the teachers to be able to teach it effectively, they will first have to learn about it. The apparatus or equipment for practical experiments will have to be provided for and teachers will have to be trained on how to use that equipment. It can then be assessed just as fossil-fuel-generated electricity is assessed. If those things are done, then it can be taught.

All three participants expressed that teaching affordance of renewable energy will require teaching material or equipment. Participants 1 and 3 also articulated that there must be teacher training for the successful implementation of renewable energy teaching affordance. Participant 3 emphasised that renewable energy will have to be included in detail (explicitly) in the curriculum. All these requirements correlate with the possible challenges that these teachers predicted. Participant 2 argued that renewable energy teaching affordance will lead to renewable energy implementation, which correlates with the literature reported on in Chapter 2.

4.5 CONCLUSION

This section focused on the justification for creating sustainable physical sciences learning environments through the teaching of renewable energy content. It analysed the curriculum, teacher knowledge, teaching and learning resources as components that play an important role in teaching and learning about renewable energy and the creation of sustainable physical sciences learning environments. This was followed by information based on the empirical data that was judged to agree, confirm or refute the literature reported on in Chapter 2. Sources of this information include policy, previous research on the issue under consideration, other similar studies, credible reports and information provided by study participants.

CHAPTER 5

FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

This last chapter of the study presents the findings, conclusions and recommendations for creating sustainable physical sciences learning environments through the teaching of renewable energy content. It commences by explaining the purpose of the study, which is followed by the presentation and discussion of the findings as they relate to each objective. After each discussion, conclusions and recommendations are presented. The findings, conclusions and recommendations are, then, summarised, and the limitations and delimitations of the study are given.

5.2 PURPOSE OF THE STUDY

This study proposed the creation of sustainable physical sciences learning environments. To this end, the study explored the incorporation of renewable energy topics in physical sciences teaching and learning. To achieve this aim, the study justified the need for explicit incorporation of renewable energy content in the curriculum, drew lessons from teachers' experiences of teaching about alternative energy and reflected on the usefulness of teaching alternative energy topics.

The rationale for this study is based on the need for sustainable teaching and learning to achieve quality education. Quality education in the context of this study is education that instils knowledge and skills that would impel learners and teachers to think about how to use their knowledge of physical sciences, in particular, energy generation, concepts, theories and laws, with skills for assembling and constructing artefacts and devices, as well as the values such as respect and care for the interests of others (social), the environment and the economic aspects. Renewable energy content teaching facilitates thinking that promotes equitable access to clean energy, that is, energy that strives to strike a balance between the economic, social and the environmental aspects for both current and future generations. Teaching and learning about renewable energy requires teachers and learners to appreciate and take an active interest in and responsibility for taking care of and conserving materials, instead of having a careless and wasteful attitude that may damage the environment and the organisms that live in it. Teaching and learning about renewable energy promotes the complementarity of the living and non-living entities through humans working with the environment to manage resources.

5.3 PRESENTATION AND DISCUSSION OF THE FINDINGS

This section starts by presenting findings based on i) the need to incorporate renewable energy in physical sciences teaching; ii) teachers' experiences of teaching renewable energy content; and iii) the usefulness of teaching about renewable energy.

5.3.1 The need to teach about renewable energy

According to the data, none of the participants included renewable energy content in their lessons. The primary reason, according to them, is the absence of a curriculum on renewable energy. It was evident that Participant 3 does not teach renewable energy content, based on her succinct but well-considered response. Participant 2's response also indicated that he does not teach it when he answered "I don't really teach it". Participant 1 said that the curriculum "does not say they [teachers] must teach about it [renewable energy]", indicating that he does not teach about renewable energy and has no obligation to do so.

These assertions support not only observations on the absence of the topic of renewable energy in the physical sciences curriculum, but also the power that the physical sciences CAPS and textbooks grants to teachers. Due to the current structure of the curriculum, teachers do not assess on renewable energy and, because they do not assess it, they do not teach it.

In response to the question whether renewable energy can be taught in the current environment, Participant 3 said that "there is no use teaching them [learners] things that will not help them when they write exams". The participants also mentioned other barriers to teaching renewable energy content, such as those related to teaching resources, good management of equipment and teacher knowledge.

Renewable energy in physical science has to be taught to learners explicitly, by focusing on renewable energy phenomena, their application and the relevance of it to everyday life. Renewable energy is a relevant topic to be taught in physical sciences and, so, needs to be taught empirically as a topic. The danger of renewable energy not being explicit is that it is shelved to the periphery.

This can easily lead to assessments that neglect projects involving building solar cells and other ways of constructing clean energy solutions (McCauley et al., 2018). If learners are not taught to use natural resources in a responsible way and use renewable sources where applicable, how, then, are learners expected to contribute responsibly to the environment as outlined in the CAPS document? Not explicitly including clean energy represents a failure to align the aims and objectives of the CAPS document and the SDGs and, thus, represents a social injustice.

5.3.2 Teachers' experiences of teaching renewable energy topics

The data presented in Chapter 4 show that the participants do not include renewable energy topics in their physical sciences teaching; at best, the teachers mention it in passing. The major reason they gave for not paying attention to renewable energy is that it is not mentioned in the curriculum. Participant 1 reported that the curriculum "does not say they [teachers] must teach about it [renewable energy]"; Participant 2 declared that "I don't really teach it" and Participant 3's thoughtful but quick response was that, "No", she does not teach renewable energy. The finding that can be drawn here is that teachers have limited or no experience of teaching renewable energy content, because it is not explicitly included in the curriculum. Even in the topic of the photoelectric effect, a phenomenon that can be used to harness solar energy, what is considered significant is the abstract concepts, instead of highlighting 'solar energy' as the main idea.

These assertions not only support the study findings regarding the lack or absence of renewable energy content in the physical sciences curriculum, but also the authority granted by the curriculum on instruction. Teachers are deprived of the opportunity to teach renewable energy content; as a result, they do not participate in bringing functional awareness of SDG 7 to the learners that they teach. Given that the SDGs and social justice are transformative conceptions, it is significant that the transformational power of sustainable physical sciences learning environments through the teaching of renewable energy content was not observed in the curriculum or in practice. As a result, little or no effort was made to mitigate the impacts of previous and contemporary social injustice practices; instead, they are covertly maintained.

5.3.3 The usefulness of teaching renewable energy topics

The usefulness of teaching about renewable energy cannot be denied. Fossil-fuel-generated electricity compromises the environment, is expensive and, as a result, has become a social burden to those who cannot afford it. South Africa has started to move towards a mixed-grid form of producing energy, with its high investment in solar energy. There is, therefore, already a need for knowledge and skills that can be applied in the maintenance of equipment and for mitigation against the risks involved in using renewable energy forms. There is also a need for opportunities to construct knowledge of how to ensure the dependability and effectiveness of renewable energy applications. Teaching the basic skills from school level will provide the basic 'know-how' and equip citizens with awareness of sustainability and enable the physical sciences learning environment to be sustainable in the South African context.

5.4 CONCLUSIONS AND RECOMMENDATIONS

This section discusses curriculum, teacher knowledge, teaching and learning resources and work integrated learning as the main factors for creating sustainable physical science learning environments through the teaching of renewable energy content. The section begins by discussing curriculum, then teacher knowledge, teaching and learning resources according to the findings from analysis of data, conclusions according to the findings and then recommendations made in response to those conclusions.

5.3.4 The need to teach about renewable energy

5.3.4.1 Curriculum affordance

Based on the analysis of the physical sciences CAPS, textbooks and assessment documents, Tables 4.1 and 4.2 illustrate that, with the exception of the inclusion in the Grade 12 curriculum of the photoelectric effect, the CAPS for physical sciences does not specifically address renewable energy under topic, concepts, content, or skills. The information offered seems to be restricted to theory, as it omits practical information that could make a meaningful connection with solar energy harvesting, as discussed in the instructors' suggestions column. In a similar way, the practical activities column provides only a single restricted and teacher-controlled practical demonstration of the photoelectric effect.

Furthermore, the resources listed beneath this demonstration's material are excellent examples of how to quantify the amount of current that is harnessed and how to use solar energy. With the exception of the ammeter, the other equipment is only intended for demonstration purposes. The idea that a "work function is material specific" (DBE, 2011, p. 132) implies that the work function values and materials that correspond to them must be determined. However, this does not appear to find another place in the physical sciences CAPS and, as a result, it tends to restrict the amount of useful application that can be made of this knowledge. An observation that can be made in this regard, then, is that the photoelectric effect in the physical sciences CAPS and the textbook do not have substantive authority for teaching about renewable energy, despite acknowledgement of its importance.

In contrast, the suggestions about the linkages between previous lessons and grades regarding the harnessing of solar energy, sustainable energy and responsibility towards future generations may not be conclusively established on the basis of implicit information given by the CAPS about renewable energy. However, we can conclude that the CAPS is not explicit about the teaching of renewable energy, which, in this case, resides in the harnessing of solar energy. Accordingly, and based on this information, we recommend adjustments to the CAPS for physical sciences, so that it includes renewable energy as a topic, harnessing of renewable energy, and related aspects as an extension in the form of concepts, content and skills.

Additionally, practical activities, which may include projects on the creation of solar ovens and solar cells, should be considered. The benefits of doing these projects resonate with facilitation of critical analysis, critical thinking and problem-solving skills (Belecina & Ocampo, 2018). The relevance and responsiveness of customised projects to address load-shedding-related challenges that affect lighting in houses, operation of computers, and charging of cell phones, cannot be overemphasised. Additionally, challenges relating to environmental pollution that result from social conduct in residential areas in relation to solid waste disposal maybe circumvented by collecting waste material in search of suitable metals and materials that can be used in the projects of the learners (DBE, 2011; MacKenzie, 2020).

On the basis of this information, the study makes the following findings:

- Renewable energy is not explicitly included as a main knowledge area, topic, concept, content or skill in the Grade 10, 11 and 12 physical sciences curricula.
- In the Grade 11 textbook, there is a table that merely lists a few of the renewable sources.
- An aspect of solar energy is included in the Grade 12 curriculum, under the photoelectric effect; it contributes to approximately 8% of the examinable work.

The photoelectric effect in Grade 12 is, essentially, limited, because learners are not taught how the energy is transferred from the disc of the electroscope and stored for use, later or instantly. This knowledge remains abstract and has very limited application, if any, in the lives of the learners. The goal is to have knowledge that is immediately useful, especially in contexts that are economically and socially challenged because of shortages of energy.

This discussion leads us to conclude that renewable energy is fundamentally excluded from the South African physical sciences curriculum. This exclusion not only affects the needy badly, but it also tends to subtly perpetuate social injustice and inequitable access to basic resources – energy, in this case. This exclusion also suggests that SDGs on matters relating to the environment are unlikely to be achieved soon or are, at best, taken for granted, sadly, to the detriment of future generations.

Accordingly, the study recommends that renewable energy is progressively incorporated in physical sciences throughout the FET phase. It should be included in a way that aims to bring awareness of South Africa's mixed grid and basic information on how it works, and should include knowledge on how to harness some of the easily accessible types of renewable energy, such as solar energy, wind, hydro-energy and biofuels. Basic models such as the ones shown in Figures 2.5 and 2.6 can be used to introduce the basic principles of solar and wind energy, respectively, in Grade 10, and the content, including models, can incorporate more detail (see detail given in Section 2.4.1.3) as the grades progress.

In hydropower, electrical energy is created by harnessing the gravitational force of falling water energy through a spinning turbine. The energy production capability is determined by the available water supply (a dam). In a classroom, it may not be possible to conduct this experiment, though schematic representations, videos and assimilations can be used to show the process. Wind energy is created by harnessing the force of wind that spins a turbine. A windmill can be installed on the school grounds, which can serve as a backup electricity generator and also be used as an illustration that can supported by schematic illustrations.

Biofuels can also be introduced to learners as a potentially carbon-neutral alternative to burning fossil fuels for energy generation (Goossen et al., 2017). Learners can make their own bioethanol (C_2H_5OH) from sugar fermentation (in Grade 10) or biodiesel from vegetable oil transesterification (in Grades 11–12) and compare the products to other readily accessible fuels, such as paraffin (Goossen et al., 2017; Rashtizadeh, 2020). These bio-energies can be taught under the physics section of physical sciences, under the topic of energy, and under the chemistry section of physical sciences under the topic of chemical change. This process could be introduced in Grade 10 through the process illustrated in Figure 2.7. More details about how each step proceeds can be gradually introduced as learners move up the FET phase (see Chapter 2). The solar cell circuit fits in well under the topic of electrical circuits, under electricity and magnetism.

Educating learners on renewable energy would equip them with the necessary basic skills, knowledge and values for maintaining a single household solar system (DiRuzza et al., 2017). The study recommendation is that the curriculum includes content on how an inverter transforms DC to AC, which then flows into the electric grid and connects to the circuit that makes up a home's electrical system. Excess AC power can be sent back into the grid. Solar irradiation strikes the solar panel, which charges a battery through a charge controller. The battery can then be utilised to power any off-grid electrical devices. When operating on the grid, this energy is sent through an inverter to a step-up transformer. Next, the stepped-up current is routed to the main grid.

Solar energy can be introduced from Grade 10, under circuits in the topic of electricity and magnetism. The circuits can be schematically represented as shown in Figure 2.4. At Grade 10 level, calculations will be similar to that of the basic circuit currently in the physical sciences curriculum, even though there will be other basic factors to consider. According to the renewable energy source, the resistance, current and voltage will still be calculated in the same way. In Grades 11 and 12, the components of the solar cell (the chargeable battery, inverter and solar panel) can be studied in greater detail. The content could include the way a solar panel uses PV cells to convert sunlight into electricity and the purpose of an inverter, including the difference between AC and DC. The relevance of the inverter as a possible component of content that is taught in a physical sciences classroom resonates with the teaching of DC and AC in Grades 10–12. Its significance can be seen in its actual use in authentic situations that have a need to convert electric energy from one type to another (see Chapter 2).

Including the above content in the curriculum would allow for household solar systems to be explored in relation to the way excess solar-generated electricity can be fed into the public utility (Eskom), which would reduce the electricity supply demand on Eskom and increase its capacity to provide more electricity to the general public (see Figure 2.1).

This way, we would all have to work together to attain the SDGs and maintain sustainable energy supply. There are also off-grid options that some South African farms have adopted and that can benefit people who live in rural areas. Given that science is meant to be an instrument for enhancing the well-being of people, the absence of renewable energy in physical sciences is a social injustice (Bales, 2017; MacKenzie, 2020). There is free, clean energy all around us, but learners are not taught how to harness it to improve their own lives, which could be particularly helpful to less privileged citizens (Carbajo & Cabeza, 2019; MacKenzie, 2020).

Consequently, the undergirding CAPS principles of credibility, quality and efficiency are instructive (DBE, 2011, pp. 4–5) for sustainable physical sciences learning environments though the teaching of renewable energy content. The 2030 SDGs are the blueprint for achieving a sustainable future globally (Stats SA, 2019; United Nations General Assembly, 2015).

The SDGs have three indispensable pillars, namely social, economic and environmental development, that take into account various national realities, capacities and levels of development while respecting national policies and priorities (Sachs, 2012; Stats SA, 2019); the pillars are consistent with the principles of inclusivity (Smith, 2019), social justice and cultural diversity. Many learners who are impacted by load shedding are part of low-income families that are unable to pay for backup generators, and are thus unable to swich on or charge their electronic devices in order to access educational materials – an inability that promotes social inequality. A sustainable physical sciences curriculum is critical for the achievement of the SDGs with their seven outcome targets and three means of implementation (Cebrián et al., 2020; Smith, 2019.).

5.3.4.2 Teaching affordance

Subject matter, curriculum and pedagogical content knowledge are components of teacher knowledge. It is not meaningful for teachers to teach subject matter that they themselves lack knowledge of. Findings relating to responses given by Grade 10–12 physical science teachers during interviews are the following:

- Physical sciences teachers are not aware that the South African government has committed to achieving the 2030 SDGs and has invested billions in renewable energy in the effort to attain those goals.
- Physical sciences teachers are not formally trained in renewable energy education, either in their higher education studies or though workshops arranged for teachers by the Department of Education.

Thus, we conclude that teachers are unable to progressively teach renewable energy concepts because they do not possess adequate pedagogical content knowledge and the skills to do so.

Accordingly, the study recommends including renewable energy in physical sciences teachers' formal training. For teachers who have completed their higher education studies, workshops will need to be presented for each grade before the physical sciences curriculum is adjusted, to ensure efficient implementation. Also, because teachers are the first line of education in communities, more effort should be made to make them aware of renewable energy and its benefits and contribution to attaining the 2030 SDGs. Teachers should also be made aware of the strides that the government has made in moving towards more sustainable ways of producing electricity, so they can encourage learners and parents to live more sustainably.

5.4 SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

This section provides an overview of the findings, conclusions and recommendations, based on the principles of the transformative paradigm that undergirded this study. The focus is, thus, on the themes identified in the data of the study, namely, physical sciences curriculum, preferred physical sciences textbooks, learning assessments and teaching affordances for renewable energy. The themes were largely informed by the main research question, the study aim, and objectives of the study.

5.4.1 Findings

The problem statement of this study was that the teaching of renewable energy in the subject of physical sciences in South Africa is limited, because it does not progress across the grades as much as current and static electricity do.

From the data that were obtained from the document analysis and responses of participants, and interpreted, it was determined that curriculum, teacher knowledge and teaching and learning resources are major factors contributing to this problem. Document analysis of the CAPS documents, CAPS-aligned textbooks, annual teaching plans and previous Grade 10–12 question papers all reveal that renewable energy was not covered as a topic or subtopic anywhere in the physical sciences FET phase curricula. All the physical sciences teachers interviewed in this study corroborated this finding. There is also a lack of teacher knowledge, because physical sciences teachers stated that they had not been trained in renewable energy content and they were not aware of the South African government's efforts to achieve sustainability.

It was also determined that education on renewable energy is not restricted by lack of resources, because teaching renewable energy does not necessitate the use of expensive resources. Two of the physical sciences teachers that were interviewed suggested practical learning, during which learners could be taken on field trips to renewable energy work environments. This would give the learners an opportunity to observe how renewable energy is applied in the real world, and possibly inspire learners to apply learned knowledge and consider renewable energy as a career.

5.4.1.1 Physical sciences curriculum affordances through a transformative lens

The CAPS, in its current form, subtly promotes the exclusion of teaching about renewable energy by virtue of it failing to be explicit about the topic, despite the historical socio-economic injustices associated with access to basic services such as electricity, inequality and exclusion (Sarkodie & Adams, 2020). In the same way, the preferred physical sciences textbooks do not provide adequate information to enrich and extend learning through to the inclusion of principles related to renewable energy. The textbooks do not provide much-anticipated thought-provoking questions relating to renewable energy and, thus, fall short of improving learners' creative, critical and problem-solving skills associated with renewable energy. The Grade 10, 11 and 12 examinations do not even mention renewable energy.

Consequently, an inference that can be drawn in this regard is that the physical sciences curriculum lacks a contribution towards the explicit inclusion of renewable energy. Thus, the notions of social injustice and cultural diversity, as expressed for physical sciences CAPS affordances discussed above, are the same for the textbooks, which do not provide explicit content, concepts and skills to connect and extend the curriculum knowledge through to renewable energy. Textbooks can be seen more as commodities for economic purposes, with very limited focus on social and environmental needs that can be unlocked by providing content, concepts and skills on renewable energy for enrichment.

5.4.2 Conclusions

Overall, it was determined that including renewable energy education into physical sciences is important, especially because non-renewable resources are unsustainable because of their depletion, negative impact on the environment, and high cost. Given the country's dedication to sustainability, teaching renewable energy for a sustainable physical sciences classroom setting makes sense. The sections of the curriculum on mining, for instance, enjoy extensive coverage during this post-industrial-revolution epoch, where ICT, decolonisation and energy crises (socio-scientific issues) prevail.

The explicit inclusion of renewable energy content in the curriculum is feasible, given that regular updates are made to physical sciences content that must be taught, or added as adjustments to the curriculum, to enhance its relevance and responsiveness to existing social, economic and environmental challenges.

Through the findings above, it can be concluded that the objectives of the study were achieved, because:

- The incorporation of renewable energy in creating sustainable physical sciences learning environments was found to be justified;
- Lessons that were drawn from teachers' experiences of teaching about renewable energy helped establish mechanisms to circumvent the challenges/factors discussed in Section 5.3; and
- Reflection of the usefulness of teaching about renewable energy indicates that it could contribute significantly to creating sustainable physical sciences learning environments.

5.4.3 Recommendations

This section recommends ways renewable energy could be integrated into physical sciences teaching and learning, given the findings of the study. It commences by explaining how this can be done through curriculum affordance and, thereafter, how teaching can be afforded.

5.4.3.1 Curriculum affordance

The study found that the curriculum does not explicitly include content, concepts and skills relating to renewable energy (beyond mentioning its types). The need to incorporate renewable energy is justified and, as a result, this study recommends that renewable energy is explicitly included as a topic in the curriculum, with detailed content, concepts and skills that progress throughout the FET phase. Renewable energy should be incorporated in a way that aims to promote understanding of how it works and include knowledge of how to harvest some of the easily accessible forms of renewable energies. The study recommends that three contextual types of sources of renewable energy be explicitly included, namely, solar, hydro and wind energy sources. These three are the most applicable in South Africa, given the weather conditions and landscape, and have already been implemented in some parts of the county.

The study proposes that solar energy be included in waves, sound and light, under electromagnetic radiation. The theory may refer to the way the sun's energy is transmitted through the atmosphere and reflected and absorbed by different materials. The necessary detail may include how electrons are excited and gain energy, and how they lose energy and emit photons (photoelectric effect), which are converted into electricity by solar panels. In electricity and magnetism, under electric circuits, the technicalities of how solar panels work in a circuit may be included. Storage of the generated electricity will be the same for all three types of renewable energy sources, as it will be in batteries. This renewable energy rechargeable battery will make circuit assembly very similar to the traditional circuits that are currently used in schools.

Hydro-electricity is powered by the kinetic energy of flowing water as it moves downstream, so the theory of hydro-electricity may be introduced in mechanics, under energy, because kinetic energy and potential energy are already familiar concepts. Wind energy may also be introduced in mechanics, under motion, because the rotation of the turbine (movement) is what generates the electricity. These renewable energies can be incorporated progressively in the curriculum from Grade 10 to Grade 12. The curriculum must also highlight the social, economic and environmental benefits of using clean energy.

5.4.3.2 Teaching affordance

The study found that physical sciences teachers were not trained in renewable energy content during their teacher training. Teachers cannot effectively teach what they themselves are not knowledgeable about. Accordingly, the study recommends that physical sciences teachers receive specialised training in renewable energy content. The Department of Education can design renewable energy short courses for physical sciences teachers. Workshops for teachers who have already finished their higher education studies should be presented for each grade level before the physical sciences curriculum is updated, to enable effective implementation.

Also, because teachers are the first line of education in communities, more should be done to raise awareness of renewable energy and its advantages, and to elicit commitment to meeting the 2030 SDGs. Teachers should be informed of the county’s progress towards more sustainable methods of providing power, so that they can urge students and parents to live more sustainably. They should be trained, so that they will understand the mixed grid and the fundamentals of how it works. Teachers can still use most of the electrical components that they currently use for demonstrations in circuits, but replace the traditional battery with a solar energy charged battery.

5.5 LIMITATIONS AND DELIMITATIONS

This section lists the limitations and the delimitations of this study. The determined limitations are inclusive of the known and the observed flaws, circumstances, or effects that the researcher could not control and that impose constraints on the approach to the study, the findings observed and the conclusions reached as a result of those findings. The delimitations for this study were determined as the decisions made by the researcher. This section commences by looking at the limitations, followed by the delimitations of the study.

5.5.1 Limitations

This study had two limitations that must be addressed by academics who intend to further research on sustainable learning environments through the teaching of renewable energy topics.

- As a qualitative study, this research has generalisation limitations, because it was done with a small group of participants.
- It was time consuming to gather data, because interviews were done individually, at different locations for each participant. The recorded interviews had to be transcribed verbatim before the data could analysed, with two of the recordings having to be translated from Sesotho to English beforehand. I returned to seek clarity from participants throughout the data analysis process to ensure that the intention and meaning of the participants' responses had been captured correctly.

5.5.2 Delimitations

- A delimitation is that all the participants were were from the Free State province, thus excluding other qualified potential participants from other provinces.
- The study investigated physical sciences and, as a result, the interviews were centred on the physical sciences curriculum and teaching affordance. Interviews were conducted with only three physical sciences teachers as arranged ahead of time, and only two participants from the energy professions were interviewed (when the opportunity arose), for enrichment purposes.

- A similar study could include other subjects, such as technical sciences, technology and geography. Second, this research focused on teaching content relating to renewable energy in the FET phase only: future researchers can expand their research to include the intermediate grades, as well as higher education.
- Researchers could also investigate how to motivate learners to pursue relevant courses in their post-secondary education if and when renewable-energy-targeted Education for Sustainable Development is available in secondary education.

5.6 CONCLUSION

The topic of renewable energy is largely absent from the South African physical sciences curriculum. This exclusion not only has a negative impact on people who live in poverty, but it also silently perpetuates social inequality and inequitable access to essential resources, in this case, energy. This exclusion also implies that sustainable development targets for environmental challenges are unlikely to be met in the near future, or are taken for granted, to the disadvantage of future generations. Physical sciences teachers are unable to gradually start teaching explicit renewable energy ideas, because it is not part of the curriculum, and even if they choose to teach renewable energy in their own capacity, they lack the necessary pedagogical content and skills to do so.

The explicit inclusion of renewable energy throughout the FET phase is feasible, given that there are updates on the physical sciences curriculum that accommodate explicit inclusion of renewable energy content. The recommendations of this study may be added as adjustments to the curriculum, to enhance its relevance and responsiveness to existing social, economic and environmental challenges. Doing so would enable the creation of sustainable physical sciences learning environments.

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ANNEXURE A

CODES

Questions	Responses	Code	Themes	Subthemes
Does the Physical Science curriculum include renewable energy?	1st participant: I don't think it [curriculum] includes it as such, it speaks only in bits and pieces like in Grade 10. It doesn't go into detail. What content of RE is there because you say it is not in detail? What would be the examples of RE content that could be considered to give RE reasonable detail in the curriculum?	Renewable Energy in the Curriculum	Limited/implicit	Implicit
	2nd participant: "Currently now in Grade 10, the subject that I am teaching which is Physical Science there is no part of renewable energy there, so it's not part of our curriculum".	Renewable Energy in the Curriculum	Not in curriculum	
	No it does not. It focused on coal-generated electricity and traditional circuits.	Fossils based electricity generation.	Coal generated (Energy Content)	
Does the curriculum afford the opportunity to incorporate renewable energy?	Participant 1: I would include it under the topic "Electricity" in Physical Science… Participant 2: Definitely, yes.	CAPS' renewable energy affordances	Renewable energy teaching opportunities	Electricity
	Participant 3: It does not include it as a focus… In grade 12 we have the photoelectric effect, which is based on solar energy, I suppose then we can say it is there…			Waves, sound & light - Photoelectric effect
Do you teach about renewable energy?	1st participant: "No"	Teaching of/about renewable energy		
	2nd participant: "No. Currently now in Grade 10, the subject that I am teaching which is Physical Science there is no part of renewable energy there, so it's not part of our curriculum".	No teaching of/about renewable energy. No renewable Energy in the Curriculum	Renewable energy absence in PS	Not taught
	3rd participant: Not really. I teach according to the guidance of the CAPS document, and I must finish the syllabus and make sure that learners understand	Teaching of/about renewable energy.	Not taught because it is not assessed	

Questions	Responses	Code	Themes	Subthemes
	concepts in the syllabus because they will be assessed on those concepts.	Curriculum completion & Assessment oriented teaching		
What challenges are experienced when teaching renewable energy?	1st participant: "I think maybe because some of the electrical things are dangerous, if for example the nuclear energy could go out of the school context somewhere somehow that could get out of hand. But apart from that solar panels and other renewable ways would be doable. The other challenges would be equipment, we would not be able to teach other topics such as "Wind Turbines" that are in certain provinces for students to see how it generates electricity".	Misunderstanding of science (Nuclear energy is not a renewable energy source). Challenges would be equipment.	Teacher content knowledge Equipment challenges	Teacher pedagogical content knowledge Resources
	2nd participant: ".It will not be much of a challenge."	No significant challenges.	None	
	3rd participant: Depending on how deep you want to go with teaching it. If teachers will be teaching the very basics, I'm sure the challenges would not be much. The school will just have to buy the equipment for practicals. But if the physics of it is more complicated, teachers will need to do a lot more research on the principles and how they work and the department will have to design courses and workshops for teachers to learn about it.	No significant challenges. Challenges would be equipment. Teacher training (increase teacher knowledge)	None Equipment challenges Teacher knowledge	
Is it feasible to incorporate RE in Physical sciences?	1st participant: "I think it is feasible, because where I teach it's a Technical school, already they do Electrical Technology and Electronics, so there's equipment that they use for studying.	Teaching renewable energy feasible.	Teaching about Renewable energy is feasible	Teaching about Renewable energy is feasible in the South African context
	2nd participant: There is no topic that deals with renewable energy or maybe renewable resources, nothing. It's just that part, a little bit in Grade 8 and 9 actually, it's just a small part. So I think it will be feasible, it's going to fit perfectly there.	Teaching renewable energy feasible.		
	3rd participant: It feasible because it is relevant to our load-shedding issues. The current energy supply system is struggling, and I believe solar energy would reduce the struggle. Just as we can	Teaching renewable energy feasible e		
How can teachers teach renewable energy to facilitate the creation of	1st participant: I think regarding "How we as teachers can teach it", our hands are tied, if the government	Challenges would be equipment.		

Questions	Responses	Code	Themes	Subthemes
sustainable physical sciences learning environments?	wants to seriously implement this then it should fund its resources.			
	2nd participant: I think to start with, I think Teachers should have a practical about the renewable energy because it is a very easy practical I think so because as a school we can buy a solar panel and install it in one of the classrooms and just monitor it	Challenges would be equipment.	Equipment challenges	
	3rd participant: Physical science is sustainable if we teach about sustainable production and maintenance of things, especially if teaching of those things is relevant to the country's context. In terms of energy, we see that our current energy supply is not sustainable but grade 10 -12 Physical science curriculum teaches the non-renewable system. It would be a challenge for us to teach other ways because we teach according to the curriculum.	Challenge is the curriculum	Lack of inclusion in the curriculum	
Between your first & final year of your teaching degree study, were you taught concepts & principles of renewable energy and how to apply them?	No.	No teacher pedagogical content knowledge.	Lack of teacher knowledge	Teacher pedagogical content knowledge
	No, not really. I was not.	No teachers pedagogical content knowledge.	Lack of teacher knowledge	
	No.	No teacher pedagogical content knowledge.	Lack of teacher knowledge	
Do you think there is a need to include renewable energy? Is incorporating renewable energy in the curriculum justifiable?	Participant 1: I'd say it should be incorporated, I live in Qwaqwa and there's no electricity there for some time. It's time South Africa looks and searches for alternative new kinds of energies they can use. I think it's important, and maybe in the next five years we should have another alternative for electricity. As I see it the teaching of it should be incorporated because it would be very helpful, to start with the students from	Renewable energy should be incorporated in PS	Need to incorporate renewable energy in PS	

Questions	Responses	Code	Themes	Subthemes
	Natural Science to plants seeds of multiple Scientists as we are at lack on that in South Africa. Participant 2: In the future we are going to use green energy, which is a clean energy. So buy now we should obviously move towards that even in curriculum. The department can just start in the lower grades. But I think in 5 years it will not just be a topic in Grade 8 or 9 then it ends there, it should be a continuous topic, or maybe have a module, because our current situation now as a country, we don't know anything about renewable energy Participant 3: Do you think there is a need to include renewable energy? Would you say incorporating renewable energy in the curriculum is justifiable?			

The codes that were generated were examined to look for patterns, and begin developing themes. Table 3 below represents the themes developed from the codes.

ANNEXURE B

TRANSCRIPTION OF THE FIRST PARTICIPANT'S INTERVIEW

Interviewer: I just want to read you your anonymity assurance as a participant. Your privacy in the study will be protected, in that your personal details such as names, ID number, or contact information will not be disclosed. You will not be deceived in any way hence I showed you the topic. You will be made aware of what you are participating in, the study and its purpose, and the answers will not be manipulated.
This study seeks to understand one of the major influences of Physical Science content, comprehension academic performance, and that is according to the topic creating sustainable Physical Science learning environments through the teaching of renewable energy.
Do you have any question regarding to anything that I have just said?
Participant: No
Q 1.Interviewer: The main question of the study is, "How can we create Sustainable Physical Science learning environments through the teaching of renewable energy?" So, my question to you is, to your knowledge does the Physical Science curriculum include renewable energy?
Participant: I don't think it includes it as such, it speaks only in bits and pieces like in Grade 10. It doesn't go into detail. We discuss the different types of electricity, such as coal, when we teach alternative electricity, they were like, "No", and so I think it does not include it.
Q2. Interviewer: Which Grades do you teach?
Participant: Grade 10, but last year it was Grade 11, and the previous year before that was Grade 12. We start afresh (rotate) each time you reach Grade 12 back to Grade 10.
Q3. Interviewer: Perfect, so have you ever taught renewable energy?
Participant: No
Q4. Interviewer: Okay, to what extent would you say you incorporated in your lessons renewable energy, or you don't really?
Participant: A certain chapter speaks of electricity in Physical Sciences, stating that there are ways of generating electricity in a sense, but it doesn't dwell much on renewable energy. It includes only the sir-gates, it does not go further than that. And we have not maybe gone as far as, Eskom nuclear terms, windmills, hydro-electricity in deeper details, we just mention them, or they tell us to talk about them in mention but it does not say that we must about it.
Q5. Interviewer: Okay, so would you say that you mention renewable energy, or do you read the theory, include calculations and practical work about renewable energy, and would you say that it's enough for learners to be able to use it in the real world? Say for instance, if the Learner has a problem at home in terms of electricity, they might be able to think about renewable energy and maybe use it somehow to help themselves.
Participant: Uhm, not really, I don't teach renewable energy, and I don't think learners would be able to learn it by themselves because the manner and way in which they are taught does not allow them to think independently, they may hear it in passing. I don't think they would read on anything that speaks of renewable energy apart from electricity.
Q6. Interviewer: According to you, you studied and you have more background than learners, so chances are, you could possibly be able to identify. If it was to be included, where or under which topics can it be included? Identify the topics with the potential to incorporate renewable energy in teaching Physical Science.

Participant: I would include it under the topic “Electricity” in Physical Science, and also under Technical Science because it is more technical or practical.

Q7. Interviewer: Would you say South Africa’s current energy network is sustainable? So the way that South Africa is currently generating electricity is in coal-produce electricity, would you say it’s sustainable?

Participant: No, I would say it’s not. I think they can do better, there are other forms that they can use. Like the other time I was in Eastern Cape I saw a lot of Wind Turbines to generate electricity while I was traveling to Port Elizabeth (Gqeberha) and I saw that it was an alternative form to generate electricity instead of depending on coal. But I don’t know, I assume the solution would depend on what works for a specific Province, because Western Cape and Eastern Cape have a lot of wind that side, hence they use the Wind Turbines. Some may use water.

Q8. Interviewer: Do you think it would be feasible for South Africa to start learning about renewable energy and how to handle it?

Participant: Solar energy, yes I think it is feasible. When you say “feasible”, do you mean financially so or?

Interviewer: Yes, financially and also would it be easy to implement?

Participant: I think so because most of our Provinces have hot temperatures such as, Northern Cape, North West, Limpopo a lot, and KZN, those provinces are very hot even in winter. If those solar panels would be used for those provinces it would work.

Q9. Interviewer: Do you think teaching it though from a school level, how feasible do you think it is? Say for instance from High School?

Participant: I think it is feasible, because where I teach it’s a Technical school, already they do Electrical Technology and Electronics, so there’s equipment they use for studying. I think some other schools, outside or in their premises may have a small plant focusing on that, where they may have solar panels displayed. Showing how it works and should be handled. It would be better if it was in the curriculum and if learners would be given a chance to see it [renewable energy] work practically as they learn better that way especially in Science because High School is not practical based. Some learners learn better by seeing to better link it with the scientific terms and theory for understanding.

Q10. Interviewer: What challenges are experienced when teaching renewable energy, or what challenges do you think could arise?

Participant: I think maybe because some of the electrical things are dangerous, if for example the nuclear energy could get out of hand. But solar panels and other renewable ways would be doable. The other challenges would be equipment, we would not be able to teach other topics such as “Wind Turbines” in certain provinces for students to see how it generates electricity.

Q11. Interviewer: How do you think teachers now as it stands can teach renewable energy to facilitate the creation of sustainable Physical Science learning environments?

What I mean by that is, our Science according to the CAPS document is supposed to teach learners to be productive in their communities, so now it means then, this Physical Science that they are learning must go with how things are going. For instance, South Africa’s government invested a lot of money in Solar Energy Panels, but it’s there, it’s out there, it’s not taught in school at a level where it is used by Eskom.

First things first, do you think that it would be important for learners to start to learn it from school so that when they are done and they are actually going to work they are able to work with the new equipment that is there for Solar Energy, because Eskom is trying to implement Solar Energy now as well.

Participant: I think we can be able to facilitate it (renewable energy), can you please repeat the question on the last part, what you said about Eskom.

Interviewer: So I asked, the government has invested a lot of money in Solar Energy, so we are the second highest in terms of GDP investment in Solar Energy Panels, which is brilliant and very good. So, with that being said, the learners are not being taught that so we have people who are finishing school and they are not able to participate productively in what the government is trying to do, which is a good thing. Do you think that there is more that we can do, or how can teachers teach renewable energy to facilitate the sustainability in Physical Sciences so that learners can be able to be productive as they go out of school in terms of sustainable renewal energy?

Participant: I think regarding "How we as teachers can teach it", our hands are tied, if the government wants to seriously implement this then it should fund its resources. I think we as schools can use our assembly time where we can start familiarizing ourselves with the equipment, say every week, to teach the students or us to teach them throughout the week, to go see the actual resources and equipment. I think that its resources would be expensive at a school level. But we as teachers, if the content would be there, we would not have a problem to teach it. And perhaps collaborate with a certain centre which has these Solar Energy Panel equipment for practical purposes it would be helpful, maybe visit weekly as well. It would be good for our students to explore other ways of generating energy and further learn about them at higher institutions. There's a new invention on generating energy using rubbish, people still get shocked by that, which means there's a gap. We deal with theory in high school and so it ends there, but if they would practically see what it is we are referring to it would be of great help because they cannot imagine something they do not know. If the practicality would be incorporated in high school it would make things easy for us.

Interviewer: Can you please justify the need for the incorporation of or the non-incorporation of renewable energy. Whether you say it should or should not be incorporated but justify why you say so.

Participant: I'd say it should be incorporated, I live in Qwaqwa and there's no electricity there for some times. It's time South Africa looks and searches for alternative new kinds of energies they can use. I think it's important, and maybe in the next five years we should have another alternative for electricity. As I see it the teaching of it should be incorporated because it would be very helpful, to start with the students from Natural Science to plant seeds of multiple Scientists as we are at lack on that in South Africa.

Interviewer: Do you have any other thoughts on how renewable energy could be taught in Physical sciences? Anything that you would like to add?

Participant: I'd add to say if Education Sector funds resources for the teaching and facilitation of Solar Energy in schools then they may consider using simulations. They may provide computers where these would take place, in fact we need more technology in our schools because with computers we can do anything. Even if they won't go to the sites at least they would experience it being assisted by someone from the relevant sector to guide us and the students. If someone from the relevant sector would come it would give us an in-depth-knowledge for us as teachers because Solar panels are now being mostly used. At least having them there to tell us if the simulation is correct as they deal with it the most would be great. Simulation workshop for teachers would be a great start because some of the questions students ask are out of our knowledge, then you would need an expert in that. This is an interesting topic, I'm enjoying it.

Interviewer: I'm glad because it is something that I really have a passion for as well.

Thank you for your time. That will be all for today, but I might contact you again if I have any further questions, if you don't mind.
Participant: Okay, I don't mind.

ANNEXURE C

TRANSCRIPTION OF THE SECOND PARTICIPANT'S INTERVIEW

Interviewer: My name Kgantse and today I will be interviewing you about sustainability and Physical Sciences learning environments through the teaching of renewable energy. So can you please introduce yourself without disclosing your real name?

Participant: Okay, I am a teacher from [redacted] School, I started working here from 2015 till now, I am Physical Science teacher, and I am teaching grade 12.

Interviewer: I just want to let you know that your personal details such as names, ID number, or contact information will not be disclosed. You will not be deceived in any way, so you will know what the interview is about. This study like I've said previously seeks to understand how sustainable Physical Science learning environments can be obtained through the teaching of renewable energy. So now my question to you is, do you teach about renewable energy, if yes, to what extent?

Participant: Currently now in Grade 10, the subject that I am teaching which is Physical Science there is no part of renewable energy there, so it's not part of our curriculum. But a little bit of energy is there but not specifically for…but Natural Sciences I think from Grade 8 and 9 there is a small part about renewable and non-renewable resources. But they are not detailed, there's just a little bit of information just, 'What are the renewable resources and non-renewable resources?' But there's no topic about renewable energy. So I don't really teach it.

Interviewer: Would you say there is room in the curriculum to incorporate renewable energy?

Participant: Definitely, yes.

Interviewer: Would you say the theory and the practical work that is there if there is any on renewable energy, is enough for learners to be able to use it in the real world?

Participant: No, it's not enough. Even on the curriculum, I don't think they did justice there because it's just for the learners to know renewable energy but there is no detailed information, how the learners can learn how to use the renewable resources in their houses and everywhere. So some of the learners they know there are solar panels at the tops of their roofs at their homes but they don't know what it's all about. I think now that we are experiencing load shedding and everything I think now that's where that part should be introduced in our curriculum. Because if you are using renewable energy because we are using renewable resources which will still be there even 100 years to come, so if the learners they can be taught about those renewable resources, remember our children are, some of them are innovative, they can even come with some of the innovative strategies to build maybe somethings out of those renewable resources such as sun, wind…you know. Those things are there and they can feel them. But they think maybe the sun is for them to…like maybe for the plants only to live and for us but they don't know that with the same sun they can produce electricity. I think our government should look into that also.

Interviewer: Thank you. So, what topics do you think have a potential to be incorporated in renewable energy?

Participant: I think chemical energy. In Physical Science there's a part of chemical energy, when they are talking about endogenic energy, exothermic energy, that part it would fit nicely there. But I think in Natural Science the Grade 8 and 9, if they can just put more information and practicals there I think it will work, whereby the learners they could create solar panels so that they can create electricity for the homes, to show that learners can know that the sun, you can use the sun to produce electricity.

Interviewer: What do you think would be the challenges to teaching renewable energy?

Participant: Fitting it into our teaching plans when they are not in the CAPS and textbooks. We do not have a guiding structure. Equipment that can be used in the classroom for demonstration and practicals would also be a challenge. Also, we would have to learn it ourselves first, before we can teach it.

Interviewer: How can teachers teach it?

Participant: Now it's very easy because these learners already they have seen some of the homes they have solar panels. So, they have seen them so it will be easy for you to demonstrate them. And some of them when they move around, they have seen the wind turbine because even if we use wind we can produce the electricity. But mostly they are used at the farms because there's no electricity there but they can use those wind turbines to produce electricity, but it would be easier for learners to understand because there are somethings that they have seen but they don't know that we can also use the wind to produce electricity. And you can even give them practicals to do those turbines just like wind mill, they can even do a practical for a windmill so that…windmill takes water from the underground right? They can even experimentally do it, so it can be easily done. I don't think it will be something that will be difficult.

Interviewer: What does sustainability mean to you?

Participant: According to me it means consistency. Something that you will use more often, just like now in our load shedding, meaning electricity is not sustainable. Because sometimes it was cut-off, sometimes during this time the electricity will be cut off. Why there is a cut-off is because they are using non-renewable resources. So now those non-renewable resources they are not cutting the deal, the demand actually of the people, that's why they have to cut-off electricity, but if we can use renewable energy then everyone would have electricity.

Interviewer: Did you know that South Africa signed an agreement to be more sustainable, the SDG goals by 2030?

Participant: Yes, yes, I know that one. It's that one of our President that have signed, that green energy?

Interviewer: Yes, by 2030 we should be more sustainable. And do you think that we are working towards the sustainable development goals effectively by 2030?

Participant: I'd say I think so but our government don't do enough, like in that part of Gauteng there, there are some houses that are using solar panels, so I think we are moving in the right direction, it's just that the process must maybe a little bit faster but at least there is something unlike you don't see any solar panel. And those solar panels remember, you just buy them once, you just use the sun, so you don't even necessarily have to go and buy electricity because the unemployment rate is high also. Our people are not working, so where do we get the money for electricity? The government should just buy them the solar panels and install them in some of the homes, actually, all the homes of the lower class people so that they can have free electricity, I think it will work that way. But I think they are moving towards that direction, I think by 2030 I think we will be in the right track because most of the homes they are having solar panels at least and some of the farms are using wind turbines, so I think we are moving in the right direction.

Interviewer: Currently, how do people help themselves with regards to power cuts? For instance when there's load shedding how do people help themselves so that they are able to continue even though there's load shedding?

Participant: Right. On that part, I will say for.., the.. obviously, the middle class they have like, the generator, like most of the companies normally they use the generator, but our people they are using candles like the old days. The middle class will also buy that electricity that uses batteries because at least they are having a job. But what about the low class, where they don't have any job? They don't even have the money to buy those candles, so they will wait for electricity to come back. Which is so…our people are struggling, so there are no ways actually unlike candles, because we don't even have the jobs so we use the candles until….

Interviewer: And they can't cook with the candles.

Participant: Exactly, so they will have to go outside and do the traditional way of cooking with the wood and so…but there's nothing to use if there's load shedding unlike to use the traditional way of buying a candle. But there are those globe-bulbs that store energy at least when there's load shedding it will still be on but for some time and then it will then be dark again. So now it goes up until 4 hours, so…it's bad.

Interviewer: Who do you say is advantaged or who do you say is disadvantaged the most by load shedding?

Participant: I think the low class, the low class are very disadvantaged. Remember I stayed in some town there, but it's a small town, the load shedding there, happens close to 4 hours, the cut-off time is 4 hours but now I'm in here in the city the cut off is just, sometimes it's an hour, sometimes it is 2 hours but it doesn't go up until 4 hours. So the people who are disadvantaged there normally they are those ones that don't have jobs, those ones they suffer the most. They don't have jobs, the electricity goes for close to 4 hours even in the Municipality, and besides the load shedding there's a cut-off by the Municipality because some of the poles are not working, so they are disadvantaged too much, but those ones the middle class they are well because they are at least staying in the houses that are well-off so the electricity doesn't go up until 4 hours, the longest is 2 hours. And strictly 2 hours the electricity comes back. But there in the small towns they will see 4 hours they can even overlap to 5, and so they are disadvantaged.

Interviewer: Would you say the content of our Physical Science curriculum is sustainable and relevant to the challenges of the 21st century?

Participant: Yes they are, yes. They just have to introduce that…because in Physical Science remember there was a part that they have taken," Fertilizers", in Grade 12 there was a part of fertilizers, then they have taken it out since it was Covid-19 so they took it out, so but they didn't actually return it on the curriculum, so I think they can introduce that renewable energy because I think it is very important in the situation that we are currently in as a country now I think if learners can have a knowledge about green energy, I think it will make learners at least to be innovative, get that understanding of why are we going to move towards the green energy.

Interviewer: So you think it is feasible then for South Africans to start learning how to harness renewable energy from school already.

Participant: Yes, it's feasible from school already, because most of the learners they know about the solar panels, they know about those wind turbines. There is no topic that deals with renewable energy or maybe renewables resources, nothing. It's just that part, a little bit in Grade 8 and 9 actually, it's just a small part. So I think it will be feasible in the FET phase, it's going to fit perfectly there.

Interviewer: How does renewable energy compare to coal generated electricity in terms of economic, social, and environmental growth?

Participant: Between green…?

Interviewer: So, say for instance renewable energy compared to coal generated energy, how do they compare to each other in terms of the economic benefits they bring to the citizens, socially as well and the environmental benefit?

Participant: Alright. For renewable resources such as sun, wind, and water those remember they can be refurnished, so there is no way in life they will say there is no wind, there is no water, and there is no sun. But coal, at some point it will be depleted because that's non-renewable resource. So but if we are using non-renewable resources…remember we will not have air pollution and obviously the electricity will not be costly like it is now because we are using non-renewable resources because at some point they will be depleted. And for coal, coal remember that's why our climate changes, it is because of the coal, those fossil fuel, because of the coal and those oil, those gases that form part of fossil fuel remember they pollute the air and that will lead to climate change, and climate change will affect our people also. Because the temperature it will be high and also the building will collapse and also our people will also suffer due to some the…because some of the diseases if the temperature is high someone obviously will fall sick. But economically, the green renewable resources they will help the country economically because there is no way you will buy this much coal to generate electricity for your people. Obviously we are going to use the renewable resources which will be the sun, the wind and water, so we will not be having that one of saying, " Eh the coal will be finished" because that's non-renewable. But if we are using the renewable resources such as…we know the sun will always be there, the wind will always be there, so there is no time that we will worry of seeing, "The wind will be finished, or the sun will be finished…" so obviously for economic we will benefit a lot because there will be no money that is used to produce electricity. So we have to buy the coal and those oils to produce electricity so we are using lot of money to buy non-renewable resources that will automatically deplete over time, we are using lot of money to do that and we can just use renewable resources and have stress-free. So I think that one it will benefit economic renewable energy, but those coal those ones are non-renewable that's why we are using more money to buy coal for producing electricity.

Interviewer: How do you think Teachers can teach renewable energy to facilitate Physical Science learning environments that are sustainable? In other words that learners can use to benefit themselves at home. How do you think teachers can facilitate that kind of learning?

Participant: I think to start with, I think Teachers should have a practicals about the renewable energy because it is a very easy practical I think so because as a school we can buy a solar panel and install it in one of the classrooms and just monitor it, anyone of the classrooms because I don't think they are expensive those solar panel. You just buy one and install it in one of the classes and just to check how the solar panel will produce electricity…just using the sunrise. So I think if the learners they can be able to see that then they would go to their parents and say, "Mama why are we having stress about electricity, we can just buy a solar panel and install it". Then remember now even the solar panels that are used now they can even store energy, so if there's no sunlight you can just use it because stored that energy that was accumulated during the sunrise. So if the learners can see that they automatically going to go to their parents and say, "Mama, you can buy this". So if you buy this you are not going to have a problem of electricity, you just buy it once but it will continue to sustain you until, until. So I think they will incorporate it in Physical Science in that way.

Interviewer: My next question which is the second last question was going to be that you justify the need for the incorporation of renewable energy. But I think you've done that, but any other thoughts on your part? Anything that you'd like to leave me with give advice on based on this topic, maybe something that you could propose should be considered by government, by teachers?

Participant: I think I will send a message like to the Minister of Education, because that part of green energy is very important. Because now the President has already signed the contract, isn't it?

Interviewer: Yes.

Participant: In the future we are going to use green energy, which is a clean energy. So buy now we should obviously move towards that even in curriculum. The department can just start in the lower grades. But I think in 5 years it will not just be a topic in Grade 8 or 9 then it ends there, it should be a continuous topic, or maybe have a module, because our current situation now as a country, we don't know anything about renewable energy, nothing. That's why we don't…most of our University students they are not innovative about that, that's why we don't even have much solution if there's load shedding now. We don't even have the students who can think because they do not have knowledge about it. Some they just know that it is a solar but they don't have that information that what is renewable energy, but if they have that information now some of you will be seating and come up with a solution already, but there's no information about renewable energy, so if the department can just introduce renewable energy maybe NS in Grade 8 and 9, step by step, but it shouldn't end there at Grade 8 and 9 because our learners and our people they need to know about renewable energy because we are just using the things that are there and will forever be there. Some of the…in rural areas they don't have electricity, but there are rivers flowing there, but they don't have electricity and those wind turbines they can be installed there on the rural areas to produce electricity. So we can use renewable resources, I don't think we should be having load shedding, we are having load shedding because we are using non-renewable resources, let us move to renewable energy, which is a clean energy. So our country will be…so I think the department needs to sit down together with whoever is responsible for Physical Science because it fits nicely there. Just to introduce it in Grade 8 and 9, or maybe construct a module or a subject about renewable energy, then they take out Creative Arts so that every learner in Grade 8 and 9 knows about that energy. That one we can even do the practicals, it's very easy it's not something that is hard. If we have enough information it can be shared amongst everyone in the country, you'll see every household will be having a solar panel.

ANNEXURE D

TRANSCRIPTION OF THE THIRD PARTICIPANT'S INTERVIEW

Interviewer: I'll first read for you your anonymity assurance as a participant. Please know that your privacy in the study will be protected, in that your personal details such as names, ID number, or contact information will not be disclosed. You will not be deceived in any way hence I showed you the topic. You will be made aware of what you are participating in, the study and its purpose, and the answers will not be manipulated.

This study seeks to understand one of the major influences of Physical Science content, comprehension academic performance, and that is according to the topic creating sustainable Physical Science learning environments through the teaching of renewable energy.

Question 1. Interviewer: The main question of the study is, "How can we create Sustainable Physical Science learning environments through the teaching of renewable energy?" So, my question to you is, to your knowledge does the Physical Science curriculum include renewable energy?

Participant: Uhm.. [as of a person thinking deeply about something or trying to recollect some idea or information on something] It does not include it as a focus. It mostly focuses on fossil fuel produced electricity. We use the provided electricity for practicals and a standard battery for circuits. In grade 12 we have the photoelectric effect, which is based on solar energy, I suppose then we can say it is there, it is included.

Question 2. Interviewer: Which Grades do you teach?

Participant: I teach anywhere from grade 8 to 12, Natural sciences and physical sciences and sometimes another subject is given to me, depending on the work allocation that Is given to us at the beginning or the end of the year.

Question 3. Interviewer: Do you teach about renewable energy?

Participant: 3rd participant: I teach according to the guidance of the CAPS document, and I must finish the syllabus and make sure that learners understand concepts in the syllabus because they will be assessed on those concepts.

Question 4. Interviewer: Do you teach about renewable energy as a topic?

Participant: Uhm… [as of a person thinking deeply about something or trying to recollect some idea or information on something] No. I have never taught it as a topic. I teach about it under the photoelectric effect to the extent that is expected according to the curriculum.

Question 5. Interviewer: According to you, where in the curriculum would you say renewable energy could be incorporated?

Participant: I would maybe include it under the topic of "Electricity" to a certain extent because Physical Sciences is just an introduction of all inorganic sciences before going to university or studying further, and the curriculum [PS curriculum] already has a lot of work that it's already accommodating.

Question 6. Interviewer: Would you say South Africa's current energy network is sustainable?

Participant: No, it's not, if it was, we wouldn't have load-shedding.

Question 7. Interviewer: Do you think it would be feasible for South Africans to start learning how to produce renewable energy?

Participant: Yes, It would. It would be good to have options, so that the best option can be chosen. Renewable energy could be very helpful. A lot of people have installed solar panels that are enough to power their houses fully, but they can afford paying for the maintenance. For people who can't afford to pay for regular maintenance it would be good if they knew how to maintain the basic things themselves.

Question 8. Interviewer: How feasible do you think it is to teach it from High School?

Participant: It would be feasible if was in the syllabus [curriculum], because it would be part of the structure of the subject.

Question 9. Interviewer: What challenges would you say would be experienced when teaching renewable energy?

Participant: Depending on how deep you want to go with teaching it. If teachers will be teaching the very basics, I'm sure the challenges would not be much. The school will just have to buy the equipment for practicals. But if the physics of it is more complicated, teachers will need to do a lot more research on the principles and how they work and the department will have to design courses and workshops for teachers to learn about it.

Question 10. Interviewer: Right now, as it stands, how can you teach it in your classroom?

Participant: I won't be able to teach it now because I have to follow the curriculum and make sure that I finish the work on time according to the work schedule. Even when I have a bit of time, maybe I'm ahead or something, I have to do revision with my learners and make sure we have covered all the work, especially the work that is challenging for them. There is no use teaching them things that will not help them when they write exams.

Question 11. Interviewer: Do you think there is a need to include renewable energy? Would you say incorporating renewable energy in the curriculum is justifiable?

Participant: There is a need to incorporate renewable energy in the curriculum. It's justifiable because it is relevant at the moment. The world has started talking about sustainability and clean energy. Uhm.., It would be good for the department to **integrate it in into the curriculum so that we don't fall behind with the way we do things**. I think it's difficult for third world countries to leave what they know, and to do what is better. We want to hold on to things even when they are not working. Teaching fossil fuel based electricity alone is not enough anymore, we should consider integrating clean energy into the curriculum."

Question 12. Interviewer: Anything you'd like to add in terms of how renewable can actually be taught in PS?

Participant: The curriculum will have to accommodate renewable energy in detail, and for the teachers to be able to teach it effectively, they will first have to learn about it. The apparatus or equipment for practical experiments will have to be provided for and teachers will have to be trained on how to use that equipment. It can then be assessed just as fossil generated electricity is assessed. If those things are done, then it can be taught.

Question 13. Interviewer: That marks the end of our interview, Thank you. And thank you for your time. I appreciate all your input.

Participant: It's a pleasure. Good luck with your study.

APPENDIX E
TITLE REGISTRATION

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13 March 2022

<u>APPLICATION FOR TITLE REGISTRATION</u>

Applicant: Ramongalo, KN
Student Number: 2008120202
Discipline: Specialisation in Science and Technology
Study Code: Masters' (EDST8900)

Dear Ms Ramongalo

***Your registered title is as follows**: "Creating sustainable physical sciences learning environments through the teaching of renewable energy"*

All of the best with your studies.

Yours sincerely,

Prof Patrick Mafora
Chair: CTR committee

Ms CS Duvenhage
Secretary: CTR committee

ANNEXTURE F

ETHICS CLEARANCE

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS UV

GENERAL/HUMAN RESEARCH ETHICS COMMITTEE (GHREC)

17-Jul-2023

Dear Miss Kgantse Ramongalo

Application Approved

Research Project Title:
Creating sustainable physical sciences learning environments through the teaching of renewable energy

Ethical Clearance number:
UFS-HSD2022/0405

We are pleased to inform you that your application for ethical clearance has been approved. Your ethical clearance is valid for twelve (12) months from the date of issue. We request that any changes that may take place during the course of your study/research project be submitted to the ethics office to ensure ethical transparency. furthermore, you are requested to submit the final report of your study/research project to the ethics office. Should you require more time to complete this research, please apply for an extension. Thank you for submitting your proposal for ethical clearance; we wish you the best of luck and success with your research.

Yours sincerely

Dr Adri Du Plessis
Chairperson: General/Human Research Ethics Committee

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ANNEXURE G

RESEARCHER'S IDENTITY